SPRING/SUMMER 2012
VOLUME 4, NUMBER 1

Print ISSN: 2152-4157
Online ISSN: 2152-4165

WWW.IJERI.ORG

International Journal of Engineering Research & Innovation

Published by the
International Association of Journals & Conferences

INTERNATIONAL JOURNAL OF ENGINEERING RESEARCH AND INNOVATION

The INTERNATIONAL JOURNAL OF ENGINEERING RESEARCH AND INNOVATION (IJERI) is an independent and nonprofit publication which aims to provide the engineering community with a resource and forum for scholarly expression and reflection.

IJERI is published twice annually (Fall and Spring issues) and includes peer-reviewed research articles, editorials, and commentary that contribute to our understanding of the issues, problems, research associated with the engineering and related fields. The journal encourages the submission of manuscripts from private, public, and academic sectors. The views expressed are those of the authors, and do not necessarily reflect the opinions of the IJERI or its editors.

EDITORIAL OFFICE:

Sohail Anwar, Ph.D.
Editor-in-Chief
Office: (814-949-5181)
Email: sxa15@psu.edu
Pennsylvania State University
Altoona College
3000 Ivyside Park
Altoona, PA 16601-3760

THE INTERNATIONAL JOURNAL OF ENGINEERING RESEARCH AND INNOVATION EDITORS

Table of Contents

EDITOR'S NOTE: IJERI NOW INDEXED BY EBSCO

Philip Weinsier, IJERI Manuscript Editor

EBSCO

IJERI is proud to be part of EBSCO Subscription Services and EBSCO Publishing, which is a subsidiary of EBSCO Industries, Inc., ranked by Forbes as the 168th largest privately-owned company in the U.S. EBSCO Subscription Services has served library and research communities for more than 60 years. EBSCO Publishing is the most prolific aggregator of full text materials, offering a growing suite of more than 300 bibliographic and full-text databases available worldwide. EBSCO currently licenses over 77,000 full-text content sources, from over 5,100 publishers, for inclusion in its databases.

Established in 1944, EBSCO is recognized as the world's leading information agent providing consultative services and cutting-edge technology for managing and accessing quality content, including print and e-journals, e-packages, research databases, e-books and more, making it the leader in the database marketplace. Not only does EBSCO supply its databases to thousands of universities, biomedical institutions, schools, and other libraries in the United States and Canada, but the company is the leading database provider for libraries outside of North America. At present, EBSCO provides nationwide access to its databases in more than 70 countries, including developing nations with emerging economies.

Thomson Reuters ISI

IJERI is currently under consideration for inclusion in the Thomson Reuters and DOAJ databases. With the breadth and scope of EBSCO's services, one might rightly ask why anyone would want or need to pursue indexing by yet other organizations. As it turns out, different organizations provide different kinds of services to aid readers and researchers alike in the pursuit of finding and quantitatively evaluating authors and journals.

Researchers, faculty, information scientists and librarians have been evaluating journals for the better part of the last 100 years. But, arguably, it wasn't until Thomson Reuters developed its citation indexes that it became possible to do computer-compiled statistical reports on the output of journals and the frequency of their citations. Then, in the 1960s, they invented the journal "impact factor", often abbreviated as IF, for use in their in-house analyses as part of their *Science Citation Index*®. Around 1975, they began publishing the information in their *Journal Citation Reports*® (*JCR*).

The *JCR*® provides quantitative tools for ranking, evaluating, categorizing, and comparing journals, of which impact factor is but one. Basically, impact factor is a measure of the frequency with which the average journal article has been cited, generally over a period of three years, and is calculated by dividing the number of current-year citations to the source items published in that journal during the previous two years. IF is frequently used to describe the relative importance of a journal within its field and is useful in clarifying the significance of total citation frequencies. What's more, it tends to level the playing field by eliminating biases related to a journal being large or small, and whether issues are published more or less often.

The Directory of Open Access Journals (DOAJ)

In their own words, the aim of the DOAJ is to increase the visibility and ease of use of open-access scientific and scholarly journals, thereby promoting their increased usage and impact; a one-stop shop to open-access journals. So while it is important for authors to publish their work, it is also important that readers be able to find and gain access to these published studies. The DOAJ helps to provide an overview of subject-specific collections and freely accessible online journals and integrate the information into a user-friendly library.

Editorial Review Board Members

Listed here are the members of the IAJC International Review Board, who devoted countless hours to the review of the many manuscripts that were submitted for publication. Manuscript reviews require insight into the content, technical expertise related to the subject matter, and a professional background in statistical tools and measures. Furthermore, revised manuscripts typically are returned to the same reviewers for a second review, as they already have an intimate knowledge of the work. So I would like to take this opportunity to thank all of the members of the review board.

As we continually strive to improve upon our conferences, we are seeking dedicated individuals to join us on the planning committee for the next conference—tentatively scheduled for 2013. Please watch for updates on our website (**www.IAJC.org**) and contact us anytime with comments, concerns or suggestions. Again, on behalf of the 2011 IAJC-ASEE conference committee and IAJC Board of Directors, we thank all of you who participated in this great conference and hope you will consider submitting papers in one or more areas of engineering and related technologies for future IAJC conferences.

If you are interested in becoming a member of the IAJC International Review Board, send me (Philip Weinsier, IAJC/IRB Chair, philipw@bgsu.edu) an email to that effect. Review Board members review manuscripts in their areas of expertise for all three of our IAJC journals—IJME (the International Journal of Modern Engineering), IJERI (the International Journal of Engineering Research and Innovation) and TIIJ (the Technology Interface International Journal)—as well as papers submitted to the IAJC conferences.

A Comparison of Different Vertical Handoff Algorithms between WLAN and Cellular Networks

Elaheh Arabmakki, University of Louisville; Sherif Rashad & Sadeta Krijestorac, Morehead State University

Abstract

Today, the advent of heterogeneous wireless networks is revolutionizing the telecommunications industry. As IP-based wireless networking increases in popularity, handoff issues must be taken into consideration. When a user switches between networks with different technologies, many issues have to be considered in order to increase the efficiency of the network during vertical handoff. In this paper, several algorithms for optimizing vertical handoff between WLAN and the cellular networks are discussed. In each of these algorithms, specific factors were considered and then a comparison made in order to see the effect of each factor on vertical handoff. It was found that when both received signal strength and service history information are taken into account in algorithm design, the number of handoffs would be reduced and the throughput of the network increased.

Introduction

Heterogeneous wireless networks consist of different Wireless Area Networks (WLAN), various cellular networks, and many other networks with different technologies. The most popular networks are WLAN and cellular networks. Recently, the use of WLAN in areas such as airports, hotels, and school campuses has increased.

On the other hand, although cellular networks such as 4G networks support a higher degree of mobility and a wider area of coverage, they offer guaranteed quality of service in data transmission at the lower data rate. The complementary features of these two networks, WLAN and cellular networks make their integration highly desirable. One of the most important issues in heterogeneous wireless networks is vertical handoff, which occurs when a user switches between two different network interfaces with different technologies. For example, if a mobile node leaves the 802.11b network domain and enters the 802.16 network domain, it is called vertical handoff. Many issues have to be accounted for in order to have an effective vertical handoff.

Classification of Vertical Handoff Algorithms (VHD)

Because of the popularity of integrated networks and the associated problems of vertical handover issues, various strategies have been developed for optimizing vertical handoff and researchers have considered many factors and have offered several algorithms. The following list classifies these algorithms (see also Figure 1).

Vertical Handoff Algorithms

1. Smart Decision Model using a score function
2. Algorithm considering Service History information
3. Vertical handoff scheme between mobile WiMax and cellular networks based on the Loosely Integration Model
4. Novel vertical handover scheme for Integrated WLAN and Cellular Networks

Received Signal Strength (RSS) Based VHD Algorithm

1. An Adaptive Lifetime-based heuristic
2. An RSS Threshold-Based Dynamic heuristic
3. A Traveling-Distance Prediction-Based heuristic

Bandwidth-Based VHD Algorithms

1. A QoS-Based heuristic
2. A Wrong Decision Probability (WDP) Prediction-Based heuristic

Cost-Function-Based VHD Algorithms

1. A multiservice-based heuristic
2. A Cost-Function-Based heuristic with Normalization and Weight Distributions
3. A Weighted Function-Based heuristic

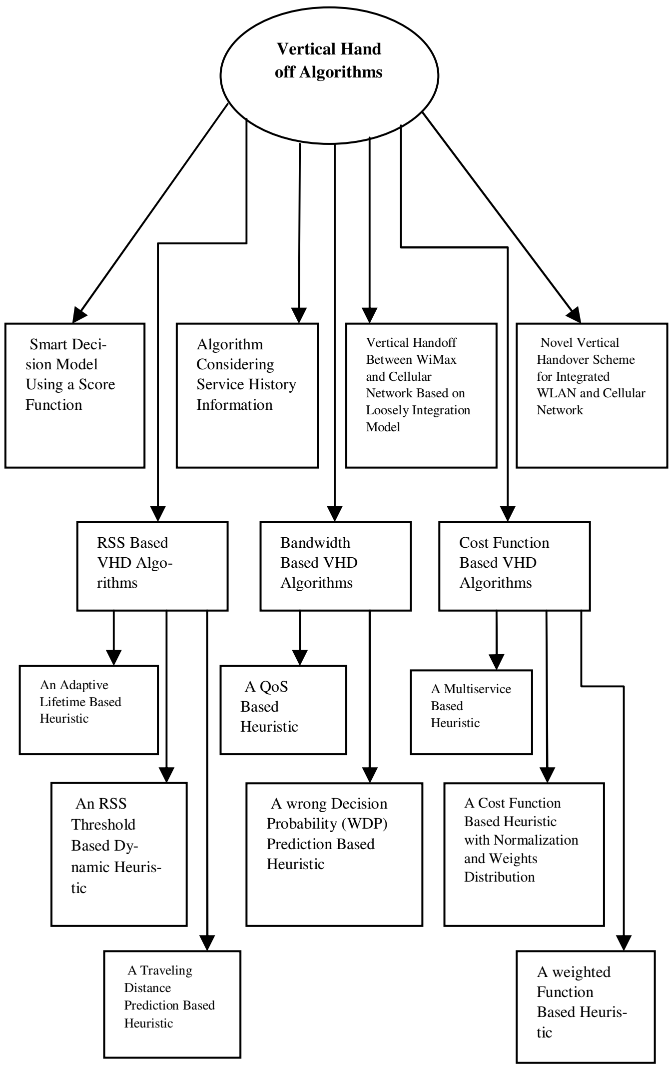


Figure 1. Classification of Vertical Handoff Algorithms

A Smart Decision Model for Vertical Handoff

A Universal Seamless Handoff Architecture (USHA), which was based on the fact that the handoff happens only under certain conditions, was previously proposed by researchers [1]. This algorithm was further developed in order to solve the smart decision problems [2]. The design of a USHA was based on the fact that the handoff occurs only in specific circumstances. It happens on overlaid networks with multiple internet access methods. In this design, the best network would be chosen with zero waiting time. The main factor in this design was based on overlapping the coverage for different kinds of access methods. In the case where the coverage fails to overlap, the USHA may lose the connection with the upper layer [2].

In this architecture, there is a Handoff Server (HS) which is connected to several mobile hosts via an IP tunnel. All of the applications in all communications layers are connected to the tunnel interface. All of the packets are also encapsulated for transmission through this channel and a UDP protocol (User Datagram Protocol) is used for transmissions. In order to maintain the connectivity between the Mobile Host (MH) and HS, there should be two sets of addresses at both ends of the IP channel, one for the HS and the other for the MH. After the handoff occurs, since the location has changed, the MH should inform the HS about the new address in order to continue the connection. The UDP protocol prevents the IP channel from resetting after handoff occurs [2].

This algorithm was further developed in order to add the smart decision model in which a handoff will occur at the appropriate moment and to the most appropriate network [2]. The proposed design consists of four parts: A Handoff Executor (HE), Smart Decision (SD), Device Monitor (DM) and System Monitor (SM). The DM is responsible for monitoring the status of each network; the SM reports the system information; the SD provides a list of all user interfaces along with the information provided by the DM and applies a score function for calculating the score for each wireless interface; and, the SM identifies the best network for the handoff. The HE performs the handoff to the target network. This model is simple and is able to perform the handover to the best network at the best time since it is able to make a smart decision based on different parameters such as link capacity, power consumption, and link cost [2].

A QoS-Aware Vertical Handoff Algorithm Based on Service History Information

In distributed VHO (Vertical Hand Off) decision algorithms, all of the users choose the target network simultaneously, ignoring each other. Several problems arise in this design, one of which might be experiencing high congestion by blindly choosing a network which cannot provide the quality of service for the users and may cause handoff call drops and handoff to other networks as well [3].

For optimizing these algorithms, a remedy was introduced by researchers in which the service history of user traffic was considered and was added to the VHO algorithms [3]. Through the introduction of this new architecture, the unstable handoff decisions were alleviated and the quality of the service was improved. Two parameters were considered from service history information for designing this algorithm [3]:

First, t_0^s is the service time for network. This time is equivalent to the amount of time since the last handoff. It is clear that the larger this number, the more efficient the system.

Second, t_i^F ($i \neq 0$) is the time calculated from the time when the last handoff was dropped. If this time is small, it means that the system experienced more dropped calls. Therefore, for improving system functionality, this number should be large. From all of the information stated above, it is obvious that if the maximum effective time of history information, T_c, is small, the user should be kept in the current network to reduce the number of dropped calls [4]. The proposed evaluation function for this architecture is expressed as:

$$E_i^h(t_i^s) = \begin{cases} \exp(-t_i^s) \ if\ i = 0, 0 < t_i^s < Tc \\ 0\ otherwise \end{cases} \tag{1}$$

$$E_i^h(t_i^F) = \begin{cases} -\exp(-t_i^F) \ if\ i \neq 0, 0 < t_i^F < Tc \\ 0\ otherwise \end{cases} \tag{2}$$

where T_c is the maximum effective time of history information and can be set differently t_i^s for a t_i^F . This algorithm improves the performance by reducing the number of handoffs, thereby decreasing the probability of a handoff occurring, as well as reducing the cost [3].

Vertical Handoff Scheme between Mobile WiMax and Cellular Networks Based on the Loosely Integration Model

Another algorithm for vertical handoff between Mobile WiMax and cellular networks was proposed which is based on the Loosely Integration Model [5]. In this model, WLAN and 3G networks exist independently and provide autonomous services. For authentication and accounting for roaming services, a gateway was added to this incorporative model; for mobility between WLAN and 3G networks, this model also uses a mobile IP. One of the advantages of this model is that it can easily be adapted to existing communications and reduces the effort in developing new standards [5].

The Smoothly Integration Scheme algorithm has an architecture similar to the Loosely Integration Model but only an IWG (Interworking Gateway) was added for interworking between Mobile WiMax and CDMA. The IWG helps by using an Extended Fast Handoff scheme in CDMA packets, which provides a gateway function for protocol adaptation. In the Fast Handoff scheme, the serving PDSN (Packet Data Serving Node) sends traffic to a target PDSN by setting up a tunnel. This traffic is forwarded to other mobile nodes by the target PDSN. In this method, the packet loss is minimized since the service anchor point is not changed [5].

A Novel Vertical Handover Scheme for Integrated WLAN and Cellular Wireless Networks

A novel vertical handover scheme for integrated WLAN and cellular wireless networks was proposed in which WLAN is overlaid within the coverage area of the cellular network [6]. There is one access point for the WLAN as well as one base station for the cellular network. A Crossover switch connects the access point and the base station. If the user starts communication with the access points, it is considered to be connected to the WLAN. However, if the packet exchange is through base stations, a user is considered to be attached to the cellular network.

The Crossover switch can decide to handover a user from one network to another and would then also transmit subsequent downlink packets to the new access point or base station. This algorithm aims to optimize system utilization without considering packet delay requirements. Two strategies have been defined in order to achieve the objective: The first one is performing unconditional handover when a mobile node is moving out of WLAN coverage and the second one when the mobile node is entering the WLAN coverage. These two conditions are called imperative and alternative, respectively [6].

An unconditional imperative handover will be executed if a user's RSS (Received Signal Strength) is lower than a given threshold, while an alternative handover occurs when a certain number of consecutive handover requests are received by the access point of WLAN from the user. The number of these requests depends on the user's traveling speed and current load of cellular networks. This algorithm can support a larger user arrival rate without dealing with a packet delay violation ratio as well as reducing the number of handovers by 10% [6].

RSS-Based VHD Algorithms: An Adaptive Lifetime-Based Handover Heuristic

For handoffs between 3G networks and WLAN, an algorithm was proposed in which a lifetime metric was considered. This shows the application-specific time period in which a user can still get services from WLAN [7]. The algorithm involves two scenarios which are described as follows:

First Scenario:
A handover from WLAN to the 3G network will happen if the RSS average of the WLAN connection is less than the predefined threshold and if the lifetime is less than or equal to the handover delay [7], [8].

Second Scenario:
A handover is initiated if a mobile terminal moves from a 3G network to a WLAN network. The handover will be triggered if sufficient bandwidth is available on the WLAN network and if the threshold of the 3G network falls below the average RSS measurement of the WLAN signal [7], [8].

In this algorithm, the author achieved many benefits in handover between these aforementioned networks. By using the lifetime metric, the number of extra handoffs was decreased and throughput of the network was dramatically increased. On the other hand, increasing the lifetime caused an increase in the packet delay, which is noted as a disadvantage of this algorithm. For solving this problem, the ASST (Application Signal Strength Threshold) was adjusted based on different parameters such as delay thresholds, mobile terminal velocities, handover signaling costs, and packet delay penalties [7], [8].

An RSS Threshold-Based Dynamic Heuristic

In this algorithm, a dynamic RSS threshold (S_{dth}) is defined when a mobile terminal is connected to a WLAN access point, and is used for a handoff decision from WLAN to 3G through comparison of the current RSS and S_{dth}. By using S_{dth} in this algorithm, the number of false handoffs will be reduced and the handoff failure will be kept below a certain limit, while the number of superfluous handoffs will remain the same [8], [9]. S_{dth} can be calculated from [9]:

$$S_{dth} = RSS_{\min} + 10\beta \log 10\left(\frac{d}{d - L_{BA}}\right) + \varepsilon \tag{3}$$

where RSS_{min} (in dBm) is the minimum RSS needed for the mobile terminal to communicate with an access point; B is the path loss coefficient; and d is the side length of the WLAN cell in meters. In this study, the assumption was that WLAN cells would have a hexagonal shape, LBA would be the shortest distance between the point at which handover is initiated and the WLAN boundary, and ε (in dB) would be a zero-mean Gaussian random variable with a standard deviation. This represents the statistical variation in RSS caused by shadowing [8], [9].

The distance, L_{BA} , varies with the desired handover failure probability, p_f, the velocity of the mobile terminal, v, and the handover delay from WLAN to 3G, which is shown as τ. LBA is calculated as follows:

$$L_{BA} = [\tau^2 v^2 + d^2 (p_f - 2 + 2\sqrt{1 - p_f}]^{\frac{1}{2}} \tag{4}$$

In this algorithm, the authors assumed that the failure probability from 3G to WLAN would be zero, so the handoff can happen anytime a mobile terminal enters WLAN coverage [8], [9]. One of the advantages of this algorithm is that when a mobile terminal's traveling time inside a WLAN cell is less than the handoff delay, then the handoff may result in a waste of network resources [8], [9].

A Traveling-Distance Prediction-Based Heuristic

This is another RSS-based algorithm in which the authors considered the time it takes for a mobile terminal to travel via a WLAN cell (t_{WLAN}) in order to reduce the number of unnecessary handoffs. In this design, a handoff will occur when the traveling time is greater than the time threshold (T_{WLAN}). The traveling time (t_{WLAN}) is calculated as follows [10]:

$$t_{WLAN} = \frac{R^2 - I_{os}{}^2 + v^2 (t_s - t_{in})^2}{v^2 (t_s - t_{in})} \tag{5}$$

While this algorithm reduces the number of extra handoffs and minimizes handoff failures, the mobile terminal's traveling time is still less than the handover delay which causes loss of network resources [8], [10].

Bandwidth-Based VHD Algorithms: A QoS-Based Heuristic

Another algorithm for handover from WLAN to WWAN (Wireless Wide Area Network) was proposed in which the remaining bandwidth, the state of the mobile terminal, and the user service requirements are taken into account [11]. In this algorithm, two scenarios are described: Handover from WLAN to WWAN, and WWAN to WLAN [8], [11].

In the first scenario, for handover decisions, while the mobile terminal is connected to WLAN, the measured RSS should fall below a threshold (RSS_{T1}). Handover will be given to the best network if the mobile terminal is in the idle state, otherwise the handoff decision is based on user application type [8], [11]. Here, two types of applications are taken into consideration.

1. Delay-sensitive applications
   For this type of application, a handover occurs if there is insufficient bandwidth available on the WLAN to serve the user, while WWAN provides available bandwidth for the user's application.
2. Delay-tolerant applications
   A handover happens if WWAN provides higher bandwidth for the user than the WLAN.

In this case, the remaining bandwidth should be calculated for the WLAN, as follows, in order to take the handoff decision. Remaining bandwidth = Throughput × (1-α×Channel Utilization) × (1-Packet loss rate). Throughput is the throughput that can be shared among mobile terminals in the WLAN. Channel utilization is the percentage of time that the access point, by using a carrier sense mechanism, senses the medium as busy. α is a factor that reflects IEEE 802.11 MAC overhead and was set to 1.25 in this study. Finally, packet loss rate is that part of the transmitted medium access control (MAC) protocol data units (MPDUs) which require retransmission, or are discarded as packets that are not delivered. The values of channel utilization and packet loss rate are obtained from the information in the beacon frame carrying the QoS basic service set (QBSS) load, which is sent by an access point [8], [11].

In the second scenario, a handover occurs from WWAN to WLAN if the RSS in the WWAN is less than the threshold (RSS_{T2}) [8], [11].

A Wrong Decision Probability Algorithm (WDP) Prediction-Based Heuristic

A WDP algorithm is another vertical handoff algorithm which is based on the probability of unnecessary and missing handovers [12]. If you consider two kinds of networks, x and y, as well as the bandwidth associated with these networks, B_x and B_y, an unnecessary handover occurs when a handoff is performed from network x to network y, while the available bandwidth in network x (B_x) is less than the available bandwidth in network y (B_y). On the other hand, a missing handover occurs when a mobile terminal in network x should perform a handover to network y because of lack of available bandwidth in network x, yet maintains its connectivity to network x [8], [12].

A handover from network x to network y is initiated if

$$P_r < \rho \times L_0 \text{ or } b_y - b_x \leq L \qquad (6)$$

where P_r is the unnecessary handover probability; ρ is the traffic load of network x; $L_0 = 0.001$; and L is bandwidth threshold [12].

The proposed algorithm has several advantages: it reduces the Wrong Decision Probability (WDP) and balances the traffic load. However, it does not consider RSS, which is a main factor in handoff decisions. Received signal strength is a main factor in every handover; however, a handover to a network with high bandwidth but weak signal strength is undesirable [8], [12].

Cost-Function-Based VHD Algorithms: A Multiservice-Based Heuristic

A cost-function-based algorithm is another VHO algorithm which works using a cost function [13]. The algorithm gives priority to active applications that need to perform a handover to a target network. Therefore, the service with the highest priority is selected On the other hand, the cost of a series of target networks will be calculated after which the handover would occur between the application with the highest priority and the network with the lowest cost [8], [13], [14]. This algorithm provides user applications with reduced blocking probability. It also satisfies more user requests, though there is no mention of the manner in which the QoS factors are weighted and normalized. This algorithm was further developed in order to consider normalization and weight-distribution methods [8], [13- 15].

A Cost-Function-Based Heuristic with Normalization and Weight Distribution

In this algorithm, by calculating the network quality factor, the performance of a target handover can be evaluated [16]. Furthermore, if the handover is necessary, then the network parameters will be collected before the weight and quality factor are calculated. Then, if the current quality is less than the candidate quality, the handover will be initiated [8], [16]. In order to avoid superfluous handovers, a metric called a handover necessity estimator was introduced. The network quality factor is calculated as follows [8], [16]:

$$Q_i = W_c C_i + W_s S_i + W_p P_i + W_d D_i + W_f F_i \qquad (7)$$

where Q_i is the quality factor of network i; C_i is cost of service; S_i is security; P_i is power consumption; D_i are the network conditions; and, F_i is network performance. Here, w_c, w_s, w_p, w_d, and w_f are the weights for these network parameters. Since each network parameter has a different unit, a normalization procedure was used [16]. Advantages of this algorithm include increased throughput of the system and user satisfaction. However, this algorithm does not provide information for estimating security and interference levels [8], [16].

A Weighted Function-Based Heuristic

A Weighted Function-Based Heuristic is another algorithm which was designed for VHO issues [17]. Despite other algorithms in which the mobile terminal was responsible for the VHD calculation, this algorithm VHD calculation is done in the visited network. The quality of network (Q_i) will be calculated as follows:

$$Q_i = W_b B_i + W_d D + W_c C \qquad (8)$$

where B, D, and C are bandwidth, dropping probability, and cost of services, respectively. And W_b, W_d, and W_c are their weights where

$$W_b + W_d + W_c = 1 \qquad (9)$$

In this algorithm, the network with the highest Qi will be selected as the target network for handover. As a result, the handover delay will be decreased, the handover blocking rate will be lowered, and the throughput will be increased. However, since there should be extended communication between the mobile terminal and the access point of the visited network, there might be additional delay and load when there is large number of mobile terminals [8], [17].

Comparison

In the Smart-Decision algorithm, based on several network parameters such as link capacity, power consumption, and link cost, the authors proposed a model to intelligently decide which network to choose in order to execute vertical handoff. By considering many factors, this algorithm decides which network is the best for executing a handover and helps to overcome many problems that may arise in the execution of the handoff.

In this algorithm, based on system history information, the number of handoffs, the values of handoff probability, and the cost were decreased. This algorithm also works better in more complicated networks. In the Vertical Handoff Scheme between Mobile WiMax and Cellular Networks, the level of packet loss is minimized. In the Novel Vertical Handover Scheme between WLAN and Cellular Networks, the total number of handovers was reduced; and, by using L_{preset} and monitoring the load in the network, the number of unnecessary handovers was reduced. Moreover, this algorithm can support a larger user arrival rate without dealing with the packet delay violation ratio.

An Adaptive Lifetime-Based Handover heuristic algorithm could reduce the number of unnecessary handoffs as well as increase the throughput of the network by considering a lifetime metric. However, if there is an increase in the lifetime, the delay in the network will increase, so this algorithm may not work properly for delay-sensitive applications.

The RSS Threshold-Based Dynamic heuristic reduces the number of false handovers and keeps the handover failures below a certain limit. However, the disadvantages of this algorithm are that the number of extra handoffs will remain the same and, if the mobile station's traveling time inside a cell is less than handover delay, there is waste of network resources.

The Traveling Distance Prediction-Based heuristic reduces the number of handover failures, superfluous handovers, and connection breakdown. However, sampling and averaging RSS will increase the handover delay. Furthermore, the mobile terminal's traveling time is still less than the handover delay which causes loss of network resources. The QoS-Based heuristic, by considering bandwidth, increased the throughput of the network. This algorithm works well for delay-sensitive applications since it decreases the delay by considering the application type.

In the Wrong Decision Probability Algorithm, the RSS was not considered but this algorithm reduces the wrong decision probability while balancing the traffic load. Since this algorithm does not consider the RSS, it is not efficient because it may cause several breakdowns in the network. The Multiservice-Based heuristic reduces the blocking probability. A Cost-Function-Based heuristic with Normalization and Weight Distribution algorithm provides high throughput for the system, but some of the parameters such as security and interference level are difficult to measure in the network. The Weighted-Function-Based heuristic provides short handover decision delays, low handover blocking rates, and high throughput. However, it may cause extra delay and load to the network.

Conclusion

Considering all of the algorithms discussed above, it is obvious that all of them have advantages and disadvantages that may affect the performance of the network.

Most of these algorithms, such as the Weighted Function-Based heuristic and the Traveling-Distance-Based Prediction algorithm have some advantages such as low handover blocking rates and reduced number of handover failures, respectively. However, those impose extra delay to the network. Of all the algorithms, the QoS Aware Vertical Handoff algorithm based on Service History Information reduces the number of handoffs, reduces handover failure probability, and increases throughput of the network without imposing any superfluous delay to the network. This indicates that considering service history information in designing VHO algorithms can benefit network a lot. Moreover, RSS-based algorithms all have one benefit in common, which is decreasing the number of handoffs. Therefore, it can be concluded that by designing an algorithm to consider both service history information and the RSS, many advantages could be obtained for vertical handoff between WLAN and the Cellular Network. This hypothesis arose from the comparison part; however, future results may vary based on different parameters, and different real network design. Therefore, the simulation and proof of the stated hypothesis will be addressed in future studies.

References

[1] Chen, L-J., Sun, T., Cheung, B., Nguyen, D., & Gerla, M. (2004). *Universal Seamless Handoff Architecture in Wireless Overlay Networks*. Technical Report TR040012, UCLA CSD.

[2] Chen, L-J., Sun, T., Chen, B., Rajendran, V., & Gerla, M. (2007). *A Smart Decision Model for Vertical Handoff*. ANWIRE International Workshop on Wireless Internet and Reconfigurability.

[3] Kim, T., Han, S-W., & Han, Y.. (2010). A QoS Aware Vertical Handoff Algorithm Based on Service History Information. *IEEE communication letters,* 14, 527 – 529.

[4] Lee, S., Sriram, K., Kim, K., Kim, Y. H., & Golmie, N. (2009). Vertical Handoff Decision Algorithms for Providing Optimized Performance in Heterogeneous Wireless Networks. *IEEE Transaction on Vehicular Technology,* 58, 865.

[5] Park, S., Yu, J., & Ihm, J. T. (2007). Performance Evaluation of Vertical Handoff Scheme Between Mobile WiMax and cellular Networks. *Proceedings of 16th International Conference o Computer Communications and Networks,* (pp. 894-899).

[6] Wang, S. H., & Kong, P-Y. (2004). A Novel Vertical Handover Scheme for Integrated WLAN and Cellular Wireless Networks. *The Ninth International Conference o Communications Systems,* (pp. 526-530).

[7] Zahran, A. H., Liang, B., & Saleh, A. (2006). Signal threshold adaptation for vertical handoff in heterogeneous wireless networks, *Mobile Networks and Applications*, 11, 625-640.

[8] Yan, X., Sekercioglu, Y. A., & Narayanan, S. (2010). A Survey of Vertical Handover Decision Algorithms in Fourth Generation Heterogeneous Wireless Networks. *Computer Networks,* 54, 1848-1863.

[9] Mohanty, S., & Akyildiz, I. F. (2006). A Cross-Layer (layer 2 + 3) Handoff Management Protocol for Next -Generation Wireless Systems. *IEEE Transactions on Mobile Computing,* 5, 1347.

[10] Yan, X., Mani, N., & Sekercioglu, Y. A. (2008). A traveling distance prediction based method to minimize unnecessary handovers from cellular networks to WLANs. *IEEE Communications Letters,* 12, 14.

[11] Lee, W. C., Chen, L. M., Chen, M. C., & Sun, Y. S. (2005). A framework of handoffs in wireless overlay networks based on mobile IPv6. *IEEE Journal on Selected Areas in Communications,* 23, 2118-2128.

[12] Chi, C., Cai, X., Hao, R., & Liu, F. (2007). Modeling and analysis of handover algorithms. *IEEE Global Telecommunications Conference,*(pp. 4473-4477).

[13] Zhu, F., & McNair, J. (2004). Optimizations for vertical handoff decision algorithms. *IEEE Wireless Communications and Networking Conference,* 2, 867.

[14] Zhu, F., & McNair, J. (2006). Multiservice vertical handoff decision algorithms. *EURASIP Journal on Wireless Communications and Networking,,* (pp. 1-13).

[15] Nasser, N., Hasswa, A., & Hassanein, H. (2006). A Context-Aware Cross-Layer Architecture for Next

Generation Heterogeneous Wireless Networks. *IEEE International Conference on Communications (ICC'06),* 1, 240.
[16] Nasser, N., Hasswa, A., & Hassanein, H. (2006). Handoffs in Fourth Generation Heterogeneous Networks. *IEEE Communications Magazine,* 44, 96.
[17] Tawil, R., Pujolle, G., & Salazar, O. (2008). A vertical handoff decision scheme in heterogeneous wireless systems. *IEEE Vehicular Technology Conference,* (pp. 2626-2630).

Biographies

ELAHEH ARABMAKKI is a research assistant of Computer Engineering Computer Science Department at University of Louisville. She earned her B.S degree from Azad University, Iran, M.S (Industrial Technology, 2009) from Morehead State University and is currently Ph.D. student (Computer science) at the University of Louisville. Her interests are in computer networks, Wireless networks, Data mining, and Internet Technologies. She may be reached at e0arab01@louisville.edu

SHERIF RASHAD is an Assistant Professor of Computer Science at Morehead State University. He received his B.Sc. (with honors) and M.Sc. degrees in Electrical Engineering from Zagazig University, Egypt in 1996 and 2001, respectively. He received his Ph.D. in Computer Science and Engineering from the University of Louisville in 2006. His research interests include mobile computing, wireless mobile networks, and data mining. He is an associate editor of the International Journal of Sensor Networks and Data Communications. He has served in many conferences as a technical program committee member. He is listed in Marquis Who's Who in America, 2009. He received the Outstanding Teaching Award from the Department of Mathematics and Computer Science at Morehead State University, 2009. He is a member of IEEE and ACM. He may be reached at s.rashad@moreheadstate.edu

SADETA KRIJESTORAC is an assistant professor in Applied Engineering and Technology Department at Morehead State University in Morehead, KY. She instructs graduate and undergraduate computer engineering and networking courses, directs graduate research, and performs research involving Wireless Communications, Data Networking and Microprocessor Based Design courses. Dr. Krijestorac may be reached at s.krijestor@moreheadstate.edu

ANALYZING PRODUCT OVERFILL

David Wischhusen, Ronald Meier, Dan Brown, Illinois State University

Abstract

A Midwest food producer's production processes were investigated to identify sources of product overfill, quantify the cost, and make suggestions for reducing the level of overfill. Product overfill occurs when a manufacturer packages more product than is statistically prudent in order to meet regulatory compliance. Overfill produces product giveaway which, at a large manufacturer, can cost millions of dollars in waste each year. Controlled, overfill can provide an adequate amount of protection from regulatory fines. However, when uncontrolled, the cost of overfill can greatly exceed the cost of noncompliance. Therefore, measuring and controlling overfill can be a significant source of cost savings. The factors investigated in this study were: day of the week of production (Sunday through Saturday), manufacturing line used, and the shift during which the product was produced. Significant differences were noted between shifts and between line numbers, though no difference between days of production was observed.

Introduction

A Midwest producer of boxed pasta products was the focal point of this study. The subject organizations, plant manager identified three project objectives. These objectives were: 1) identify significant sources/causes of product overfill; 2) quantify the financial impact of the overfill; and, 3) recommend solutions for reducing the level of product overfill.

The pasta packages, as with most food packaging in the United States, are subject to strict regulations governing the accuracy of their labels. With few exceptions, food packages sold in the United States must conform to a Maximum Allowable Variation (MAV). This value is the smallest acceptable product weight that can be sold to the general public while at the same time being the maximum weight that the actual product package weight is allowed to vary below the labeled weight [1], [2]. Failure to meet or exceed these minimum packaging requirements can result in substantial fines and penalties. The challenge for organizations is to balance the cost of overfill and the cost of compliance. The subject organization adopted a strategy known as overfilling which, while providing protection from regulatory fines, can result in expensive product giveaway. Overfill occurs when more product is placed in a package than is printed on the label. This practice ensures that a package will always exceed that product's MAV, thus protecting the company from regulatory infractions. The positive difference between the actual product and labeled amount is known as "giveaway" [3] and excessive giveaway poses financial risk to organizations.

In packing applications where a product is being filled into individual packages that have a nominal labeled weight, there are three risks that organizations face: 1) Under-filled packages could place an entire production run lot on hold and result in substantial rework; under-fill discovered at the retail level could result in a product recall, significant losses in sales revenue, additional re-work expenses, and damaged customer loyalty and organizational image. 2) Disproportionate and/or uncontrolled fill variation necessitates added labor in an attempt to better monitor and control packaging equipment to minimize negative impact. 3) Over-filled packages result in product "giveaway", which is lost revenue to the organization. Consider a product with a 1lb nominal labeled weight per package, which holds product worth \$1.00 per pound, processed at the rate of 1,000,000 packages per week, 50 weeks per year. The savings generated by a 1% reduction in overfill could save 500,000 lbs per year or \$500,000 per year.

Background

All food packaging processes contain natural variation. The magnitude of variation changes depending on the quality and age of equipment used as well as the tolerance levels for the specific process. However, even in the most tightly controlled environments, no two packages or products will consistently weigh exactly the same over time [4]. For the subject organization in this study, the natural process variation could cause less pasta to be packaged than is labeled. Thus, overfill was used to compensate for the variation intrinsic to the system.

For consumer protection, there are federal requirements regarding packaging and labeling practices to ensure that the package label is a true reflection of the amount of product contained. The federal government began regulating package labels after the 1958 amendment to the Federal Food, Drug, and Cosmetic Act (FD&C Act). Differences between labeled and packaged weight fell under the purview of a "misbranding" clause in the act [3]. Later, in 1967, the Fair Packaging and Labeling Act (FPLA) was passed adding additional labeling requirements for all consumer commodities [5].

Title 21 Section 343 of the FD&C Act states that any package bearing a label must contain "an accurate statement of the quantity of contents in terms of weight, measure, or numerical count..." [5]. Reasonable variations are permitted and are known as the MAV. These requirements necessitated fair disclosure of net contents, identity of commodity, and the name and place of a product's manufacturer. The Food and Drug Administration (FDA) administers the FPLA as it pertains to food products [6]. Beginning in 1979 with the endorsement of the National Conference on Weights and Measures (NCWM), the National Institute for Standards and Technology (NIST) begin compiling the latest Uniform Laws and Regulations as they relate to the measurement and labeling of consumer quantities. This publication is NIST Handbook #130 and is the standard for uniform weights and measures laws and regulations in the United States [7]. If a company is found to have violated a labeling regulation, for instance by over-representing the contents of a package, that company will face stiff penalties including fines and other punitive measures as outlined in NIST Handbook #130 [8].

However, while creating the aforementioned legislation, regulators were aware of natural process variation in manufacturing [4] and took the principle of variation into account when establishing the packaging and labeling requirements [3]. The acceptable amount of variation for a particular product, i.e., the greatest amount that the actual measure of contents is allowed to vary from the labeled quality, is called the Maximum Allowable Variance (MAV) [1]. The MAV is determined on a per-product basis and is dependent on the type of product being packaged (labeled by weight, by volume, by count, etc.) and in what quantity. The values for product MAVs are determined by The National Conference on Weights and Measures and are published regularly in NIST Handbook #133 [1].

In addition to specifying MAV values, Handbook #133 also outlines test procedures for measuring and testing products for compliance. Specific product MAV values can be found in the Appendix of NIST #133. Natural process variation is intrinsic to the regulations; therefore, manufacturing processes are afforded a limited amount of regulatory protection while still maintaining the integrity of package labels. Since process variation is already part of the MAV value, penalties for noncompliance can be very strict. Penalties can include fines and even criminal damages awarded, depending on the frequency of infractions and whether or not they were intentional [8].

Furthermore, customer satisfaction and brand reputation may be negatively affected if a company is caught underfilling its products [9]. In 2000, a lawsuit involving a California man and under-filled Heinz ketchup bottles was settled. Heinz insisted that the ketchup bottles were not intentionally under-filled but damages were expected to total approximately $830,000 which included civil penalties and the estimated cost of the year-long practice overfill required of Heinz as part of the settlement [10]. Product overfill is often a deliberate strategy used by manufacturers to further guard themselves against regulatory fines and other legal actions and often a calculation is made that establishes the cost of overfill to be less than the cost of the penalties and fines associated with packaging infractions [11]. Therefore, while the cost of giveaway may be significant, overfill is often seen as the necessary cost of compliance.

Cost of Overfill

While product overfilling may be prudent and the cost per package may be minor, when the individual amounts of overfill are measured, summed, and annualized, the cost can become quite large. The degree to which overfill can damage a company's bottom line increases with the scale of production.

Overfill and product giveaways are problems that have been examined and addressed at other manufacturing firms, often very successfully. Past successes from the literature were analyzed in order to provide guidance for implementing effective strategies. Swankie Food Products, a fish product manufacturer from the UK, successfully used statistical process control (SPC) tools such as control charts to gain insight into the nature of their manufacturing processes [11]. Control charts are graphs that are used to study how a process changes over time. These charts contain historical (and sometimes real-time) performance data along with lower and upper process control limits. The lower and upper control limits assist in determining if the process variations are under control [12].

As noted earlier NIST #133 standards do not stipulate limits for overfilling, only that fill weights are required to be above the MAV weight but as close as possible to the label declaration. The approach to meeting this regulation is to shift the curve up, so that the average is at or above the label weight, and the lower tail is just above the MAV weight. SPC tools allow organizations to tighten the curve, thus eliminating MAVs and producing less overfill.

These charts were used by Swankie Foods Products to determine if their production processes were out of control and thus a risk to the manufacturer. The Flavor Division and

McCormick, which manufactures sauces, dressings, and condiments, experienced overfill challenges that were addressed using the same GainSeeker SPC software that was implemented at the subject organization of this study. McCormick was able to reduce overfill material costs by up to 30% and realized three times their desired reduction using control charts from GainSeeker to understand their process variations [13].

Another food manufacturer (whose name was left unspecified for proprietary reasons) that also made use of similar SPC strategies (and also used the GainSeeker suite) was able to reduce their product overfill, eventually producing an overall savings of $3.4 million over six months [14]. Following an internal study, Heinz implemented an SPC initiative at a recently acquired small company (Heinz Single Service). This company produced a high volume of products, shipping 900 million units on 13 different filling lines. Heinz chose to use a product from MVI Technologies to handle the real-time data monitoring and was able to bring their levels of overfill completely under control in three months [15]. While the literature confirmed that standard SPC tools such as control charts, Pareto charts, and capability charts represent appropriate and effective approaches to controlling overfill, they provide no indications as to potential sources of overfill within a process as such information is often guarded and proprietary. The use of real-time data, as opposed to time-delayed data, to study a process was also repeatedly cited as advantageous when addressing product overfill.

The annual cost of overfill for the subject organization was reported by the plant manager to be just over $4,000,000. The pasta business unit with seven production lines was responsible for $1,250,000 of the overfill problem. The two production lines investigated in this study were responsible for $878,000 of product overfill for the preceding 12 months. [16].

Methodology

At the start of this project, the authors led a brainstorming session with management, line supervisors and operators, and maintenance and quality personnel. An affinity analysis was used to organize the participant's ideas as to the causes of product overfill. As such, each participant was asked to record each idea on a separate sticky note. While participants were writing their ideas, the authors randomly spread the sticky notes on a whiteboard so that all sticky notes were visible to everyone. The brainstorming exercise contributed 127 potential causes of product overfill. These 127 ideas were reduced to 57 unique ideas by eliminating redundancies and formalizing standard definitions.

Upon completion of the brainstorming activity, participants were asked to review the ideas and then look for ideas that seemed to be related in some way by placing like ideas in columns and repeating the process until all notes were grouped or assigned to a column. Upon completion of the grouping exercise, participants were then asked to determine a column heading for each group of related ideas. The column heading needed to be representative of all the individual sticky notes in the column. Column headings included equipment, operators/personnel, raw materials, the environment, operating procedures, and maintenance.

Once column headings were determined, each sticky note representing a column heading was pulled aside and all column headings placed in a circle. For each column heading the participants were asked, "Does this heading cause or influence any other idea?" Arrows were drawn from each idea to the ones it caused or influenced. This question was repeated for every column heading. The next step was to analyze the diagram and its relationships.

Upon completion, the researchers counted the arrows in and out for each column heading. The column headings with the most out arrows influenced the most other column headings. These are the basic "causes". The column headings with primarily incoming (to) arrows were the final "effects" that also may be necessary to address. The number of arrows is only an indicator, not an absolute rule. The results are shown in Table 1.

Table 1. Interrelationship Diagraph Ranking of Column Headings

Column Heading	*Out Arrows*	*In Arrows*	*Rank*
Equipment	1	2	4
Operators/Personnel	2	3	2
Raw Materials	0	2	6
Environment	1	2	4
Operating Procedures	4	1	1
Maintenance	2	1	3

The highest priority column headings were operating procedures, operators/personnel, and maintenance. At this point, the business unit manager reviewed the findings and selected three sticky notes from the operating procedures column heading to be the focus of investigation. These variables were: 1) day of the week, 2) line number, and 3) production shift number. The business unit manager cited shift operating differences as a potential cause of excessive product overfill. Operating differences included the number of people working per shift, clean-up or sanitization expectations per shift, and lack of training for third shift operators. Additionally, the three variables selected were deemed to be variations which were under the direct control of the business unit manager.

Automated Data Collection

The subject organization's attempts to quantify and control product overfill relied on automated data collection software from the GainSeeker software suite from Hertzler Systems, an industry leader in SPC applications. Data were extracted daily from the GainSeeker software for five months (January 4, 2011, through May 31, 2011). Both production lines were limited to one product mix for the duration of the study. Weight sets (five consecutive packages) had to be taken at least every 30 minutes with a recommended target of every 20 minutes. Weight control deviations were issued if there were more than 30 minutes between sample sets. When a weight deviation was issued, every package between the last acceptable weight check and the last package produced had to be individually weighed. Each production line produces between 230 and 280 packages per minute. Thus, there could be as many as 8400 packages that need to be individually weighed. This process must be repeated if any weight set of five packages fails to meet required weights.

The GainSeeker suite calculates a value called the Hertzler Target and uses historical data to account for process variation and minimizes overfill. If properly computed, the Hertzler Target is the amount of product to package so that the MAV weight will never be exceeded for a particular process. When using the Hertzler Target, overfill is defined as the amount of product that exceeds the target.

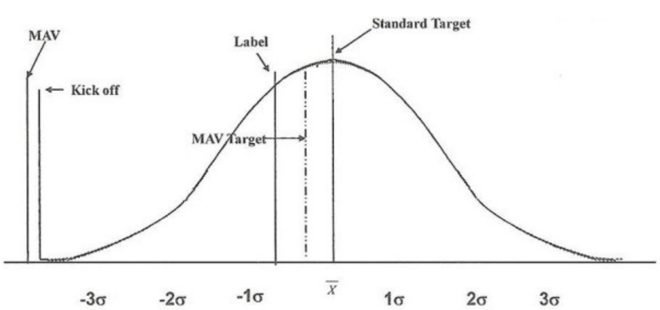


Figure 1. MAV and Target Relationships [9]

Figure 1 illustrates the relationship between the MAV, the labeled value, and the Hertzler Target. In this figure, the lines labeled "MAV Target" and "Standard Target" are both the Hertzler Target. If the production line uses a checkweigher (a highly precise machine to automatically check the weight of packaged materials), the MAV Target value is used. If a production line doesn't have a checkweigher, the Standard Target value is used to provide additional security [7]. The GainSeeker software supports SPC calculations and analysis. The researchers imported the data from GainSeeker into Minitab to conduct the analysis reported from this study.

Data collected from the GainSeeker software included: line number—one or two, product codes—only one product was run during the data collection period, Average of Hertzler (MAV) Target in grams, Average of Actual in grams, overfill in grams—the difference between the Average of Actual and Average of Hertzler Target, and Opportunity in dollars. Both production lines used checkweighers to monitor product weights.

Control chart data from GainSeeker revealed product overfill to be out of control. Prior to this study, management had not addressed assignable or common-cause data. Corrections to possible assignable causes were not documented or tracked. As directed by management, the researchers did nothing to correct the out-of-control nature of the process prior to analyzing the data. Management's first priority was to determine if there was a difference in overfill levels among the three variables cited previously.

Hypothesis

Three factors (each with multiple levels) were examined to determine their impact on product fill. These factors were: day of the week of packaging (Sunday through Saturday), shift number (1-3), and line number (1 or 2). The percent overfill (the actual of amount of product compared to the target value) was the dependent variable. To analyze which days, shifts, or line numbers produced the greatest amount of overfill, an ANOVA was used to analyze the level of each independent variable. This resulted in three hypotheses:

For days of the week (Sunday - Saturday):

$$H_0: \mu_{1d} = \mu_{2d} = \ldots = \mu_{7d} \tag{1}$$

where μ_{nd} is the mean on day *n* (Sunday through Saturday).

For shift number (1, 2, or 3):

$$H_0: \mu_{1s} = \mu_{2s} = \mu_{3s} \tag{2}$$

For line number (1 or 2):

$$H_0: \mu_{1l} = \mu_{2l} \tag{3}$$

Data Analysis

Three factors were analyzed for their contributions to total product overfill. For simplicity, an analysis of variance (ANOVA) was used to check for differences in the amount of overfill present within each factor. For example, an ANOVA performed on the Day of Week factor would compare the variation of product that was produced on Sunday, Monday, Tuesday, etc. and determine if one of those days produced a significantly different amount of overfill. Interaction effects were not considered. All analyses were done using Minitab. As a standard, a 95% confidence level was selected for all analyses.

Day of the Week

The day of the week that the product was packaged was thought to be a potentially significant source of overfill. The day of the week itself was not thought to be a direct contributor, though data contained within the day was thought to be potentially significant (personnel configurations, proximity to the weekend, variations due to maintenance cycles, etc.). The ANOVA table for days of the week determined that this factor was not a significant source of overfill (see Figure 2). The p value exceeded the alpha value of 0.05 required to establish significance. It was therefore concluded that there was not a significant difference in the amount of overfill produced on the different days of the week.

Figure 2. Overfill versus Day of Week

One-way ANOVA: Diff versus Day of Week

```
Source        DF       SS    MS     F      P
Day of Week    6     2.82  0.47  0.06  0.999
Error        475  3470.23  7.31
Total        481  3473.05

S = 2.703   R-Sq = 0.08%   R-Sq(adj) = 0.00%


                                Individual 95% CIs For Mean Based on
                                Pooled StDev
Level       N   Mean  StDev  --+---------+---------+---------+-------
Friday     82  3.792  2.484    (--------------*-------------)
Monday     59  3.839  2.541   (----------------*----------------)
Saturday   59  3.967  2.803      (----------------*----------------)
Sunday     53  3.905  2.570   (-----------------*-----------------)
Thursday   79  3.719  2.632  (--------------*--------------)
Tuesday    71  3.898  2.912      (--------------*---------------)
Wednesday  79  3.814  2.915    (--------------*--------------)
                             --+---------+---------+---------+-------
                              3.20      3.60      4.00      4.40

Pooled StDev = 2.703
```

Line Number

Due to subtly different equipment and maintenance track-records on the two production lines, the specific production line that a product was packaged on was suspected as a significant source of overfill. As with days of the week, the two production lines were analyzed using an ANOVA. A significant difference between the production lines was discovered (see Figure 3). The p value was below the 0.05 threshold required for significance. It was therefore concluded that there was a significant difference in the amount of overfill produced between the two production lines.

Figure 3. Overfill versus Line Number

One-way ANOVA: Diff versus LN_Coded2

```
Source      DF       SS      MS      F      P
LN_Coded2    1   460.13  460.13  73.31  0.000
Error      480  3012.92    6.28
Total      481  3473.05

S = 2.505   R-Sq = 13.25%   R-Sq(adj) = 13.07%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level    N   Mean  StDev  --------+---------+---------+---------+-
1      149  5.300  2.695                                (-----*----)
2      333  3.185  2.416  (---*--)
                          --------+---------+---------+---------+-
                                3.50      4.20      4.90      5.60

Pooled StDev = 2.505
```

Shift Number

Shift number was suspected as a potential source of overfill due to different personnel configurations between shifts as well as disparate levels of training. After completing the analysis, it was concluded that there were significant differences in the cost of overfill between the three different shifts. Specifically, shift 3 produced significantly less overfill than shifts 1 & 2 (see Figure 4). The p value was under the 0.05 threshold for significance. It was therefore concluded that there were significant differences in the amounts of overfill produced among the three shifts.

Figure 4. Overfill versus Shift Number

One-way ANOVA: Diff versus Shift

```
Source   DF       SS      MS      F      P
Shift     2   211.73  105.86  15.55  0.000
Error   479  3261.32    6.81
Total   481  3473.05

S = 2.609   R-Sq = 6.10%   R-Sq(adj) = 5.70%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level    N   Mean  StDev  ----+---------+---------+---------+-----
1      161  3.987  2.577                (-----*-----)
2      165  4.545  2.706                        (-----*-----)
3      156  2.940  2.538  (-----*-----)
                          ----+---------+---------+---------+-----
                            2.80      3.50      4.20      4.90

Pooled StDev = 2.609
```

Conclusions

Two conclusions were drawn from this study: 1) the line number the product was run on contributed significantly to product overfill—specifically line #2 produced the least amount of overfill (p = 0.000); and, 2) there was a significant difference in product overfill levels between production shifts—specifically the third shift produced the least amount of overfill (p = 0.000).

When examining the two production lines in more detail, the following characteristics were noted. Production lines 1 and 2 were both installed in 1969. The two production lines were located adjacent to each other. Production lines 1 and 2 produced the same products since installation. Minimal preventive maintenance had been performed. Both production lines were run until there was a mechanical failure that forced production to stop. At that time, repairs were made. Uptime or run-time percentages were greater than 95% for both production lines.

The analyses showed a difference in product overfill between the two production lines. However, the variables examined in this study were not directly attributable to these differences. The researchers recommended further analysis to determine the root cause of this difference. When examining employee work schedules and shift differences, the following characteristics were noted. Third shift was comprised of mostly new hires. Employees moved from third, to second, to first shift based strictly on seniority. There were fewer employees allocated to each production line on third shift. Third shift had the least amount of direct management supervision. Uptime or run time percentages were greater than 95% for all three shifts.

Managerial Implications

This study was the first in a series of ongoing studies to address product overfill. Thus, there are limitations in terms of managerial implications. The plant manager and business unit manager asked the authors to target "low hanging fruit" or opportunities directly under managerial or supervisory control to decrease product overfill without spending significant dollars to upgrade equipment and infrastructure. Furthermore, the researchers were asked to identify and raise additional questions for other improvement teams to address. Management wanted a fresh set of eyes and outside input into additional improvement ideas. Therefore, many of the managerial implications focus on identifying additional studies, data collection or experiments to be carried out in the future.

General Trends in the Food Processing Industry

The production facility in this study faced the same general trends found across the food processing industry. These trends include:

- Organization-wide Strategic Cost Reduction Goals

One question that needs to be addressed through further investigation is why the third shift—with the fewest employees on each production line—produced the least amount of product overfill. One assumption from the researchers was that the employees on the third shift did not have time to sit and watch the computer monitor as it tracks the real-time values for product overfill. Human nature tends to encourage operators to add their personal touch or setup expertise in an attempt to add value to their jobs. This may be one case where overall production would be better if the operators were more hands-off. Operators were observed making minor adjustments to product mixes, line speeds, fill pressures, etc., as soon as the monitors started to trend toward the MAV target. These changes may have been unneeded and just reflective of natural process variation. The researchers felt that the operators were over adjusting based on too little data and not utilizing the full potential of the GainSeeker software to see real production trends. One suggestion from the researchers to management was increased training, application, and interpretation of run and control charts. Specifically, operators need to know and understand the rules for run charts and proper use of such information for process improvement.

An additional recommendation regarding the differences in shifts was for management to facilitate an effort to minimize or simplify the steps and complexity of their standard operating procedures (SOPs). It was recommended that the SOPs include best-practice reviews and/or procedural checklists.

- Cleaning and Sanitization

It was noted by the researchers that first- and second-shift employees resisted performing regular cleaning and sanitization. The culture within the organization was such that employees on the first shift felt that they had earned a reprieve from cleaning and sanitization responsibilities. As such, even though the production line uptime percentages were almost identical, it was evident that the third shift was more conscientious and adept at performing mandated cleaning and sanitization duties. One question not addressed by this study was: "is there a relationship between the level of performance of cleaning and sanitization and product overfill?" This question needs to be addressed. And, if the findings support a relationship, management will need to undertake efforts to better communicate the importance of cleaning and sanitization to first- and second-shift employees.

• Utilization

One of the subject organization's strategic goals was to reduce operating expenses by 10% per year. Management must achieve these goals or face not being promoted or possibly even fired. Prior-year initiatives focused on production utilization.

The subject organization utilized Overall Equipment Effectiveness (OEE) to determine individual production line and overall plant production utilization. OEE takes into account all three OEE factors and is calculated as: OEE = Availability x Performance x Quality. Although the two production line OEEs were greater than 95%, management always tried to squeeze out that extra percent or two. This may have negatively impacted overfill for the first and second shifts. Since there was minimal managerial presence during the third shift, the pressure to increase line speeds and production rates was much less evident. Over the five-month period of this study the researchers often observed management and production line supervisors trying to increase the production line speed. It was the researcher's belief that there may be a point of diminishing returns. Although there was no empirical evidence to support this, it appeared that increasing production line speeds may have contributed to other mechanical, production, and operator problems. Therefore, the researchers recommended another study to determine the optimum production line operating speed. Such a study would need to examine both optimum production line operating speed and its relationship to uptime, as well as optimum production line operating speed and its relationship to product overfill.

Summary

The subject organization is in the initial stages of implementing a company-wide quality-improvement program. To date, the focus has been on reducing internal wastes (LEAN) and implementing six sigma projects to address process variations. This study was one of the initial six sigma projects. As with any organization, both lean and six sigma projects can have tremendous impacts on an financial performance. The product overfill problem discussed in this paper is a multi-million-dollar-per-year problem for this organization. What the subject organization found was that ongoing improvement initiatives require a culture change at all levels of the organization. Without the culture change they will never be able to achieve the full financial benefits of their lean and six sigma initiatives. People's daily routines must change. Managers and employees must now focus on new duties and responsibilities. The new emphasis is on data collection and problem solving. Managers, who in the past have relied on fire-fighting, are being replaced with people who can find data-driven solutions to problems. Organizations such as the subject organization in this study need managers and employees who can carry out experiments, analyze data, and solve problems. But, more importantly, they need to examine their organizational culture and values. After all, people are the key to the successful implementation of organizational change.

References

[1] The National Institute of Standards and Technology (2011, September 23). Checking the Net Contents of Packaged Goods. NIST Handbook 133- 2011. Retrieved January 10, 2012, from http://www.nist.gov/pml/wmd/pubs/hb133-11.cf

[2] Wachs, S. (2011). Optimizing Product Target Weights of Foods and Beverages: How to minimize overfills while minimizing risks of noncompliance. *Quality Digest*. Retrieved January 31, 2012, from http://www.qualitydigest.com/inside/metrology-article/optimizing-product-target-weights-foods-and-beverages.htm

[3] Rounds, H. G. (1962). The Major Considerations in the Problem of Package Weight Control. *Journal of the American Society of Sugar Beet Technologists*, 12 (1), 73-80.

[4] Hubbard, M. R. (2003). *Statistical Quality Control for the Food Industry*. (3rd ed.). New York, NY: Kluwer Academic/Plenum Publishers.

[5] Food and Drug Administration. (2010). U.s.c. Title 21 - Food and Drugs. Retrieved January 4, 2012, from http://www.gpo.gov/fdsys/pkg/USCODE-2010-title21/html/USCODE-2010-title21-chap9-subchapIV-sec343.ht

[6] Federal Trade Commission (n.d.). Fair Packaging and Labeling Act. FLPA Introduction. Retrieved January 4, 2012, from http://www.ftc.gov/os/statutes/fpla/outline.htm

[7] Koenig, J. (n.d.). Uniformity in weights and measures laws and regulations. Retrieved January 4, 2012, from http://nvlpubs.nist.gov/nistpubs/sp958-lide/368-370.pd

[8] The National Institute of Standards and Technology (October 25, 2011). Uniform Laws and Regulations in the areas of legal metrology and engine fuel quality. NIST Handbook 130 - 2012. Retrieved February 29, 2012, from http://www.nist.gov/pml/wmd/hb130-12.cf

[9] Hertzler Systems, Inc. (n.d.). Retrieved January 4, 2012, from http://www.hertzler.com/php/solutions/foods.ph
[10] Associated Press (2000, November 30). Redding Man Spurs Heinz to Add More Ketchup. Los Angeles Times. Retrieved December 12, 2011, from http://articles.latimes.com/2000/nov/30/business/fi-5933
[11] Grigg, N. P., Daly, J., & Stewart, M. (1998). Case study: the use of statistical process control in fish product packaging. *Food Control*, 9(5), 289-297.
[12] Tague, N. R. (2005). The quality toolbox. (2nd ed.). Milwaukee, WI: ASQ Quality Press.
[13] Hertzler Systems, Inc. (n.d.). McCormick Flavor Division reduces overpack and material costs by 10-30%. Hertzler Systems Inc.. Retrieved January 4, 2012, from http://www.hertzler.com/php/portfolio/case.study.detail.php?article=
[14] Hertzler Systems, Inc. (n.d.). State-of-the-art SPC System drives financial results. Hertzler Systems Inc.. Retrieved January 4, 2012, from http://www.hertzler.com/php/portfolio/case.study.detail.php?article=3
[15] Manufacturing Computer Solutions (2006, September). Cutting the mustard the Heinz plant way. findlay media. Retrieved December 13, 2011, from http://fplreflib.findlay.co.uk/articles/7655%5CMCSSEP_P45.pd
[16] Plant Manager. (2010). *Outline of Production Overfill and Associated Business Unit Costs*. Unpublished manuscript, Subject Company.

Biographies

DAVID WISCHHUSEN is a graduate student at Illinois State University. He earned his B.S (Physics, 2010) and M.S. (Project Management, 2012) from Illinois State University. His interests include Six Sigma, LEAN, and the Theory of Constraints. David Wischhusen can be reached at dtwisch@ilstu.edu

RONALD MEIER is a professor in the Technology Department at Illinois State University. He is an educator, trainer, and consultant with an emphasis on assisting organizations with the integration of project, quality, and enterprise-wide risk management. He is the Vice-Chair of e-Based Initiatives for the Quality Management Division of the American Society for Quality. Dr. Meier may be reached at rlmeier@ilstu.edu

DAN BROWN is a professor in the Technology Department at Illinois State University. His teaching responsibilities include project team leadership, training implementation, and evaluation of training programs. He is coordinator of graduate studies for the Department of Technology. Dr. Brown may be reached at dcbrown@ilstu.edu

The Importance of Strategically Managing Intellectual Capital to Develop Innovative Capacity in Brazilian Companies

Ingrid Paola Stoeckicht, Fluminense Federal University; Carlos Alberto Pereira Soares, Fluminense Federal University

Abstract

This paper presents a study conducted among 35 Brazilian companies of varying sizes and sectors into their innovative capacity based on an analysis of their intellectual capital management practices, systems, and models. Using the *Intellectual Capital Innovation Assessment Model®*, this analysis was conducted on 19 intellectual-capital-related indicators considered important to the development of an organization's innovative capacity. The results point to a significant correlation between the companies´ capability to innovate and the intellectual capital management models they adopted.

Introduction

The concept of innovation has attracted the interest of researchers, academics, and business people since 1970. In the last decade, innovation has become recognized as essential to the competiveness of organizations and has been included into their corporate strategic agendas. Several researches [1-3], show a strong correlation between innovation, economic development, productivity, and organizational performance. It is, therefore, paramount that 21st-century organizations be able to continually upgrade their products, services, processes, competencies, and organizational designs in order to guarantee sustainable growth and, consequently, their survival in the market. Regardless of the economic sector in which they operate, knowledge-based companies are becoming more abundant, thus making innovation management a strategically important area in organizations.

Stewart [4] asserts that three important ideas have transformed the way organizations have operated over the last few decades: Total Quality Management, reengineering, and the concept of Intellectual Capital. In linking intellectual capital with innovation, he makes two interesting statements: "Intellectual capital and knowledge management are two of the most important topics in business today" and "innovation is treated as a mysterious, external factor". His observations suggest the need to conduct further research on innovation in order to better understand the dynamics of the processes which leverage innovative capacity in organizations.

Research on Innovation and Innovative Capacity

According to the Oslo Manual [5], innovation activities take place in small, medium, and large companies across all sectors of the economy, such as manufacturing, services, public administration, health, and even in the homes of people. As the concept of innovation is still somewhat vague, especially in some economic sectors, the Manual recommends that research on this subject should primarily focus on innovation activities in market-oriented industries, including service industries.

Moreira & Queiroz [6] warn us about the difficulty of systemizing studies in applied social sciences, particularly in the field of business administration under which innovation research falls. They emphasize that innovation studies form a complex area of research about various branches and specializations, but have witnessed a surge in popularity in the last two decades. These authors affirm that the understanding of innovative behavior in companies is still rather limited, and that most research on innovation have largely generated inconclusive results. They go on to state that research on innovation may be categorized into two main groups: research conducted in the higher levels of an aggregate, such as a nation, an industry as a whole, a manufacturing sector or a particular industrial group; and research carried out at the company level, investigating innovation in a certain company or a small set of companies from the same industry, as in multiple case studies.

Moreira & Queiroz break down innovation studies at a company level into three classes: research on the Diffusion of Innovation (DI), on an organization's Innovative Capacity (IC), and on the Theory of Processes (TP). Research on innovative capacity seeks to discover which factors stimulate innovation in a company. This involves identifying the determining factors contributing to an organization's capability to innovate.

Strategic Management of Intellectual Capital and Innovative Capacity

Intellectual capital refers to a company's intangible assets, with people as its mainspring. These intangible assets are related to the market, suppliers, partners, internal processes, technological infrastructure, and education, which may be defined as an organization's value chain [7].

Sveiby [8] proposed a taxonomy of intellectual capital in his book, "The New Organizational Wealth: Managing and Measuring Knowledge-Based Assets". He claims that knowledge assets are concentrated in three main areas: the competencies of a company's staff, its internal structure (patents, models, and internal systems), and its external structure (brands, reputation, customer and supplier relations).

Edvinsson & Malone [9] also divide a company's intellectual capital into three main areas: structural capital, customer capital, and human capital, as shown in Figure 1. They divide structural capital into organizational, innovation, and process capital. The first refers to the company's investment in organizational systems, instruments, and corporate culture, which facilitate the flux of knowledge through the organization, its external departments, and the supply and distribution channels. It is a systemized, organized, and codified competency, as are the systems that harness this competency. Innovation capital refers to the capacity for renovation and the results of innovation in terms of legal commercial rights, intellectual property, and other intangible assets used to create new products and services, and release them onto the market. Process capital refers to processes, techniques, and programs, used by the organization's collaborators with the aim of improving product or service efficiency. It is the practical knowledge employed in the ongoing value creation.

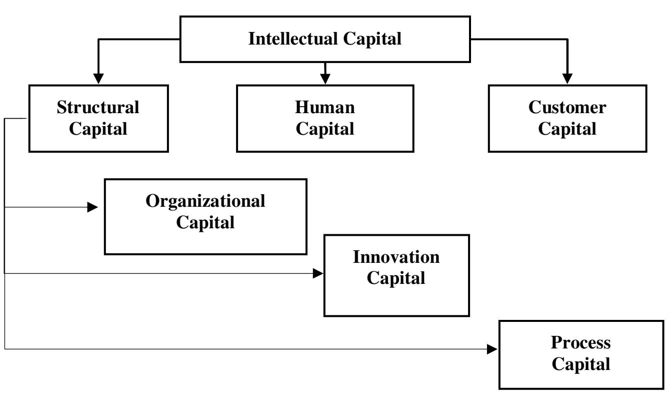


Figure 1. Model of Intellectual Capital [9]

Stewart [4] defines intellectual capital as "knowledge assets including talent, skills, know-how, know-what, and relationships, as well as the relevant machines and networks – used to create wealth." This means that intellectual assets may be found both in routine and unexpected places: in people, in the organizational structures and infrastructure, in the company's relationships, its customers' staff, and its external collaborators, and should consequently be cultivated and aligned by an organizational strategy. According to Stewart, the most common taxonomy used by theorists and researchers operating in the field of Intellectual Capital Management to represent these elements has been: Human Capital, Structural (or Organizational) Capital, and Customer (or Relationship) Capital.

Cavalcanti et al. [10] add a fourth element to be contemplated in the analysis of intangible assets: Environmental Capital, which incorporates the other three dimensions. For these authors, the four capitals defined as Human, Structural, Relationship, and Environmental, are important sources for the creation of value and innovation in an organization. According to several other authors [4], [9], [11-15], a sustainable competitive edge emerges when a company is able to channel its knowledge and technological competencies into innovation in services, products, processes, administrative and management models, and commercialization strategies, in order to leverage organizational performance in the execution of its strategic objectives.

Jonnash & Sommerlate [14] highlight the need to stimulate innovation through the synergy and complementarities in the organization´s technological, financial, and human resources—knowledge and talents—found in the company's business ecosystem. According to these authors, identifying intellectual capital resources in the company's value network [16] within the extended enterprise [14], which comprises intangible assets of clients, suppliers, direct and indirect collaborators, partners and even competitors, and strategically managing them to innovate must become a core competency for organizations to sustain and leverage their business in current and future competitive scenarios.

Chesbrough [17], [18] states that a company may seek innovation resources from outside the extended company and its value network. He proposes an open innovation management model for the development of both products and services, which presumes that resources which stimulate innovation are found both internally and externally, and can be obtained from organizations and professionals located anywhere in the world. According to Chesbrough, companies wishing to leverage their innovative capacity should open their doors to external human, financial, and technological resources found in research centers, universities and even competing companies. Therefore, they should establish collaborative strategies and agreements with these companies for the transfer of innovation-oriented knowledge and technologies.

Almeida [19] emphasizes that intellectual capital is a starting point for innovativeness and that it is a company's intangible assets that add value and credibility to the business, thereby determining its innovative and learning capacity, rendering it necessary for companies to employ strategic management of their intellectual resources. All in all, according to the above-mentioned authors, innovation management through the strategic management of intellectual capital in the extended enterprise has become an important management tool to increase a firm´s capability to innovate.

Study on Innovative Capacity in Brazilian Companies

The research method adopted in this study was the case-study method. According to Yin [20], this method is used to explain contemporary events of how some social phenomenon works, and for in-depth descriptions of this phenomenon, thereby enhancing knowledge of individual, group, social, political, and organizational determining factors that contribute to the phenomenon. The case-study method, then, allows for retention of meaningful characteristics of organizational and managerial behavior, such as the innovative capacity in firms. Yin also states that the case-study method can be the basis for significant explanations and generalizations, allowing one to draw a set of "cross-case" conclusions.

Innovative capacity, as defined here, deals with the ability of an organization to develop strategic processes to gain a competitive edge, resulting from at least one of five types of initiatives: a new product or service, a new process, a new management model, a new marketing/commercial approach, a new business model, or the improvement of these, which should add a significant, tangible and/or intangible value to an individual, group, organization, market, or society as a whole.

In this paper, the authors present the results of a multiple case study which set out to analyze innovative capacity across 35 Brazilian companies using the Intellectual Capital Innovation Assessment Model® and its diagnostic tool, the Innovation Assessment Questionnaire (I.A.Q.®) [15]. This model is a quantitative-qualitative diagnostic tool that aims to help managers assess how and to what extent the systems, models, and practices adopted by the organization to manage its intellectual capital may contribute to the development of the company´s innovative capacity. It was developed based on the innovation management models proposed by Higgins [12], Jonnash & Sommerlate [14], and Tidd et al. [11], which identified organizational models, practices, systems, and routines considered important for innovation processes, necessary to leverage innovation capacity in firms.

This study sought to assess how these organizations promoted the development of their innovative capacity through the management of the financial, technological, and human resources available in the human, structural, relationship, and environmental Capitals, within the extended enterprise and business ecosystems, so as to identify the main barriers to innovation within these organizations, considering their industry and marketplace. An additional objective of this study was to assess the level of understanding of the managers, who responded to the I.A.Q.®, about the importance of the systems, models, and practices adopted by their companies to help develop the organization's innovative capacity.

The Innovation Assessment Questionnaire (I.A.Q.®)

The I.A.Q.® took the form of 64 questions about management practices related to 19 intellectual capital-related indicators that leverage innovation capacity within an organization [11], [12], [14], [15], [17]. Each indicator was assessed on a scale of 0 (zero) to 1.0 (one) points. The key indicators and their descriptions are outlined in the Table 1:

The I.A.Q.® was applied to analyze how the following factors might stimulate or restrict organizational innovation: strategies, goals, targets, organizational culture and values, structural and infrastructural resources, people and business management models, and administrative systems. This study was conducted over a period of 24 months, from 2007 to 2009, and carried out at the company level [6], involving 35 Brazilian organizations, eight of which belonged to the public sector, and 27 to the private sector, with a geographical distribution as displayed in Figure 2, and of various sizes, as per Figure 3.

The companies that participated in this study were selected based on their interest in assessing their innovative capacity, and identifying inhibiting factors to innovation in their organizations. Of the 35 companies analyzed, 31% belong to the industrial sector, 66% to the service sector, and 3% to the commercial sector. They operate in a variety of segments including: petrochemicals, food, commodity distributors, pharmaceutics, iron and steel, IT, education, energy, clothing, sports, insurance, telecommunications, and automobiles.

Table 1. Intellectual Capital Innovation Indicators

Innovation Indicators	Description
Essential Competencies and Critical Knowledge	The degree to which the organization identifies its Core Competencies and Critical Knowledge in order to conduct its current and future activities.
Environmental monitoring	The degree to which the organization monitors the external environment in tracking innovative and technological developments, and market trends.
Culture and Organizational Values	The degree to which the organizational culture and values encourage innovation, innovative and entrepreneurial behavior.
Organizational Learning and Knowledge Creation	The degree to which the organization adopts practices to enhance its learning capacity and create new knowledge aimed at developing innovative solutions.
Organizational Communication	The degree to which internal communication systems and I.T. stimulate and sustain innovation processes in the organization.
Creativity and Idea Capture and Management	The degree to which the organization promotes creative problem-solving and develops innovation by utilizing idea capture and management systems for collaborators in the value network.
Performance assessment, recognition, remuneration and promotion	The degree to which performance assessment, recognition, remuneration and promotion systems value innovative behavior, critical knowledge, individual competencies, and collaborators' capacity to contribute to innovation in the organization.
Recruitment and Selection	The degree to which the internal and external recruitment and selection systems values innovative behavior, critical knowledge, individual competencies, and collaborators' capacity to contribute to innovation in the organization.
HR Retention	The degree to which the organization adopts practices to retain collaborators and their critical knowledge in order to leverage the organization's innovative capacity.
Innovation Indicators	Description
Collaborative Work Models	The degree to which the organization adopts collaborative work models to stimulate interaction aimed at co-creation and co-innovation processes within the organization´s value network.
Leadership Roles	The extent to which managers and leaders understand and manage innovation processes and strategies, and promote and strengthen the necessary competencies for innovation at all organizational levels.
Relationship Network	The degree to which the organization identifies and utilizes intellectual capital resources available in the company's extended value network to develop innovation.
Management of Collaborative Agreements	The degree to which the organization establishes and manages collaborative agreements and partnerships in order to develop its innovative capacity.
Innovation Strategy	The degree to which the organization establishes strategic guidelines to promote and align collaborators' actions in order to strengthen innovative capacity at individual and organizational levels.
Organizational Structure and Infrastructure	The degree to which the organization is structured in order to better promote the sharing and creation of knowledge and generation of innovative solutions.
Innovation Generation	The degree to which the organization has generated innovative solutions in the last 24 months by means of its collaborators´ contributions.
Barriers to Innovation	This identifies the degree to which barriers inhibit innovation and if they are individual in nature (behavioral) and/or organizational (structural/infrastructural).

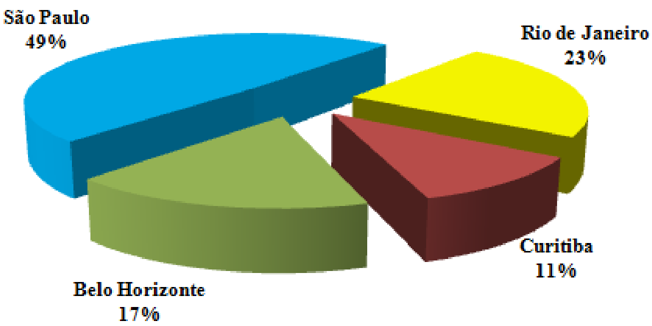


Figure 2. Geographical Location

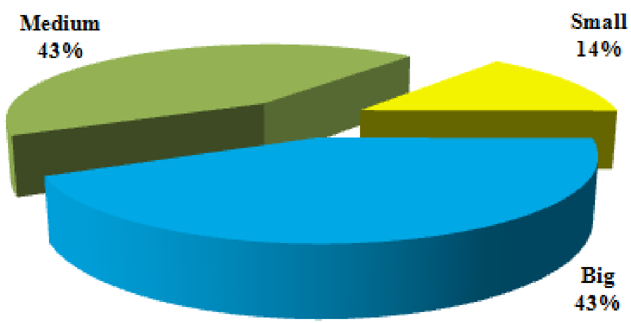


Figure 3. Company Size

Application of the Intellectual Capital Innovation Management Assessment Model

The first step to the application of the Intellectual Capital Innovation Management Assessment® was to identify the respondents to the I.A.Q. in each company, so as to ensure an appropriate selection. The respondents were mid- and high-level managers selected according to the divisions they worked in, and their knowledge of the business and marketplace. A meeting was held with the respondents to clarify any questions about the application procedure and the content of the questions in the I.A.Q. considering that the reliability of the results obtained in this study would be strongly correlated with the precision with which the respondents analyzed the routines, systems, and practices adopted in the management of intellectual capital resources aimed at developing the company's innovative capacity.

Data Analysis and Consolidated Results

Data on the following main questions were obtained upon processing and analysis of the questionnaires:

1) What are the main organizational models, systems, and practices used to manage intellectual capital which may restrain innovation capacity in the organizations that were studied?
2) What is the managers' level of perception/knowledge of factors critical to innovation processes in the management of capital intellectual resources?

Main Barriers to Innovation Capacity in Private-Sector Organizations

The results presented in the following graphs have been separated into the public sector, in which eight organizations were analyzed, and the private sector, which includes the remaining 27 companies. A third graph shows the consolidated results of the 35 organizations studied.

Figure 4 presents the eight main barriers to developing and sustaining innovative capacity in the 27 private-sector companies that participated in this study. It therefore identifies the main organizational models, systems, and practices adopted in capital intellectual management that inhibit the innovation process and innovative capacity of the companies analyzed.

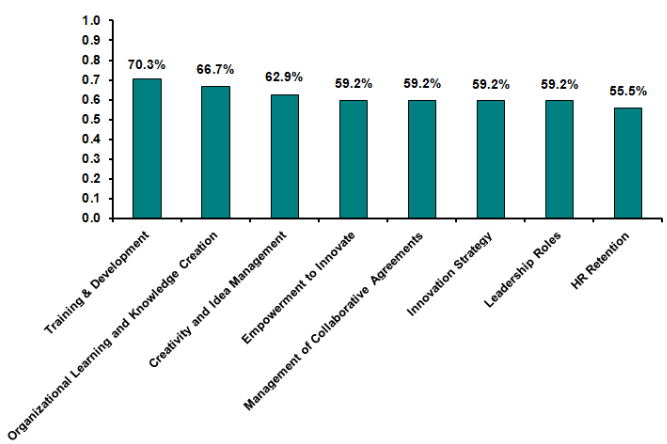


Figure 4. Main Barriers to Innovation: Private-Sector Organizations

The results obtained from the I.A.Q. showed that 70.3% of the companies identified a lack of training programs to develop the competencies necessary for innovation as the most restrictive factor to the organization's innovative capacity. The capacity for Organizational Learning and Knowledge Creation was identified as the second most significant barrier to innovation in 66.7% of the companies analyzed, signaling that these companies had not adopted adequate systems and practices to nurture the creation of new knowledge to sustain innovative development. Creativity and Idea Management by means of a well-structured and managed system was the third most restrictive element identified in approximately 63.0% of the companies analyzed. This indicates that these companies fail to adequately promote creative problem-solving processes or use structured systems for collecting and managing the ideas of collaborators in the value network, in order to develop innovation. Approximately 60% of companies indicated that they did not afford the necessary empowerment to innovate to collaborators in the organization's value network. Furthermore, there was a lack of adequate management of collaborative agreements to support the identification and strategic use of intellectual capital resources for innovation in the extended enterprise. Managers´ lack of knowledge about innovation processes and the consequent inability to manage these processes was also among the eight most restrictive factors identified, coupled with the lack of clearly defined and publicized organizational strategies on innovation. Finally, managers in 55% of the companies analyzed indicated that they did not adopt practices to promote the retention of employees who have knowledge critical to innovation and the sustainability of future business, thus compromising their organizations' innovative capacity.

Main Barriers to Innovation in the Public Sector

Figure 5 presents the eight worst-performing indicators in terms of intellectual capital resource management for the capacity to innovate in the eight public-sector organizations analyzed using the I.A.Q.

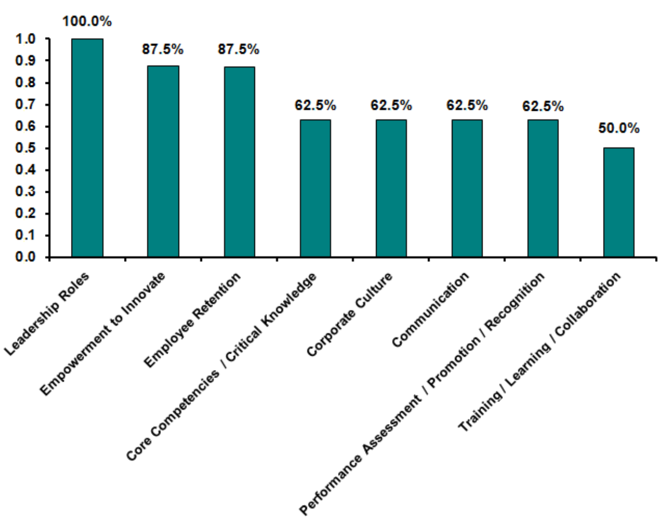


Figure 5. Main Barriers to Innovation – Public Sector

The respondents of all eight organizations indicated that leadership and their roles in organizational administration, represented the main restrictive factor to innovation. The lack of empowerment to innovate and the challenge provided by employee retention were identified by 87.5% of these organizations as the second factor to most inhibit innovative capacity. It is interesting that these three factors also feature among the eight most restrictive factors identified in the 27 private sector companies analyzed.

Of the eight public-sector organizations analyzed, 62.5% indicated that they failed to adequately identify the core competencies and critical knowledge to conduct their current activities and support innovation in the future. The same percentage of organizations indicated that their organizational culture and values did not promote innovation, innovative behavior, and an intra-entrepreneurial attitude, and, likewise, the communication systems did not promote and sustain innovation in the organization. Similarly, performance assessment, recognition, and promotion systems do not consider innovative behavior, critical knowledge, individual competencies, and staff members' capacity to contribute to innovation in the organization. The last restrictive factor is partially due to limitations imposed by the legislation in force. Finally, managers in 50% of the organizations indicated that they did not adopt collaborative work models to promote the interaction necessary to disseminate good practices and lessons learned among collaborators in the value network in order to support innovation processes and generate new solutions in the organization.

Main Barriers to Innovation: Consolidated Data for the Public and Private Sectors

The consolidated results for the 35 organizations analyzed are shown in Figure 6, which shows the eight worst-performing indicators in relation to the systems and practices adopted in the intellectual capital management aimed at developing innovative capacity.

The responses show that the most restrictive factors identified in organizations across both the public and private sectors are related to systems adopted by the organizations in the management of intangible asset resources. The results seem to suggest the necessity to better manage structural and human capital resources, and in particular Human Resource management models related to the intellectual assets of the organization's value network. Interestingly, both public- and private-sector organizations pointed to the necessity to strategically generate relationship capital resources, since one of the main restrictive factors identified in private-sector organizations was the need to better manage collaborative agreements and, in the public sector, the need to develop collaborative work models to promote organizational learning which is critical for enhancing and sustaining innovative capacity in organizations.

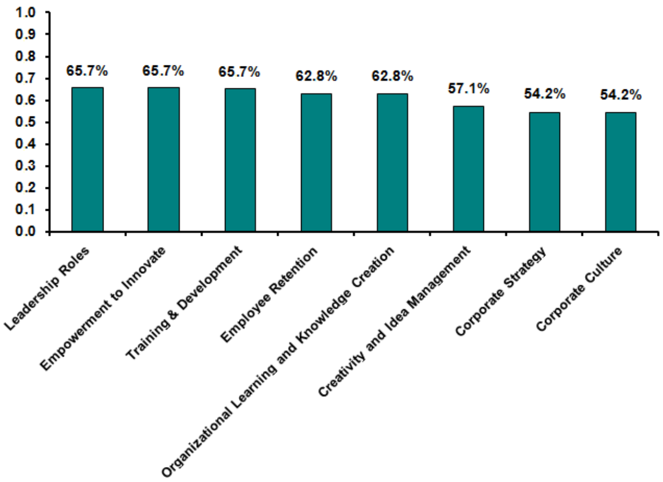


Figure 6. Main Barriers to Innovation – Consolidated Results for the Public and Private Sectors

Barriers to Innovation and Generation of Innovations by Sector

Applying the I.A.Q. across the 35 organizations analyzed allowed some complementary results to be inferred. Based on the consolidated results, an analysis was conducted to verify the possible existence of low, medium, or high barriers to innovation according to the particular organizational and market realities. These data were compared with the degree to which these organizations had developed innovation by means of contributions from collaborators in the value network within the 24-month period covered in this study.

The data obtained indicated that eight of the public-sector organizations under analysis encountered high barriers to innovation (0.78, see Figure 7), of an individual (behavioral) and/or organizational (structural/ infrastructural) nature. The data provided by the private-sector companies, on the other hand, suggest the existence of medium barriers (0.429) to innovation. Even though there is a significant difference between these two values, private-sector companies generated innovation at a slightly higher rate than in public-sector organizations: 61.7% compared to 50%, respectively.

Another significant I.A.Q. finding is related to the respondents' level of knowledge and perception of factors critical to innovation processes in terms of the organizational models, systems, and practices adopted in their intellectual capital management. Mangers from public-sector organizations demonstrated a higher level of knowledge on factors critical to innovation processes (0.87%), even though they adopted only 44.33% of practices to generate innovation. Managers from private-sector companies demonstrated a slightly lower level of knowledge on the importance of practices, systems, and models, key to innovation (0.81%), despite adopting approximately 53% of routines analyzed to generate innovation.

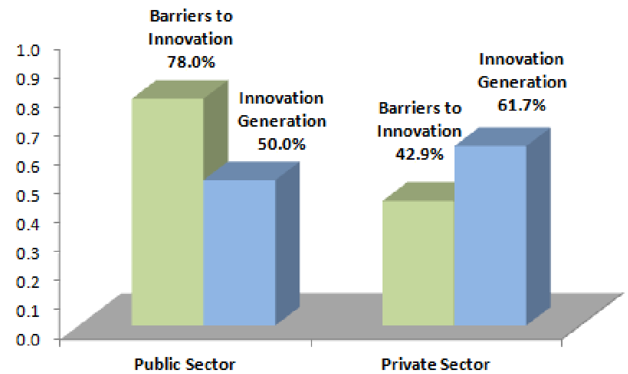


Figure 7. Barriers to Innovation versus Innovation Generation

Conclusions and Future Research

This multiple case study was limited to 35 Brazilian organizations and, therefore, provides little basis for scientific and statistical generalizations. However, the data collected by means of the application of the Intellectual Capital Innovation Assessment Model® and its diagnostic tool, the Innovation Assessment Questionnaire (I.A.Q.®) provide a basis to expand and generalize existing theories on innovation management, and provide for some preliminary "cross-case" conclusions.

The results obtained from the application of the Intellectual Capital Innovation Management Assessment Model® seem to indicate that the 35 organizations analyzed lack more specific knowledge on how to strategically manage the existing intellectual capital resources in their companies and value networks in order to stimulate innovation. The results also suggest that most of the companies analyzed share similar restrictions and challenges in terms of implementing practices, systems, and management models to stimulate their organizations' innovative capacity. There is certainly greater understanding among managers on the strategic importance of innovation as a factor for the organization´s competiveness and sustainability, but it still seems that they face several restrictions to transform this knowledge into concrete innovation actions.

It is important to highlight that the application of the I.A.Q. in the 35 organizations analyzed also contributed toward the managers developing a greater understanding of the dynamics of innovation processes within their organizations and marketplace, allowing them to debate how to improve organizational practices, systems, and models they employ to manage intellectual capital in order to foster their innovative capacity.

Innovation management through the strategic management of intellectual capital in the extended enterprise has become an important management tool to increase a firm´s capability to innovate. Managers must learn how to identify and manage the existing intellectual capital resources in their companies and value networks in order to leverage their companies´ level of innovativeness. However, there are still few studies which correlate Intellectual Capital management models with innovative capacity. Therefore, future research should be directed to in-depth studies on organizational models, systems, and processes that enhance or inhibit an organization´s innovative capacity at higher levels of an aggregate, such as a specific industry, sector, or a particular industrial group.

Considering that innovation activities take place in small, medium, and large companies across all sectors, future research will help managers develop a more comprehensive understanding of innovation management systems and models considering their organization and marketplace realities.

References

[1] Pesquisa Industrial De Inovação Tecnológica 2008 - PINTEC 2008 (2010). Instituto Brasileiro de Geografia e Estatística – IBGE.

[2] Pesquisa Industrial De Inovação Tecnológica 2005 - PINTEC 2005 (2007). Instituto Brasileiro de Geografia e Estatística – IBGE

[3] Stoeckicht, I. P. (2010). A importância da gestão do capital social para o desenvolvimento da capacidade de inovar em empresas brasileiras. *INGEPRO – Inovação, Gestão e Produção Journal*, 02(10), 23-37.

[4] Stewart, T. A. (2002). *A Riqueza do Conhecimento: O capital intelectual e a organização do século XXI.* Rio de Janeiro: Editora Campus.

[5] Oslo Manual: proposed guidelines for collecting and interpreting technological innovation data. (1997). Paris: OECD: Statistical Office of the European Communities.

[6] Moreira, D., & Queiroz, A. (2007). *Inovação Organizacional e Tecnológica.* São Paulo: Editora Thompson.

[7] Rodriguez, Y., & Rodriguez, M. (2002). *Gestão Empresarial: Organizações que Aprendem.* Rio de Janeiro: Qualitymark Editora Ltda., Petrobrás.

[8] Sveiby, K. E. (1997). *The New Organizational Wealth: Managing and Measuring knowledge-based Assets*. São Francisco: Berrett-Koelher Publishers.

[9] Edvinsson, L., & Malone, M. (1998). *Capital Intelectual.* São Paulo: Makron Books.

[10] Cavalcanti, M., Gomes, E., & Pereira, A. (2001). *Gestão de empresas na sociedade do conhecimento*. Rio de Janeiro: Ed. Campus.

[11] Tidd, J., Bessant, J., & Pavitt, K. (2001) *Managing Innovation -.Integrating Technological, Market and Organizational Change.* (2nd ed.). John Wiley and Sons Ltda.

[12] Higgins, J. M. (1995). *Innovate or Evaporate - Test and Improve Your Organization I.Q*. Florida: The New Management Publishing Company.

[13] Druker, P. (2001). *Inovação e Espírito Empreendedor. Prática e princípios.* São Paulo: Thompson Pioneira, (6th ed.).

[14] Jonash, R., & Sommerlatte, T. (2001). *O Valor da Inovação. Como as empresas mais avançadas atingem alto desempenho e lucratividade*. Rio de Janeiro: Editora Campus Ltda.

[15] Stoeckicht, I. P. (2005). *Gestão Estratégica Do Capital Humano - Avaliando O Potencial De Inovação De Uma Empresa: Estudo De Caso* (2005). Dissertation presented at Master´s program in Integrated Management Systems – M. Sc degree earned at the Fluminense Federal University of Rio de Janeiro.

[16] Allee, V. (n.d.). Understanding Value Networks. Article retrieved in January, 2009 from: http:/ www.vernaallee.com/library.

[17] Chesbrough, H., WEST, J., & Vanhaverbeke, W. (2006). *Open Innovation: Researching a New Paradigm*. New York. Oxford University Press.

[18] Chesbrough, H. (2011). *Open Services Innovation: Rethinking your Business to Grow and Compete in a New Era*. New York. Jossey-Bass – A Wiley Imprint.

[19] Almeida, P. (n.d.). Inovação sem inteligência é apenas criatividade sem objetivo. Article retrieved October, 2009, from the Agência Sebrae. http:// www.agenciasebrae.com.br in.

[20] Yin, R. K. (2009). *Case Study Research ´Design and Methods. Fourth Edition*. Sage Publications, Inc.

Biographies

INGRID PAOLA STOECKICHT is a knowledge and innovation management professor at the Fundação Getúlio Vargas Business School in Rio de Janeiro, Brazil. She earned her M.Sc. degree from the Fluminense Federal University in Rio de Janeiro, Brazil (Integrated Management Systems, 2005), and is currently taking her doctorate program in Civil Engineering at the Fluminense Federal University in Rio de Janeiro, Brazil. She is the founding partner and executive director of the National Institute of Entrepreneurship and Innovation, a Rio de Janeiro-based non-profit organization. Her interests are in knowledge and innovation management, innovation and human resource management. Professor Stoeckicht may be reached at ingrid@inei.org.br

CARLOS ALBERTO PEREIRA SOARES is an Associate Professor in the Post graduate Program in Civil Engineering at Federal Fluminense University (UFF) in Rio de Janeiro, Brazil. He holds a Master's Degree in Civil Engineering from UFF, and a Doctoral Degree in Civil Engineering from Federal University of Rio de Janeiro (UFRJ). His interests are in knowledge and innovation management, innovation and management systems. Professor Soares may be reached at carlos.uff@globo.com

A NOVEL FIVE-INPUT CONFIGURABLE CELL BASED ON SINGLE ELECTRON TRANSISTOR MINORITY GATES

Amir Sahafi, Science and Research Branch, Islamic Azad University, Tehran, Iran; Keivan Navi, Shahid Beheshti University

Abstract

Single Electron Technology (SET) is one of the future technologies that can be distinguished not only by its very small device size but also by its low power dissipation. The purpose of this paper is to introduce a five-input configurable SET cell based on single electron transistor minority gates. The proposed cell accepts five signals as its inputs and produces two complementary outputs. By applying appropriate input logic to the control gate(s), the cells can act as non-inverting/inverting buffers, Minority/Majority, two- and three-input NAND/AND or NOR/OR logic gates. As an application, a full adder, based on this proposed cell, was designed. All of the simulations for the proposed cell were done with SIMON 2.0.

Introduction

Current technologies like CMOS are predicted to encounter technological limitations [1], [2]. Further progress of such integration scale technology will be limited by a number of physical effects such as power dissipation [3]. Due to the problem of successfully scaling CMOS technology to meet the increased performance, density, and decreased power dissipation required for future technology generations, new technologies that will completely or partially replace silicon are being researched [3], [4]. Among the emerging technologies which strive to address these shortcomings is single electron technology (SET). SET uses a coulomb blocked effect and works by controlling the transfer of electrons one at a time [5], hence the device size and power dissipation decrease significantly [2], [5], [6]. These two properties, size and power, allow large density integration without exceeding the power density physical limits [7].

In this paper, a five-input single electron transistor-based configurable cell is introduced. With different configurations of these cells, functions such as non-inverting/inverting buffers, Minority/Majority, two- and three-input NAND/AND or NOR/OR logic gates can be gained. As an application, a full adder is designed by using proposed cell.

The Proposed Design

The proposed cell accepts five input signals and produces two complementary outputs. As shown in Figure 1, each cell consists of two, five-input minority gates which are based on single electron transistors [8], which themselves are serially connected to each other. In the second Minority gate, if two of the five inputs are connected to a logical 1 and another two to a logical 0, the output of the gate will be a complement of the fifth input, which is connected to the output of the first minority gate. The Boolean function of output1 and output2 can be described by Equations (1) and (2), which are known as minority and majority functions, respectively.

$$\text{OUTPUT1} = \text{Minority}(a,b,c,d,e) = \overline{a.b.c + a.b.d + a.b.e + a.c.d + a.c.e + a.d.e + b.c.d + b.c.e + b.d.e + c.d.e} \quad (1)$$

$$\text{OUTPUT2} = \text{Majority}(a,b,c,d,e) = a.b.c + a.b.d + a.b.e + a.c.d + a.c.e + a.d.e + b.c.d + b.c.e + b.d.e + c.d.e \quad (2)$$

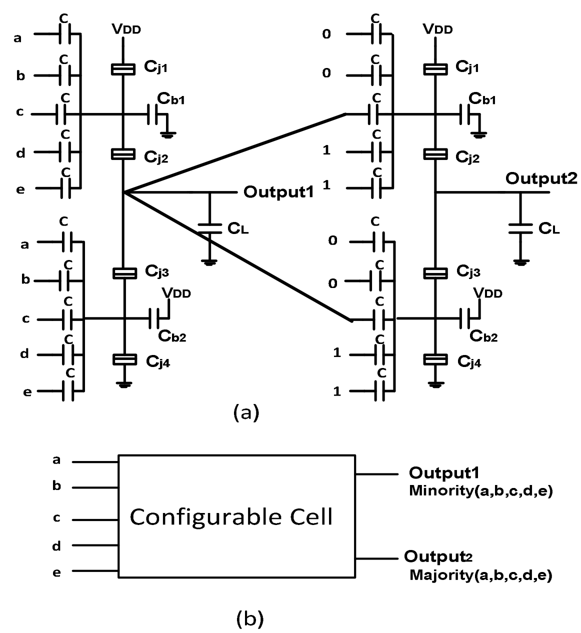


Figure 1. (a) Proposed Cell (b) The block diagram

In order to achieve a two-input NAND/AND gate or a two-input NOR/OR gate, two of the five inputs to the cell should be fixed to a logical 0 or 1 and another one to a logical 1 or 0, respectively. This can be illustrated by the following equations:

$$\mathrm{OUTPUT1} = \mathrm{Minority}(a,b,0,0,1) = \overline{a.b.0 + a.b.0 + a.b.1 + a.0.0 + a.0.1 + a.0.1 + b.0.0 + b.0.1 + b.0.1 + 0.0.1} = \overline{a.b} \equiv \mathrm{NAND}(a,b) \tag{3}$$

$$\mathrm{OUTPUT2} = \mathrm{Majority}(a,b,0,0,1) = a.b.0 + a.b.0 + a.b.1 + a.0.0 + a.0.1 + a.0.1 + b.0.0 + b.0.1 + b.0.1 + 0.0.1 = a.b \equiv \mathrm{AND}(a,b) \tag{4}$$

$$\mathrm{OUTPUT1} = \mathrm{Minority}(a,b,1,1,0) = \overline{a.b.1 + a.b.1 + a.b.0 + a.1.1 + a.1.0 + a.1.0 + b.1.1 + b.1.0 + b.1.0 + 1.1.0} = \overline{a+b} = \mathrm{NOR}(a,b) \tag{5}$$

$$\mathrm{OUTPUT2} = \mathrm{Majority}(a,b,1,1,0) = a.b.1 + a.b.1 + a.b.0 + a.1.1 + a.1.0 + a.1.0 + b.1.1 + b.1.0 + b.1.0 + 1.1.0 = a+b = \mathrm{OR}(a,b) \tag{6}$$

A three-input NAND/AND function can be represented by setting two inputs to a logical 0 (d=e=0) such that the Boolean function for output1 and ouput2 would be $\overline{abc}$ and abc, respectively. Similarly, to design a three-input NOR/OR gate, two inputs of a five-input minority gate should be set to a logical 1 (d=e=1), making the Boolean function for output1 equal to $\overline{a+b+c}$ and output2 equal to $a+b+c$.

If two of cell's inputs are a logical 1 and two are a logical 0, then the gate will act as an inverting/non-inverting buffer. To achieve a three-input minority/majority cell, one of the inputs should be set to a logical 1, and another one to a logical 0. This can be determined using Equations (7) and (8):

$$\mathrm{OUTPUT1} = \mathrm{Minority}(a,b,c,0,1) = \overline{a.b.c + a.b.0 + a.b.1 + a.c.0 + a.c.1 + a.0.1 + b.c.0 + b.c.1 + b.0.1 + c.0.1} = \mathrm{Minority}(a,b,c) \tag{7}$$

$$\mathrm{OUTPUT2} = \mathrm{Majority}(a,b,c,0,1) = a.b.c + a.b.0 + a.b.1 + a.c.0 + a.c.1 + a.0.1 + b.c.0 + b.c.1 + b.0.1 + c.0.1 = \mathrm{Majority}(a,b,c) \tag{8}$$

Using the SIMON simulator [9] with simulation parameters of $C_{j1}=C_{j4}=1aF$, $C_{j2}=C_{j3}=2aF$, $C_{b1} = C_{b2}=9aF$, $C_L=24aF$, $R_j=100$ kΩ, C=0.6aF, $V_{DD}=6.5mV$, logic 1=6.5mV, and logic 0=0V, the correct operation of the proposed cell is illustrated as shown in Figures 2-5.

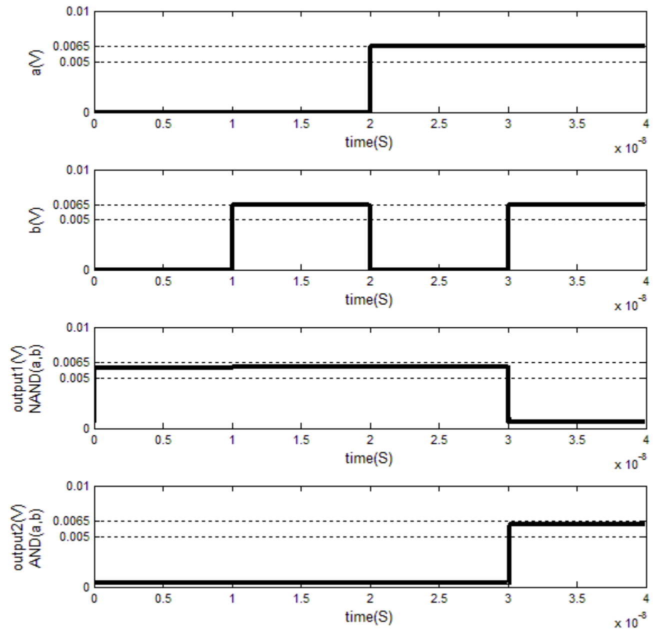


Figure 2. The Cell Output Waveforms for the Two-Input NAND/AND (c =d=0, e=1)

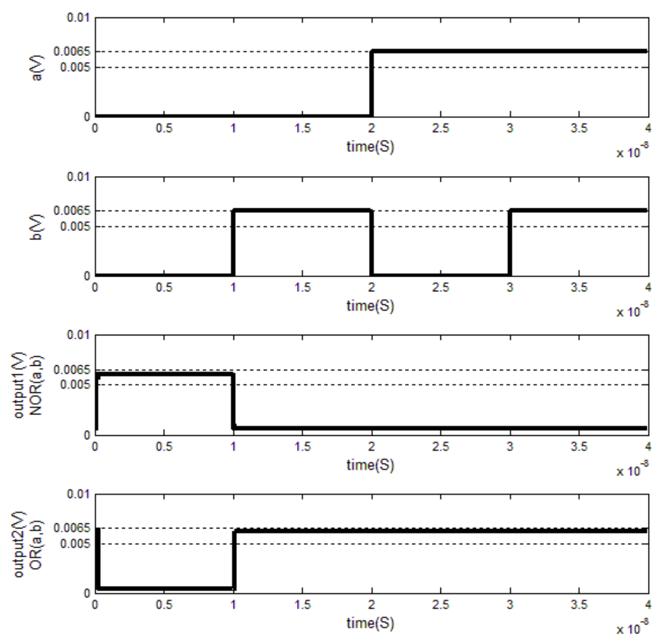


Figure 3. The Cell Output Waveforms for the Two-Input NOR/OR(c=d=1, e=0)

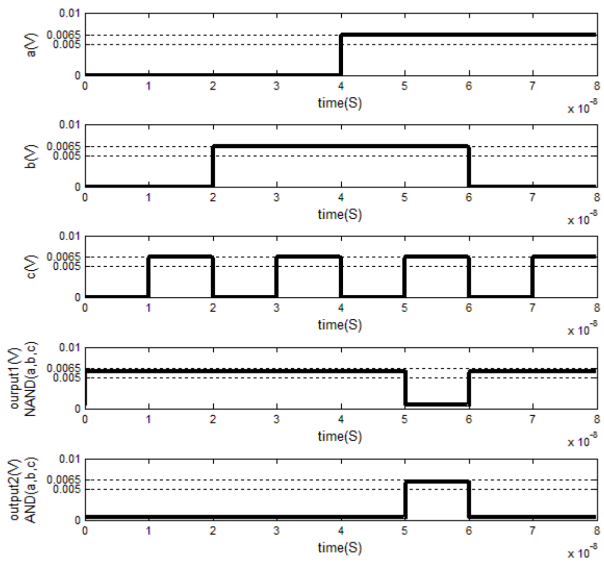


Figure 4. The Cell Output Waveforms for the Three-Input NAND/AND (d=e=0)

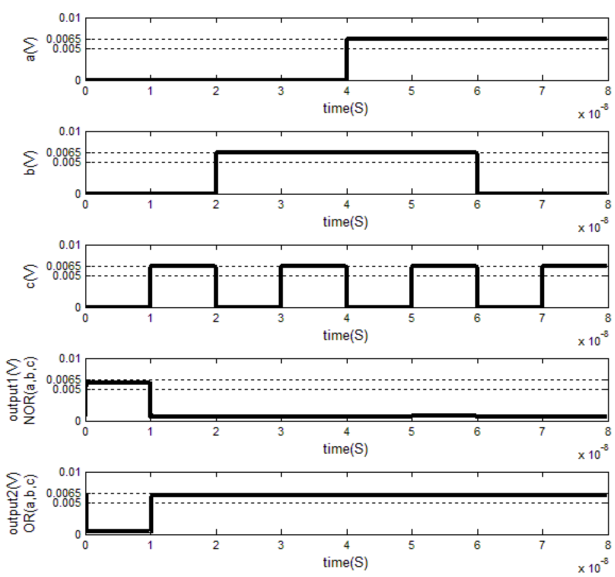


Figure 5. The Cell Output Waveforms for the Three-Input NOR/OR(d=e=1)

Designing a Full Adder using the Proposed Cell

Full adders are one the most important parts of each an arithmetic logic unit (ALU). Any kind of improvements in full-adder design result in significant improvement in ALU functionality. Hence, different devices are used in order to implement full adders [3], [10]. The functionality of a 1-bit full adder with a, b, and c_{in} (Input Carry) inputs, and sum and c_{out} (Output Carry) outputs, can be described by the following equations [11]:

$$c_{out} = ab + ac_{in} + bc_{in} = \text{Majority}(a, b, c_{in}) \quad (9)$$

$$\text{Sum} = (a + b + c_{in}) + a.b.c_{in} = \text{Majority}(a, b, c_{in}, \overline{c_{out}}, \overline{c_{out}}) \quad (10)$$

The basic idea of the design proposed in this study is that the c_{out} function would be the same as the three-input majority function. Also, the sum output can be generated from $\overline{c_{out}}$ by using a five-input majority function with a, b, c_{in}, and two $\overline{c_{out}}$ inputs, as shown in Table 1. With regard to Equations (9) and (10), the block diagram and simulation results of a full adder using this proposed cell is depicted in Figure (6).

Table 1. Functionality of 1-bit Full-Adder

a	b	c_{in}	$\overline{c_{out}}$	$\text{Majority}(a,b,c_{in},\overline{c_{out}},\overline{c_{out}})$	Sum
0	0	0	1	0	0
0	0	1	1	1	1
0	1	0	1	1	1
0	1	1	0	0	0
1	0	0	1	1	1
1	0	1	0	0	0
1	1	0	0	0	0
1	1	1	0	1	1

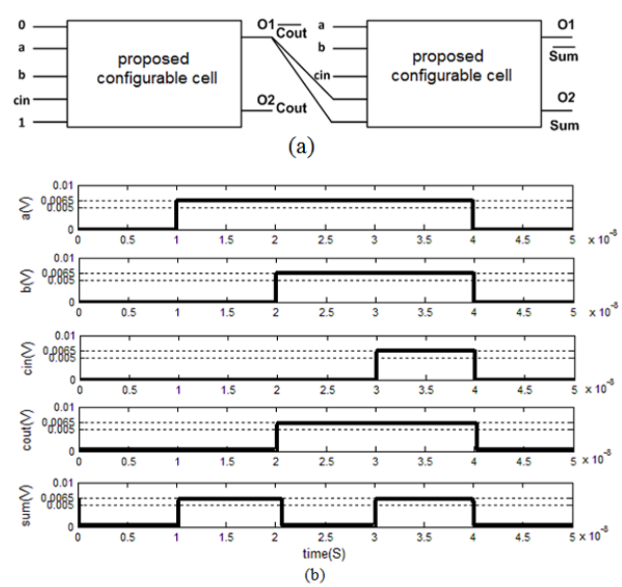


Figure 6. (a) Block Diagram of Full Adder Based on Proposed Cell (b) Input and Output Waveforms for the Proposed Full Adder

Conclusion

In this study, a five-input configurable cell based on single electron technology was introduced which is suitable for implementing inverting/non-inverting buffer, Minority/ Majority, NAND/AND and NOR/OR majority logic gates. As an application, a full adder based on a five-input cell was presented. All of the simulations were performed using a SIMON simulator.

References

[1] Meindl, J. (2001). Special issue on limits of semiconductor technology. *Proceedings of IEEE*, 89, 223-226.

[2] Soheili, N., Bahrepour, D., Loloeyan, P., & Navi, K. (2009). A Novel Five-Input Configurable Cell Based on Irreversible Single Electron Box. *Contemporary Engineering Sciences*, 2(4), 149-163.

[3] Navi, K., Kavehie, O., Rouholamini, M., Sahafi, A., Mehrabi, S., & Dadkhahi, N. (2008). Low-Power and High-Performance 1-Bit CMOS Full-Adder Cell. *Journal of Computers (JCP)*, 3(2), 48-54.

[4] Suleiman, M., & Beiu, V. (2005). On Single Electron Technology Full Adders. *IEEE Transactions on Nanotechnology,* 4(6), 669–680.

[5] Likharev, K. K. (1999). Single-elecron Devices and their applications. *Proceedings of IEEE*, 87, 606-632.

[6] Kastner, M. A. (2000). The single electron transistor and artificial atoms. *Annalen der Physik*, 9(11), 885-894.

[7] Zhirnov, V., Cavin, R., Hutchby, J., & Bourianoff, G. (2003). Limits to binary logic switch scaling Agedanken model. *Proceedings of IEEE,* 91, 1934–1939.

[8] Iwamura, H., Akazawa, M., & Amemiya, Y. (1998). Single-electron majority logic circuits. *IEICE Trans. Electron*., E81-C, 42-48.

[9] Wasshuber, C., Kosina, H., & Selberherr, S. (1997). SIMON - A Simulator for Single-Electron Tunnel Devices and Circuits. *IEEE Transactions on Computer-Aided Design*, 16, 937–944.

[10] Rahimi Azghadi, M., Kavehei, O., & Navi, K. (2007). A Novel Design for Quantum-dot Cellular Automat Cells and Full Adders. *Journal of Applied Sciences*, 7(22), 3460-3468.

[11] Navi, K., Moaiyeri, M. H., Mirzaee, R. F., Hashemipour, O., & Nezhad, B. M. (2009). Two new low-power Full Adders Based on Majority-not Gates. *Microelectronics Journal*, 40(1), 126-130.

Biographies

AMIR SAHAFI is since 2008 enrolled as a Ph.D. Student at Islamic Azad University, Tehran science and research branch. His Ph.D. project focuses on efficient Single Electron Technology gates and circuits. He may be reached at Sahafi@iau.ac.ir

KEIVAN NAVI received his B.Sc. and M.Sc. in Computer Hardware Engineering from Beheshti University in 1987 and Sharif University of Technology in 1990, respectively. He also received his Ph.D. in Computer Architecture from Paris XI University in 1995. He is currently associate professor in faculty of electrical and computer engineering of Beheshti University. His research interests include VLSI design, Single Electron Transistors (SET), Carbon Nano Tube, Computer Arithmetic, Interconnection Network, and Quantum Computing. Dr. Navi may be reached at navi@sbu.ac.ir

Application of Fuzzy System and Intelligent Control for Improving DMD Processes

Jaby Mohammed, The Petroleum Institute, Abu Dhabi, UAE

Abstract

Manufacturing products in the United States is an extremely competitive business. Global manufacturing also has been fundamentally reshaped by the innovative improvements in computing, communications, methodology of production, and distribution. Each factor, standing alone, has greatly expanded the opportunities for trade, investment, and global production. When rapid changes in all of these factors are taken in combination, it tends to change the way manufacturing is done. What these factors have done is raise the bar for companies to compete in today's manufacturing environment. Like any other manufacturing industry, the plastic injection molding and die casting industries are also under heavy pressure to cut costs and increase productivity in order to remain competitive against global competition. Die casting is a versatile process for producing engineered metal parts by forcing molten metals under high pressure into reusable steel molds containing a cavity of the desired shape of the casting. These molds, called dies, can be designed to produce complex shapes with a high degree of accuracy and precision. Direct Metal Deposition (DMD) could be used to manufacture quality molds with comparable manufacturing costs. There are various process parameters involved with the manufacture of molds using the DMD machine. This study looked at the use of fuzzy logic and intelligent control for process optimization of DMD in the development of molds. DMD is a laser-based, additive fabrication technology that produces dense metal products from the ground up using powdered metal.

Introduction

This study focused on developing an optimal mold material composition for use in the die casting industry. The material composition was manufactured using Direct Metal Deposition (DMD). The DMD process blends five common technologies: lasers, computer-aided design (CAD), computer-aided manufacturing (CAM), sensors, and powder metallurgy, as shown in Figure 1.

A combination of tungsten and Inconel 718 as the surface layer and copper chromium as the substrate was selected for evaluation. Experiments were conducted to understand the significant variables that influence the property of the mold manufactured via DMD and also to establish a relationship between the various process parameters.

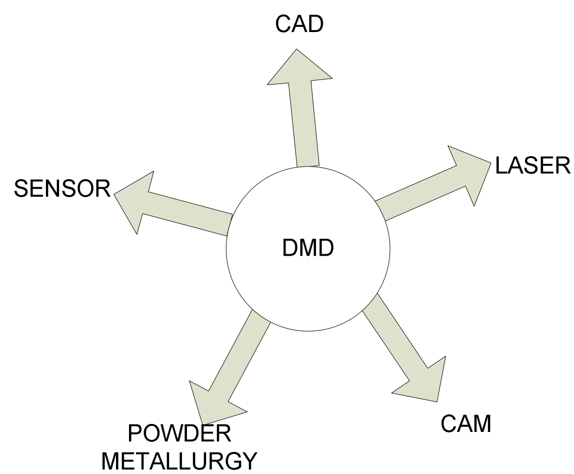


Figure 1. DMD Blend of Technology

The process parameters investigated here included laser power, transverse speed, substrate temperature, preheating, and mass flow rate, along with the composition of the metallic powders. Material properties that were evaluated included hardness, tensile strength, abrasive resistance, thermal conductivity, and porosity. Any change in any one of the process parameters made a significant change in the responses, so the optimization of the process parameters was necessary to get the desired results. This optimization of the process parameters to get the desired results could be done using fuzzy logic.

Fuzzy logic is a departure from classical two-valued sets and logic, which uses "soft" linguistic (e.g., large, hot, tall) system variables and a continuous range of truth values in the interval [0,1], rather than strict binary (true or false) decisions and assignments. It was introduced by Dr. Lotfi Zadeh of UC/Berkeley in the 1960s as a means to model the uncertainty of natural language. Fuzzy logic is useful to processes like manufacturing because of its ability to handle situations that the traditional true/false logic cannot adequately deal with. It lets a process specialist describe, in everyday language, how to control actions or make decisions without having to describe the complex behavior [1],

[2]. Formally, fuzzy logic is a structured, model-free estimator that approximates a function through linguistic input/output associations.

The key benefits of fuzzy design are its simplified and reduced development cycle, ease of implementation, and ability to provide more user-friendly and efficient performance. Humans are generally unsuccessful at making quantitative predictions, whereas they are comparatively efficient in qualitative forecasting. Furthermore, humans are more prone to interference from biasing tendencies if they are forced to provide numerical estimates since the elicitation of numerical estimates forces an individual to operate in a mode which requires more mental effort than that required for less precise verbal statements [3], [4]. Since fuzzy linguistic models permit the translation of verbal expressions into numerical ones, thereby dealing quantitatively with imprecision in the expression of the importance of each criterion, some multi-attribute methods based on fuzzy relations are used. Applications of fuzzy sets within the field of decision-making have, for the most part, consisted of extensions or fuzzifications of the classical theories of decision making. Kahraman [5] used fuzzy logic as a multi-criteria model for his facility location problem. While decision making under conditions of risk and uncertainty have been modeled by probabilistic decision theories and by game theories, fuzzy decision theories attempt to deal with the vagueness or fuzziness inherent in subjective or imprecise determinations of preferences, constraints, and goals. Sun [6] and Buyukozkan [7] have used fuzzy logic along with neural networks in identifying a best conceptual design candidate and also for new product development. The work that had been done by these authors inspired this current study on optimizing the DMD process.

Most users of the direct metal deposition machine depend very much on the manufacturer's guidelines, experts' advice and services, and information from the suppliers who provide the metallic powders for fabrication rather than a formal evaluation practice that is used to stabilize the process. Most of the evaluation process involves subjective and qualitative criteria, which makes the decision process ineffective. The importance of these conflicting criteria often strongly depends on the type of application and different factors such as duration, quantity, and shape of the deposition [8].

Fuzzy logic is a powerful methodology that has been used in modeling to control uncertain multi-criteria decision-making processes [9], [10]. In this project, there were many parameters that could affect the final result. Many researchers have adopted fuzzy logic techniques in their decision-making problems. Graham et al. [11] applied fuzzy logic for selecting the optimum machining parameters and cutting tools for cutting selected materials.

Visual Fuzzy in Analysis

The DMD machine was used to deposit a coating material over the base material. The main process parameters involved in depositing the material were laser power, CNC speed, feed rate, composition and pre-heating. Any change in one of these parameters made a significant change in the responses. It is difficult to attain a result by visually looking at a deposit, and none of the property measurements could be done visually. The only property that could be done visually was pores and cracks, but there is not much fuzziness involved because the result will be either that there are pores and cracks in the material or not. The presence of pores and cracks is totally undesirable. The fuzziness that could be used would be something like "this deposit has fewer pores and cracks". This concept could be used in getting closer to a clear deposit. The feasibility study allowed us to conclude that deposits obtained in final runs would be free from pores and cracks. Thus, additional work should be undertaken. This current study assumed then that a good deposit would be attained with the selected five process parameters and four responses which are shown in the diagram of Figure 2.

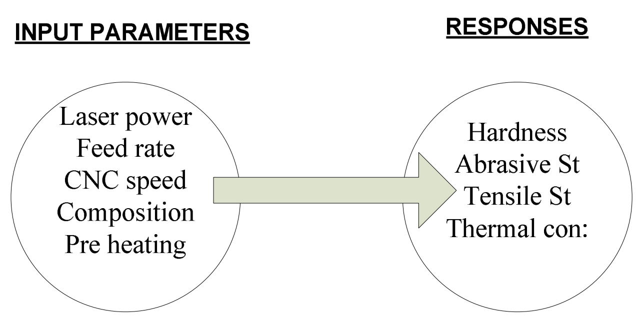


Figure 2. Relationship Between Input Parameters and Responses (Output Parameters)

For any set of input values a set of responses was obtained, and with any change in any of the input parameters there would be a change in the responses. For example, consider a fuzziness situation such as "close to a higher hardness", where the input parameters could be used to select suitably. In such a situation, one would try to fuzzify the data. Visual fuzzy, then, can generate the hardness that would be obtained by different combinations of the input parameters. So the input parameter needed to achieve the desired hardness could be found using fuzzy.

Initially, more than 32 input variables were identified which could change the output variables. Based on design of experiments and professional expertise, the list of input variables was reduced to five. And out of these five input variables, the most significant input variables were laser power and speed. Experiments were conducted on laser power and speed in order to determine the quality of the deposit as well the hardness of the deposit.

Consider Figure 3a as a Fuzzy set for F1 using hardness as an example. Similarly, different fuzzy set data can be generated for different hardnesses with the same membership functions. This means that there are different fuzzy set data for varying hardnesses.

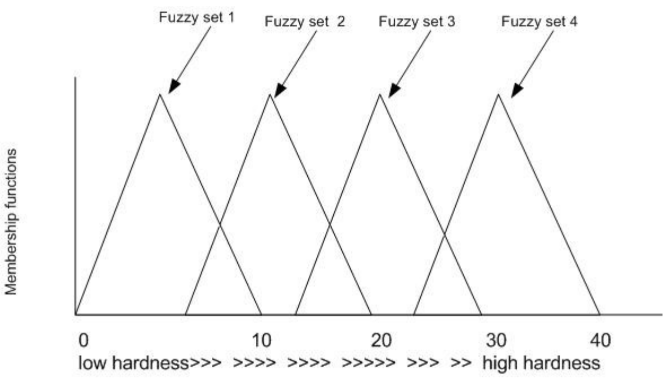


Figure 3a. Fuzzy Set Considering Hardness

Figure 3b shows the schematic design of the system. Laser power and laser speed were used to determine the output of the system, which is the hardness. If the requirement is for a desired output, then one of the inputs can be used as a variable.

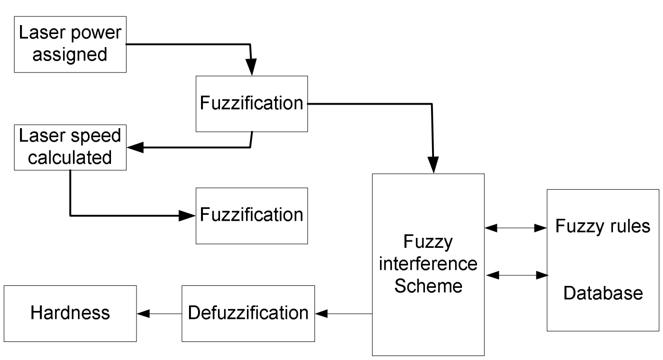


Figure 3b. System Schematic Diagram

Figure 3c is a modification for system schematic design, where a known output is desired. For example, if the hardness requirement is set to a value of 60 HRC (Rockwell hardness), the fuzzy system would automatically calculate the speed at which the laser would move for a set laser power.

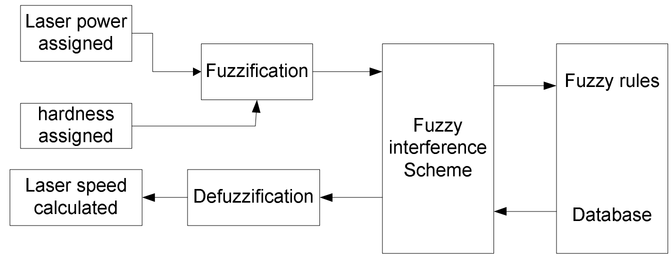


Figure 3c. Speed Calculation for a Desired Output

Fuzzy Rules

The decisions are based on rules. Although we may not be aware of it, all of the decisions that are made are based on computer if-then statements or using logical relationships. If the material hardness is low, then the decision may be made to decrease the speed, or change any other parameter that would increase the hardness. Rules associate ideas and relate one event to another. Fuzzy machines, which always tend to mimic the behavior of man, work the same way. However, the decision and the means of choosing that decision are replaced by fuzzy sets and the rules are replaced by fuzzy rules. Fuzzy rules also operate using a series of if-then statements. For instance, if X then A, if Y then B, where A and B are both sets of X and Y. Fuzzy rules define fuzzy patches, which is the key idea in fuzzy logic and is made smarter using the Fuzzy Approximation Theorem (FAT). The universe of discourse on the membership functions for each variable were defined earlier through various experiments. Laser power was controlled to between 2000 and 2900 watts; laser speed was between 5mm/second and 4.0mm/second. All of the membership functions and their corresponding labels are explained in Figures 5 and 6.

Fuzzy Control

Fuzzy control, which directly uses fuzzy rules, is the most important application in fuzzy theory. The three steps that are used to control fuzzy systems are as follows:

- Fuzzification (using membership functions to graphically describe a situation)
- Rule Evaluation (application of fuzzy rules)
- Defuzzification (obtaining the crisp or actual results)

The current experiment has five inputs and four outputs. However, to more easily explain fuzzy, consider an experiment that has only two inputs and one output. Here, the problem is to obtain a good laser deposit. Laser power and transverse speed are chosen as the inputs of the system. Hardness of the deposit, then, is chosen as the corresponding output.

STEP 1: Membership Functions

First of all, the different levels of output (high hardness and low hardness) of the platform are defined by specifying the membership functions for the fuzzy sets. The graph of the function is shown in Figure 4.

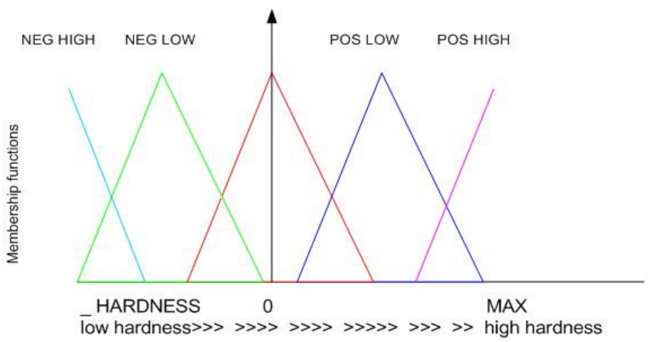


Figure 4. Membership Function for Fuzzy Set

Similarly, the different levels of the input are specified by the membership functions and similar data are collected based on the other inputs (laser power and CNC speed). Figure 5 shows the membership functions based on laser power and CNC speed.

STEP 2: Define Fuzzy Rules

The fuzzy rules are basically a series of if-then statements as mentioned earlier. These statements are usually derived by an expert to achieve optimum results. The following are the sets of fuzzy rules that are applied to the system for generating deposits that are free of pores and cracks. The output value and hardness will vary accordingly.

1) If laser power is 2700–2900 and measured speed is operating, then set laser speed to 5mm/s
2) If laser power is 2500–2700 and measured speed is 3.5mm/s – 4.0mm/s, then set laser speed to 4.9mm/s
3) If laser power is 2500–2700 and measured speed is 3.0mm/s-3.5mm/s , then set laser speed to 4.8mm/s
4) If laser power is 2300–2500 and measured speed is 3.5mm/s – 4.0mm/s, then set laser speed to 4.7mm/s
5) If laser power is 2300–2500 and measured speed is 3.0mm/s-3.5mm/s , then set laser speed to 4.6mm/s
6) If laser power is 2100–2300 and measured speed is 3.0mm/s-3.5mm/s , then set laser speed to 4.5mm/s
7) If laser power is 2300–2500 and measured speed is 3.0mm/s-3.5mm/s , then set laser speed to 4.4mm/s
8) If laser power is 2100–2300 and measured speed is 3.0mm/s-3.5mm/s , then set laser speed to 4.3mm/s
9) If laser power is 2100–2300 and measured speed is 3.0mm/s-3.5mm/s , then set laser speed to 4.2mm/s
10) If laser power is 1900–2100 and measured speed is 3.0mm/s-3.5mm/s , then set laser speed to 4.1mm/s
11) If laser power is 1900–2100 and measured speed is 3.0mm/s-3.5mm/s , then set laser speed to 4.0mm/s

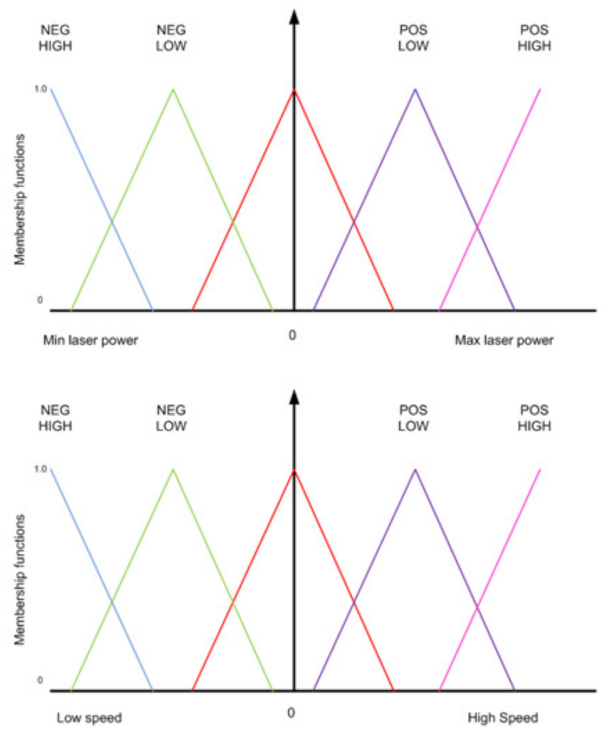


Figure 5. Membership Function Based on Varying Input, Laser Power, and for CNC Speed

Expertise in the process is needed in order to define fuzzy. Unintended results will be obtained if the rules are not followed. Based on the set rules, the input values are given. For example, 0.75 and 0.25 for zero and positive low power, and 0.4 and 0.6 for zero and negative laser speed. These points are shown on the graph of Figure 6.

Consider the rule "if speed is zero and laser power is zero, then hardness is zero". The actual value belongs to the fuzzy set zero to a degree of 0.75 for laser power and 0.4 for speed of the laser. Since this is an AND operation, the minimum criterion is used, where the fuzzy set zero of the variable "speed" is cut at 0.4 and the patches are shaded up to that area. This is illustrated in Figure 7.

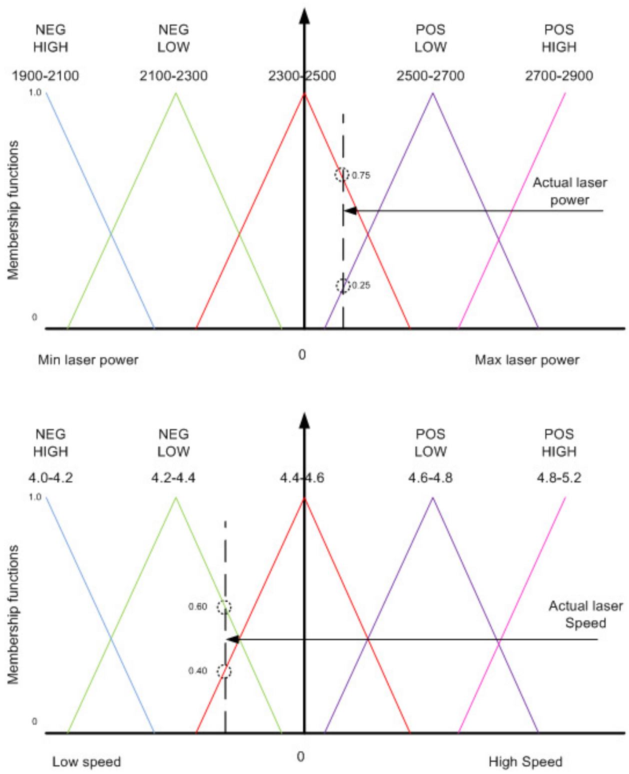


Figure 6. Defining Fuzzy Rules for Laser Power and CNC Speed Based on Defined Rules

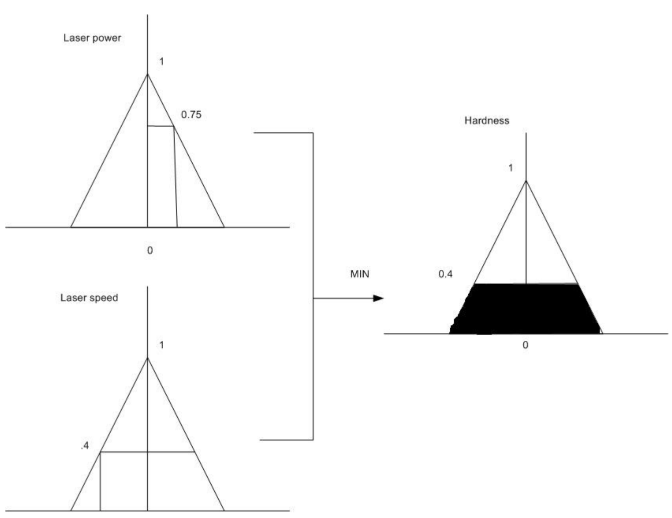


Figure 7. Applying Fuzzy Rules on Laser Power and Laser Speed to Provide the Final Value on Hardness

Similarly, using the minimum criterion rule for the other three, the following results are obtained as shown in Figure 8.

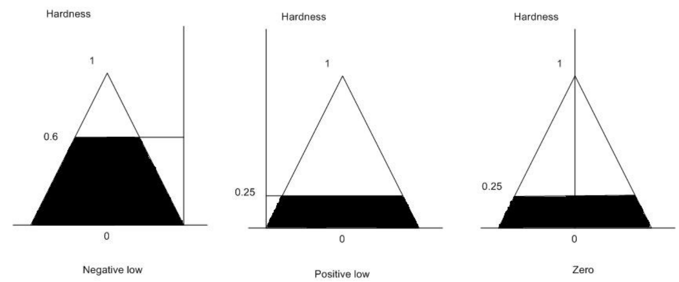


Figure 8. Minimum Criterion Rule for Hardness

Step 3: Defuzzification

The result of the fuzzy controller thus far is a fuzzy set of hardness. In order to choose an appropriate representative value as the final output (crisp values), defuzzification must be done. The five commonly used defuzzification techniques are:

- Five Methods
- Center of Gravity
- Bisector
- Middle, Smallest, and Largest of Maximum
- Picking a Method

Any of the defuzzification methods would work. For the defuzzification in this current study, the authors chose the Center of Gravity method, which is shown in Figure 9.

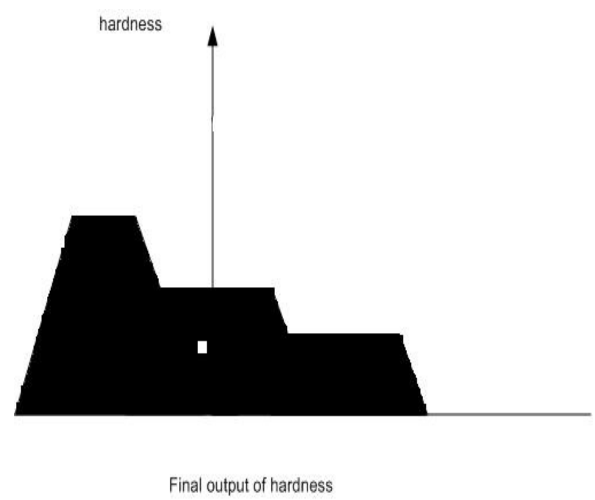


Figure 9. Defuzzification of Hardness

The white spot in the figure shows the corresponding value of the hardness. The concept of visual fuzzy could be used in the analysis of the experiments. In this example, the authors considered only one response and two inputs, and no real rules were applied. Only arbitrary values were used to try to explain the concept of how the fuzzy system and intelligent control could be applied in optimizing the response variables. In the current study, there were five inputs and factors considered with the four outputs (responses). The concept of multi-criteria decision making or multi-response fuzzy logic [10] could be used to describe the problem and to arrive at a solution.

Critical Results

It was observed that on five occasions the fuzzy logic controller brought the DMD process back into optimum conditions without any external intervention. The deposits were all free from pores and crack, but had varied hardness. On some occasions, fuzzy logic slightly over compensated for the critical laser power, which can be adjusted by tuning the membership functions. The pilot experiment involved only two inputs. But once more data are available with all the varying inputs, it could be expanded for a more in-depth study. The results of the deposits show that a fuzzy logic controller ensured that the DMD process was used to create quality deposits without any plasma formation incidents.

Conclusion

Fuzzy logic integration was successful; and, although it worked for two inputs, the authors admit that it may not be the most robust method to use with more than five varying inputs. Where there are complex factors and parameters involved, which are suitable for processes where a linear process is not achieved and also where human logic is based on experience, it would have an edge over the various manufacturing tools. What these results prove is that fuzzy logic control could be used to improve the DMD process, though further work needs to be done to establish the role of fuzzy logic with varying input parameters.

References

[1] Terano, T., Asai, K., & Sugeno, M. (1992). *Fuzzy Systems Theory and Its Applications*. Academic Press.

[2] Sugeno, M. (Ed.). (1985). *Industrial Applications of Fuzzy Control*. North-Holland.

[3] Bertholda, M. R., Wiswedela, B., & Patterson, D. (2005). Interactive exploration of fuzzy clusters using Neighborgrams. *Fuzzy Sets and Systems*, 149, 21–37.

[4] Lee, C. C. (1990). Fuzzy Logic in Control Systems: Fuzzy Logic Controller - Parts I & II. *IEEE Transactions on Systems, Man, and Cybernetics*, SMC-20, pp. 404-435.

[5] Kahraman, C., Ruan, D., & Dogan, I. (2003). Fuzzy group decision-making for facility location selection. *Information Sciences*, 157, 135-153.

[6] Sun, J., Kalenchuk, D. K., Xue, D., & Gu, P. (2000). Design candidate identification using neural network-based fuzzy reasoning. *Robotics and Computer Integrated manufacturing*, 16, 383-396.

[7] Buyukozkan, G., & Feyzglu, O. (2004). A fuzzy-logic-based decision-making approach for new product development. *International Journal of Production Economics*, 90, 27–45.

[8] Armillota, A. (2008). Selection of layered manufacturing techniques by adaptive AHP decision model. *Robotics and computer integrated manufacturing*, 24, 450-461.

[9] Tong, L-I., & Su, C-T. (1997). Optimizing Multi-Response Problems in the Taguchi Method by Fuzzy Multiple Attribute Decision Making. *Quality and Reliability Engineering International*, 13, 25-34.

[10] Lai, Y-J., & Hwang, C-L. (1994). Fuzzy Multiple Objective Decision Making: Methods and Applications (Lecture Notes in Economics and Mathematical Systems). Springer-Verlag, Berlin, Heidelberg.

[11] Hashmi, K., Graham, I. D., Mills, B., & Hashmi, M. S. (2003). Adjustment approach for fuzzy logic model based selection of non-overlapping machining data in the turning operation. *Journal of material processing technology*, 142, 152-162.

Biographies

DR. JABY MOHAMMED is an Assistant Professor of Engineering Design at The Petroleum Institute, Abu Dhabi. He earned his B.S. degree from Kerala University, India, MBA in operations management from Indira Gandhi National Open University, MS (2003) and PhD (2006) in Industrial engineering from University of Louisville. He had previously worked at Morehead State University and Indiana Purdue Fort Wayne. Dr. Mohammed's interests are in product life cycle management, supply chain management, and quality control. Dr. Mohammed may be reached at jaby.mohammed@louisville.edu

ENHANCED PERFORMANCE OF BIXIN-SENSITIZED TiO_2 SOLAR CELLS WITH ACTIVATED KAOLINITE

Ayong Hiendro, Ferry Hadary, Winda Rahmalia, Nelly Wahyuni, Tanjungpura University

Abstract

The development of a natural dye sensitizer for solar cell applications has attracted much attention because of its inherent advantages, such as inexpensive, simple preparation, easily available resources, and being environmentally friendly. However, the main problems associated with dye-sensitized solar cells (DSCs) are low photostability and low efficiency. In this study, an alternative method for improving DSC performance using activated kaolinite was evaluated. Pure bixin extracted from achiote seeds (*bixa orellana l.*) was immobilized on the activated kaolinite. Kaolinite-bixin was synthesized and used as a sensitizer in nanocrystalline titanium-dioxide-based DSCs. Experimental results showed that kaolinite-bixin is better than pure bixin in ultraviolet-visible (UV-Vis) light absorption, photostability, and photoelectric conversion efficiency. In this case, the titanium dioxide (TiO_2) kaolinite-bixin sensitized solar cells yielded conversion efficiencies up to 1.01%.

Introduction

Organic dyes from natural extracts have been applied in DSCs [1-11]. These natural dyes were obtained by purification from fruits, flowers, and leaves of plants. Thus far, these natural dye sensitizers can provide photoelectric conversion efficiencies of 0.05% to 2.09% [1-11].

Wongcharee et al. [1] reported conversion efficiencies of DSCs with rosella, blue pea, and mixed extracts as 0.37%, 0.05%, and 0.15%, respectively. Fernando & Senadeera [2] used natural anthocyanins extracted from hibiscus surattensis, sisbania geandiflora scarlet, hibiscus rosasinensis, nerium oleander, ixora macrothyrsa, and rhododendron arboretum zeylanicum for DSCs. The best conversion efficiency was 1.14%, and it was achieved by using hibiscus surattensis extract as a sensitizer. Using rose bengal extract resulted in a conversion efficiency of 2.09% [3]. Red sicilian orange and eggplant peel extracts yielded conversion efficiencies of 0.66% [4]. Luo et al. [5] used canna indica l., salvia splendens, cowberry, and solanum nigrums l. extracts as photosensitizers and achieved conversion efficiencies of 0.29%, 0.26%, 0.13%, and 0.31%, respectively. Calogero et al. [6] reported a conversion efficiency of 1.70% using red turnip extract and 1.26% when using wild sicilian prickly pear fruit extract as a sensitizer. Gomez-Ortiz et al. [7] used bixin extracted from achiote seeds as a sensitizer and reported their best results in efficiencies up to 0.53%. Chang & Lo [8] used pomegranate leaf and mulberry fruit extracts as sensitizers. They reported conversion efficiencies of pomegranate leaf, mulberry, and mixed extracts of 0.597%, 0.548, and 0.722%, respectively. Bazargan et al. [9] reported a conversion efficiency of DSCs with pomegranate extract of 1.50%. Zhou et al. [10] used 20 natural extracts in their studies with the highest conversion efficiency of 1.17% obtained with mangosteen pericarp extract as a sensitizer. Other researchers used bougainvillea extract and achieved a conversion efficiency of 0.48% [11].

The results obtained with natural extracts have shown a successful conversion of visible light into electricity in DSCs. However, DSCs with natural extract dye sensitizers have low photoelectric conversion efficiencies. In this study, bixin extracted from achiote seeds was utilized as a photosensitizer in DSCs. Bixin has conjugated double-bond molecules, which give it the ability to capture solar energy. Bixin has a great ability to absorb UV-Vis light spectra. However, the conjugated structures cause the pigment molecules to degrade quickly from the UV radiation.

An alternative method for enhancing the bixin performance by immobilizing it on a solid matrix was proposed in this study. Kaolinite, a clay mineral, was used as a host material to improve the absorption, photostability, and electron transfer of the pure bixin and, hence, increase the photoelectric conversion efficiencies of the bixin-sensitized TiO_2 solar cells. Kaolinite has interlayer regions that can be intercalated by both polar and nonpolar organic molecules. In this manner, kaolinite gives the advantage as a bearer to protect bixin molecules from degradation.

Extraction of Bixin

Achiote seeds (100g) were dissolved in acetone and acidified with ascorbic acid. Ascorbic acid assists in preventing oxidation of the pigment. Calcium carbonate ($CaCO_3$) as a neutralizing agent was also added to the mixture. Afterward, the mixture was stirred by a magnetic stirrer. The residue obtained by filtration was then re-extracted in acetone and partitioned with diethyl ether. The ether layer was collected, added to anhydrous sodium sulfate (Na_2SO_4), and dried under N_2 gas. Afterward, column chromatography was performed on the silica gel-60 (stationary-phase) using n-hexane/acetone (2/1, v/v) as a mobile phase. Each fraction was collected into bottles and then dried under N_2 gas.

Preparation and Activation of Kaolinite

The kaolinite sample was washed with distilled water 3 times. Subsequently, it was centrifuged at 2000 rpm for 15 minutes. The wet kaolinite was then dried at a temperature of 80°C. The dried kaolinite was crushed into a fine powder and finally screened using a 100-mesh sieve (149 microns). Kaolinite powder (50g) obtained from the preparation process was prepared. Next, 400ml of hydrochloric acid (HCl-8M) was added, stirred and refluxed for 24 hours. The resulting kaolinite was then filtered and washed with distilled water until neutral.

Immobilization of Bixin on Kaolinite

The bixin solution (50ml) was mixed with 0.97 mmol/l of acetone. Activated kaolinite was then added piecemeal to the solution and stirred for 24 hours. Three different masses of kaolinite were immobilized: 1g (KBx1), 2g (KBx2), and 3g (KBx3). The products were then dried with N_2 gas. The immobilization process of bixin was conducted under illumination with red light in a dark room. The final results were characterized by IR spectroscopy and a UV-Vis spectrophotometer.

Preparation of Solar Cells

A polymer gel electrolyte was prepared by dissolving 7g of polyethylene glycol (PEG) in 25ml of chloroform. Several drops of a potassium iodide (KI) solution were added to the gel. The mixture was then stirred gently at a temperature of 80°C until a homogeneous gel was obtained. A TiO_2 electrode was prepared by adding 7g of TiO_2 powder to 7ml of acetylacetone until a paste was formed. Two drops of Triton X-100 were added to the titanium paste. The titanium paste was then coated on a transparent conductive oxide (TCO) glass substrate, dried in air, and heated at 130°C for 25 minutes. The TiO_2 on the TCO glass substrate (working electrode) was immersed in the kaolinite-bixin (KBx1, KBx2, or KBx3) suspension for 24 hours. A drop of electrolyte solution was added on the TiO2/TCO, and then the carbon counter electrode was placed on top of the working electrode.

Electrical Measurements

The photovoltaic properties of the DSCs are short-circuit current density (J_{sc}, mA/cm^2), open-circuit voltage (V_{oc}, mV), fill factor (FF), and photoelectric conversion efficiency (h, %). The conversion efficiency of DSCs at an irradiation intensity of P_{in} (mW/cm^2) is

$$\eta = \frac{J_{sc} \cdot V_{oc} \cdot FF}{P_{in}} x100\% \tag{1}$$

where

$$FF = \frac{J_m \cdot V_m}{J_{sc} \cdot V_{sc}} \tag{2}$$

The maximum power point current density (J_m, mA/cm^2) and voltage (V_m, mV) are determined from the maximum power point of the DSCs current-voltage curve.

Identification of Activated Kaolinite and Kaolinite-Bixin

Kaolinite activation in hydrochloric acid (HCl) aims to enlarge the interlayer region of kaolinite. The X-ray diffraction (XRD) patterns of kaolinite before and after activating (see Figure 1) shows that there is a decrease in the intensity at angles of 2q = 12° and 2q = 25°. The treatment reduced the peak intensities down to 249 counts. This indicates that the acidity process has removed aluminum hydroxide (Al_2O_3) from the layer (dealumination). The dealumination does not only expand the interlayer region but also increase the percentage of silicon dioxide (SiO_2) in the kaolinite. Silicon dioxide (SiO_2) is identified by the intensities between 47 and 1743 counts. Table 1 presents the percentage compositions of prepared and activated kaolinite. It was observed that the silica-alumina mol ratio of kaolinite increases from 1.96 to 2.21 after the dealumination.

Impregnating the activated kaolinite into bixin contributes greatly to the bixin. The advantage of the large interlayer region is that it gives kaolinite a greater ability to trap more bixin molecules during the immobilization process. Moreover, silicon in the kaolinite layer can act as a semiconductor and improve the electron transfer of TiO_2 in solar cells.

Bixin molecules can form complexes with kaolinite molecules due to hydrogen bonding between the hydroxyl group (-OH) of bixin and the silicate group (-SiO) of kaolinite. Another hydrogen bonding that may occur is between the carbonyl group (C=O) of bixin and the hydroxyl group (-OH) of kaolinite.

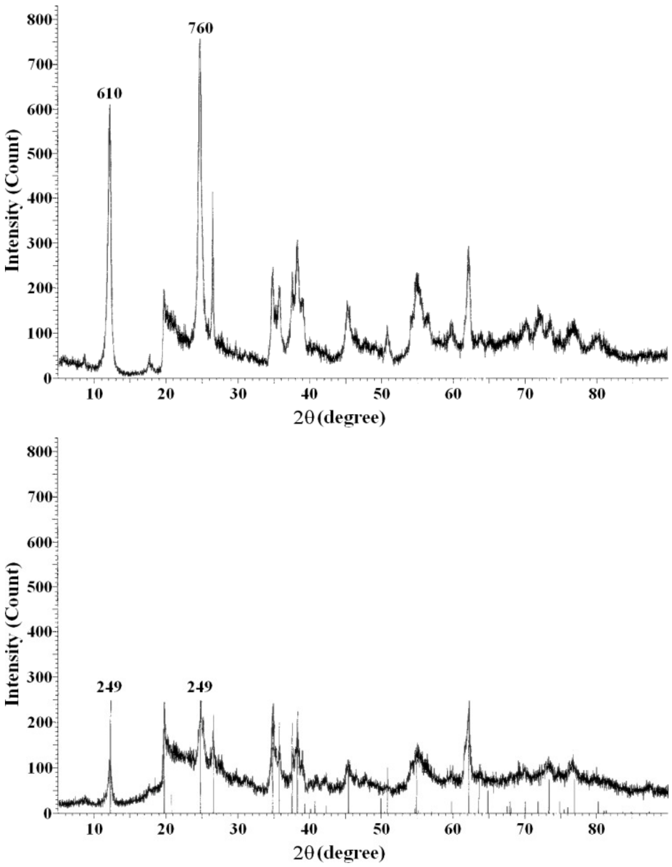


Figure 1. XRD Patterns of Kaolinite and Activated Kaolinite

Table 1. Percentage Composition of Prepared and Activated Kaolinite

	Prepared Kaolinit	Activated Kaolinite
SiO_2 (%)	60.56	62.64
Al_2O_3 (%)	30.88	28.31
Fe_2O_3 (%)	1.06	0.65
K_2O (%)	0.02	0.01
Na_2O (%)	0.03	0.01
MgO (%)	2.15	1.98
TiO_2 (%)	0.01	0.01
Si/Al	1.96	2.21

An infrared (IR) absorption spectrum of bixin shows certain characteristic absorption bands (as seen in Figure 2). A broad absorption band at 3410cm^{-1} indicates the presence of –OH stretching of the hydroxyl group. The band of absorption at 1745cm^{-1} indicates the presence of C=O. The bands at 1612cm^{-1} and 2924cm^{-1} were assigned to C=C and C-H, respectively.

The infrared absorption spectra of kaolinite-bixin (KBx1, KBx2, KBx3, in Figure 2) show two absorption peaks; the first near 1600cm^{-1}, which was associated with C=O, and the second near 1700cm^{-1} which was attributed to C=C. Furthermore, the spectra also show broad absorption bands at 3400cm^{-1}, which indicate the presence of the hydroxyl group (-OH). These specific absorption bands do not appear in the IR spectra of kaolinite and activated kaolinite. The IR absorption spectra of KBx1, KBx2, and KBx3 indicate that bixin molecules have successfully entered the interlayer region of kaolinite through the impregnation process.

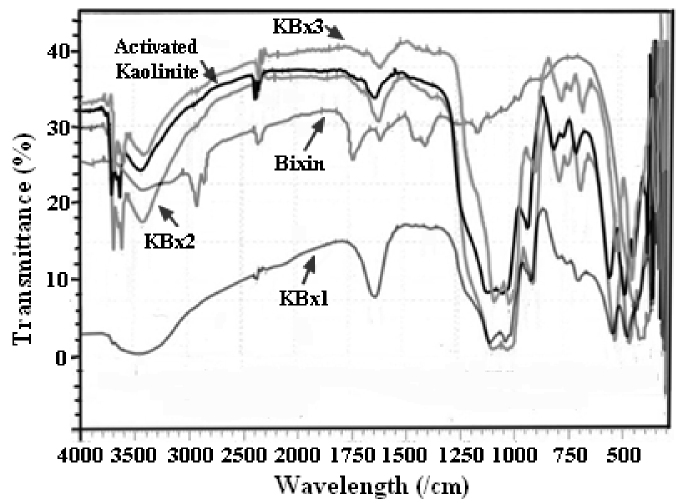


Figure 2. Infrared Absorption Spectra of Bixin, Activated Kaolinite, and Kaolinite-Bixin (KBx1, KBx2, KBx3)

UV-Vis Absorption

From the UV-Vis absorption spectra (as seen in Figure 3), it was found that the maximum absorbance peak of bixin decreases dramatically to less than 3% after 12 hours. Kaolinite-bixin received the same treatment as bixin and still had the maximum absorbance peak of 30% after 12 hours (as seen in Figure 4). It is clear that activated kaolinite can improve the photostability of bixin. Kaolinite-bixin showed better light absorption and higher photostability than pure bixin.

Photovoltaic Properties

A typical current-voltage curve for a kaolinite-bixin sensitized solar cell prepared with TiO_2 is shown in Figure 5. The measurements were taken in sunlight with an irradiation intensity of 55mW/cm^2, resulting in a short-circuit current of 1.3mA/cm^2, an open-circuit voltage of 0.7V, and a fill factor of 0.61. The overall energy conversion efficiency of 1.01% was obtained, which was much higher than that obtained with pure bixin [7]. The conversion efficiency of bixin-kaolinite sensitized solar cells was higher than that of pure bixin sensitized solar cells. This was due to better light absorption of kaolinite-bixin compared to pure bixin. Moreover, kaolinite provides strong interaction between TiO_2 and bixin, and this leads to better electron transfer in the solar cell.

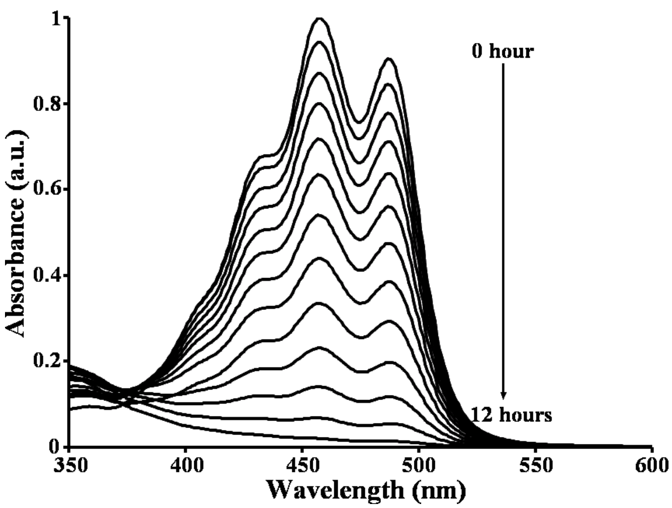


Figure 3. UV-Vis Absorbance of Bixin: 0 to 12 Hours

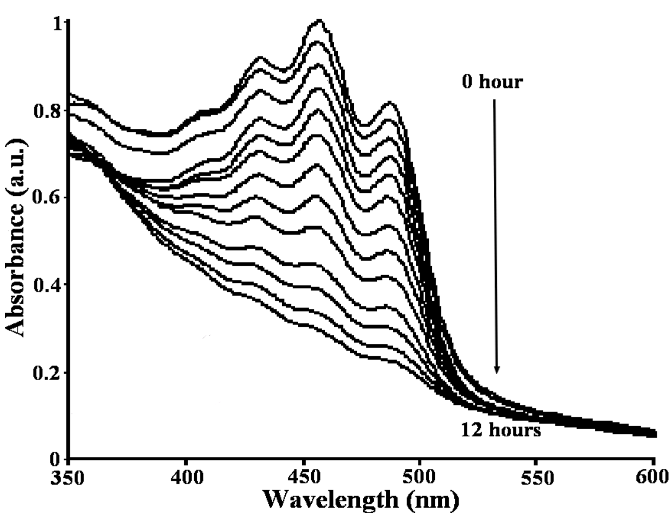


Figure 4. UV-Vis Absorbance of Kaolinite-Bixin: 0 to 12 Hours

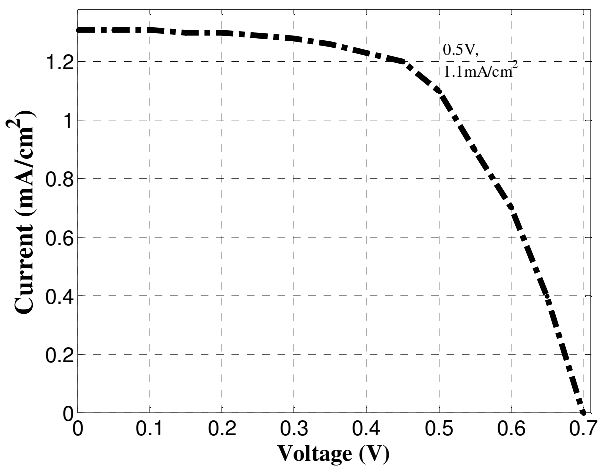


Figure 5. Current-Voltage Curve for a DSC with TiO_2 and Kaolinite-Bixin in Sunlight Irradiation Intensity of 55mW/cm^2

Conclusion

Natural dye sensitizers used in DSCs give low photoelectric conversion efficiencies. An alternative technique for improving efficiencies is by impregnating activated kaolinite into the pure natural dye. In this study, activated kaolinite was impregnated into pure bixin. Experimental results showed that activated kaolinite enhances the photostability and light absorption characteristics of the DSCs based on TiO_2 and bixin as sensitizers. Kaolinite-bixin gave higher photoelectric energy efficiency than pure bixin in the DSCs.

Acknowledgements

This work was financially supported by the National Strategic Priority Research Program-2011, the Directorate of Research and Community Service (DP2M), and the Directorate General of Higher Education, Indonesia.

References

[1] Wongcharee, K., Meeyoo, V., & Chavadej, S. (2007). Dye-Sensitized Solar Cell Using Natural Dyes Extracted from Rosella and Blue Pea Flowers. *Solar Energy Materials and Solar Cells*, 91(7), 566–571.

[2] Fernando, J. M. R. C., & Senadeera, G. K. R. (2008). Natural Anthocyanins as Photosesitizers for Dye-Sensitized Solar Devices. *Current Science*, 95(5), 663–666.

[3] Roy, M. S., Balraju, P., Kumar, M., & Sharma, G. D. (2008). Dye-Sensitized Solar Cell Based on Rose Bengal Dye and Nanocrystalline TiO_2. *Solar Energy Materials and Solar Cells*, 92(8), 909–913.

[4] Calogero, G., & Marco, G. D. (2008). Red Sicilian Orange and Purple Egg Plant Fruits as Natural Sensitizers for Dye-Sensitized Solar Cells. *Solar Energy Materials and Solar Cells*, 92(11), 1341–1346.
[5] Luo, P., Niu, H., Zheng, G., Bai, X., Zhang, M., & Wang, W. (2009). From Salmon Pink Blue Natural Sensitizers for Solar Cells: Canna Indica L., Salvia Splendens, Cowberry and Solanum Nigrums L. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, 74(4), 936–942.
[6] Calogero, G., Carlo, G. D., Cazzanti, S., Caramori, S., Argazzi, R., Carlo, A. D., et al. (2010). Efficient Dye-Sensitized Solar Cells Using Red Turnip and Purple Wild Sicilian Prickly Pear Fruits. *International Journal of Moleciular Sciences*, 11(1), 254–267.
[7] Gomez-Ortiz, N. M., Vazquez-Maldonado, I. A., Perez-Espadas, A. R., Mena-Rejon, G. J., Azamar-Barrios, J. A., & Oskam, G. (2010). Dye-Sensitized Solar Cells with Natural Dye Extracted from Achiote Seeds. *Solar Energy Materials and Solar Cells*, 94 (1), 40–44.
[8] Chang, H., & Lo, Y. J. (2010). Pomegranate Leaves and Mulberry Fruit as Natural Sensitizers for Dye-Sensitized Solar Cells. *Solar Energy*, 84(10), 1833–1837.
[9] Bazargan, M. H., Byranvand, M. M., Kharat, A. N., & Fatholahi, L. (2011). Natural Pomegranate Juice as Photosensitizers for Dye-Sensitized Solar Cell (DSC). *Journal of Optoelectronics and Advanced Materials-Rapid Communications*, 5(4), 360–362.
[10] Zhou, H., Wu, L., Gao, Y., & Ma, T. (2011). Dye-Sensitized Solar Cells Using 20 Natural Dyes as Sensitizers. *Journal of Photochemistry and Photobiology A: Chemistry*, 219(2-3), 188–194.
[11] Hermandez-Martinez, A. R., Estevez, M., Vargas, S., Quintanilla, F., & Rodriguez, R. (2011). New Dye-Sensitized Solar Cells Obtained from Extracted Bracts of Bougainvillea Glabra and Spectabilis Betalain Pigments by Different Purification Processes. *International Journal of Molecular Sciences*, 12(9), 5565–5576.

Biographies

AYONG HIENDRO is a Senior Lecturer at Tanjungpura University (UNTAN), Pontianak, Indonesia. He earned his B.Eng. degree from Tanjungpura University and M. Eng. (Electrical Engineering) from Institut Teknologi Bandung (ITB), Bandung, Indonesia. He is currently teaching at Department of Electrical Engineering, Tanjungpura University. His interest is in energy conversion. He may be reached at ayongh2000@ieee.org

FERRY HADARY is an Assistant Professor of Control Systems at Tanjungpura University (UNTAN), Pontianak, Indonesia. He earned his B.Eng. degree from Tanjungpura University, M. Eng. from Tokyo Institute of Technology, Japan, and Dr. Eng. from Kyushu Institute of Technology, Japan. He is currently teaching at Department of Electrical Engineering, Tanjungpura University. His interests are in control systems, robotics, new and renewable energy. He may be reached at ferryhadary@engineering.untan.ac.id

WINDA RAHMALIA is an Assistant Professor of Chemistry at Tanjungpura University (UNTAN), Pontianak, Indonesia. She earned her B.S. degree from Tanjungpura University and M. Si. (Natural Science for Pigments and Chlorophyll) from Christian University of Satya Wacana, Indonesia. She is currently teaching at Department of Chemistry, Tanjungpura University. Her interests are in pigments as light harvesting and renewable energy conversion and storage systems. She may be reached at winda_rahmalia@mipa.untan.ac.id

NELLY WAHYUNI is an Assistant Professor of Chemistry at Tanjungpura University (UNTAN), Pontianak, Indonesia. She earned her B.S. degree and M. Si. (Natural Science for Inorganic Chemistry) from Gadjah Mada University (UGM), Indonesia. She is currently teaching at Department of Chemistry, Tanjungpura University. Her interests are in inorganic materials especially clay materials for adsorbent, catalysts and host materials. She may be reached at nelly_kimiauntan@mipa.untan.ac.id

SAMPLE SIZE AND TEST STANDARDIZATION FOR TASK PERFORMANCE ANALYSIS

Reza Karim, Kambiz Farahmand, North Dakota State University

Abstract

In today's industry, many occupations require manpower for both labor and cognitive resources. Due to rapid technological advancement, people are becoming more dependent on cognitive task performance to make critical decisions. It is critical for many operations to design systems so that the effects of physical stress, however minute, on task performance are considered. In this study, a computer assessment tool was developed to evaluate the effect of low-level physical stress on task performance. The effect of stress was analyzed on overall task performance by the subjects who completed the test with and without any exposure to physical stress. The study focused on how sample size was determined and how test procedures could be standardized for data collection.

Introduction

The evaluation of cognitive task performance is very important in the research and improvement of human-machine interfaces for comfort, satisfaction, efficiency, and safety in the workplace. The need for a standardized way of measuring task performance has been well recognized in today's industry. It is recognized that task efficiency and task quality require standardized work procedures, yet an appropriate measure of human task capacity is still a very challenging topic. It has been examined through various studies in the area of neurology, clinical psychology, and human factors on exactly how human task performance is conducted. In this current study, a standardized task method was developed in order to measure the effect of low-level physical stress on cognitive task performance with a greater degree of accuracy.

An extensive review of the literature indicated that there is a lack of standardization on how to design a test for stress -effect evaluation. This study, then, focused on determining if low-level stress has any effect on task performance. Various authors describe stress in different ways. Lazarus [2], for example, defines stress as a feeling experienced when a person thinks that the social or work demands exceed the personal and social resources the person is able to mobilize. Stress and anxiety are core concepts of psychopathology [3]. A diathesis-stress model assumes that most stress-related complications arise from complex interactions between environmental stressors and biological dispositions that can make an individual collapse. Physical load can cause stress and influence operator performance. In the case of a short–duration, high-intensity physical activity, a decrease in accuracy when performing cognitive tasks was observed, such as in the case of map interpretation while running on a treadmill [4]. Human factors researchers recognize the difficulties in defining the construct of physical stress or fatigue and measuring the effect of fatigue under experimental conditions [5].

This study evaluated the effect of physical stress on various types of tasks in the area of general computation, three-dimensional review, vocabulary, pattern recognition, comparison and arithmetic reasoning. It is critical for many operations to design systems such that the effects of physical stress, however minute, on task performance are considered. The authors focused on standardizing the test protocol to establish a guideline for future research. This study focused mainly on how the number of subjects required for the test was determined.

Background

The assessment of task load and stress and the impact on performing a task are very important when individuals are required to perform a specific type of task. Critical decisions made under stressful conditions result in poor performance which could often be catastrophic. It is critical to determine the effect of stress in the demanding fields of aviation, mining, military, transportation, and other industries involved in engineering and critical-thinking processes. Therefore, it is important to develop a standardized tool that is capable of measuring the effect of stress on task performance and is transferable to various types of industries. Accuracy and response time were utilized to find any effect of physical stress on task performance [6]. Task capacity can be measured from objective and subjective queries. Several studies related to human factors show that self-report (subjective) measures can be useful [7].

Sample size determination is an essential factor to validate any new tool. Statistical power tells us if the results of any test are statistically significant or not. A statistically insignificant result with a high statistical power is explained as either the research hypothesis not being properly selected or there being less of an effect than predicted. The other approach to determining sample size is to run a pilot test [8]. The results from this study should provide a reasonable estimate of the effect of size. A pilot study is not always feasible and, in such cases, previous experience and theories are used to estimate the effect of size.

In many studies related to cognitive tasks, determinations of sample size are not described. Paas & Adam [9] studied two information processing tasks with sixteen subjects. Eight of the sixteen subjects participated in the test of endurance versus interval protocol physical exertion information processing. The other eight subjects participated in rest versus minimal load protocol exertion information processing. The authors did not discuss the process of selecting the number of the samples and statistical power considered in the test. But, the authors were able to find statistically significant results using the F-test. Aks [10] studied the influence of exercise on visual search with eighteen participants and was able to find statistically significant results using an ANOVA. Joyce [11] conducted a time course effect study of moderate intensity exercise on response execution with ten subjects. The authors found statistically significance results using the F-test. But the authors did not discuss statistical power and how the number of participants was determined for the test.

The tasks performed in any industrial facilities are routine and repetitive in nature. It is important to standardize task performance. The Delphi technique is usually applied to reach a consensus level on a problem where it is difficult to solve the problem experimentally or achieve consensus among the users. One of the key features of the Delphi method is that the participants remain anonymous to ensure that the participants are not influenced by others. The Delphi method is generally conducted through mail service or any other media when the participants cannot meet with the researcher. Also, Delphi allows the flexibility needed for participants to provide feedback at their own pace.

The Delphi method was used for collecting and aggregating information from a group of experts on specific questions and issues related to the subject matter [12]. The Delphi method develops a platform for future knowledge and policy for a specific problem. The results from Delphi studies are widely accepted by the research community because of grassroots involvement. Authors used the Delphi method in different types of research topics. Shah [13] applied the Delphi method to develop a graduate-level lean manufacturing course curriculum. Hasson [14] studied issues in nursing research that included preparation and action steps to be taken by nurses. Any assumption that was considered for developing the tool was challenged when the Delphi mechanism was applied to validate it. The Delphi method helps streamline work flow. Scientific merit questions are an essential part of a Delphi study [15]. The diversified viewpoints help to generate interest among the experts to continue to participate and provide feedback.

To increase efficiency and quality of production, standardized work procedures [16] are required. Many authors developed simulation tools to standardize work procedures [17]. A tool that is built with a standard and widely acceptable method to measure task performance is able to measure task performance capacity with a greater degree of accuracy. As the human brain consists of a complex processing mechanism, task capacity measured using a standard tool is useful in different environmental conditions.

Methodology

In this study, the Delphi method standardized the test procedures to use the task capacity tool. The Delphi method considers views from participants involved in different job functions within the same professional field or closely related professional fields related to the research subject. The research protocol consisted of experimental parameters, variables, procedures, experimental characteristics, number of subjects required, subjects' qualifications, time commitments of subjects, equipment requirement, and a physical exertion protocol. Different mechanisms were introduced in the current study in order to standardize the test protocol. The Delphi method was considered here for evaluating the experimental parameters and variables of the research only.

All of the participants in the Delphi study had science and engineering backgrounds. Since the types of tasks considered were general, no specific branch of scientific background was required for testing the participants. A few samples from the questionnaire include: i) which pair of name is the same, ii) add (+): 76543 and 11111, iii) which picture displays flat piece bent, rolled or both? The seven types of tasks described earlier were considered in order to develop the test in the area of problem solving, memory, and situational awareness of the subjects.

The tasks were classified based on Miller's information task functions [18]. Each question was classified into memory, IQ, and problem-solving type based on the information tasks described by Miller. The reason for classifying these into three performance parameters was to differentiate the effect of stress on each of these measures. A total of twenty-one subjects completed the survey. In the first step, the subjects were asked to comment on the test setup, time allocated for each question, total time taken for the test, and user friendliness. Based on their feedback, time allocation for some of the questions was increased and the tutorial was improved. In the next step, the subjects were asked to evaluate each of the questions in the test to check the task validity. Finally, redesign of the test based on the feedback was recorded. This methodology standardized the procedure to conduct the task capacity test.

This study was broken into two phases: Phase I and Phase II. Phase I tasks and Phase II tasks were identical. The order of appearance of the questions in both of the tests was random. Phase I was considered as performance without any stress. Phase II was considered as performance after stress. There was one experimental trial for each subject in Phase I. Each experimental trial consisted of thirty tests in a random order. Similarly, Phase II consisted of one experimental trial with thirty tests in a random order. The Phase II test followed immediately after ten minutes of light physical work at the set room air temperature and relative humidity. There was a standard protocol described in the test for biking. The Borg scale was used to rate each participant's stress level. The Borg scale has a range of 6 to 20. The participants were all asked verbally to rate their stress level right after biking. A rating of 10 or lower was considered low-level stress.

This study focused on how to have a balanced experimental design for subsequent statistical analysis. It was desired that the same subjects participate in both experimental phases. However, if subjects dropped out after completing Phase I, they were not replaced by other volunteers during Phase II.

Performance Parameters

The sample size can be determined in numerous ways. The approaches considered for this study are described below.

Approach One:
After the task performance measurement tool was developed, five subjects completed the test at the Phase I level, as shown in Table 1. Based on the test results, a minimum number of participants required for the test was calculated from the sensitivity, power, and statistical analysis of the accuracy level. The sample size was determined from the Operating Characteristics, OC, curve [19], as shown in Figure 1. The OC curve is the plot for type II error. The β error is a function of sample size. For a given value of δ (difference of two means), β error decreases as the sample size increases. The task capacity measured in this study used lower-order cognitive tasks. The tasks selected for the test were considered under a general science category and the subjects who participated had science backgrounds.

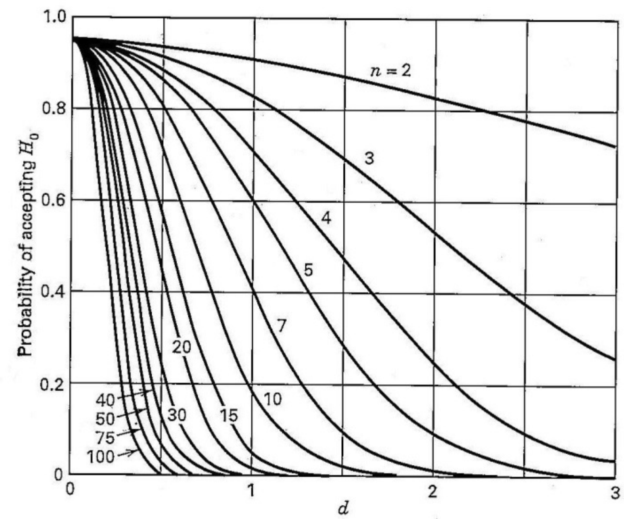


Figure 1. Operating Characteristics Curve [19]

Table 1. Preliminary Data for Sample Size Determination

Overall Correct Answer (%)	Standard Deviation (σ)	Average (μ)	Difference (τ)
85	6.5	84	1
90		84	6
80		84	-4
90		84	6
75		84	-9

From the report of the Army General Classification Test Scores for Civilian Occupation [1], the Binet Intelligence Scale mean IQ values for accountants, engineers, and lawyers are 122 with a standard deviation of 16 and where the minimum value was 96 and the maximum value was 144. The level of difficulty for this test is considered 90% of the maximum score and it can be assumed to be equivalent to the maximum score of 144. The mean score of 122 can be converted to 76.25% of the maximum score with a converted standard deviation of 4.58. Initially in the experiment, it was assumed that task capacity differences between phase I and phase II were not more than 15% of correct results with a standard deviation of less than 5%. The effect size, d, can be calculated using Equation (1).

$$d = \frac{|\mu 1 - \mu 2\ |}{2\delta} \tag{1}$$

$$= 15/2*4.58 = 1.64$$

From the OC curve (Figure 1) for $\beta = 0.1$ and the d value from Equation (1),

$$n^* = 6.5 \quad (2)$$

where sample size, n, is calculated by

$$n = (n^* + 1)/2 \quad (3)$$
$$= 3.75 \approx 4$$

Based on this approach, the sample size was determined to be four. As the study progressed, it was observed that the mean difference was lower than 15%. Thirty two subjects were considered for this study as the variability between subjects was high and some subjects were expected not to complete both tests.

Approach Two:
A paired t-test was considered in order to determine the sample size using the SAS (Statistical Analysis System) statistical analysis program. Table 2 shows the results from paired-t test runs for mean differences (4), standard deviations (6, 7 and 8), correlations (0.5, 0.6, 0.7 and 0.8), and power considered for the test (0.8).

Table 2. Paired t-Test (Partial Results)

	Computed N Total				
Index	Mean Diff	Std Dev	Corr	Actual Power	N Total
1	4	6	0.5	0.806	20
2	4	6	0.6	0.818	17
3	4	6	0.7	0.807	13
4	4	6	0.8	0.808	10
5	4	7	0.5	0.818	27
6	4	7	0.6	0.828	22
7	4	7	0.7	0.818	17
8	4	7	0.8	0.823	12
9	4	8	0.5	0.852	34
10	4	8	0.6	0.837	28
11	4	8	0.7	0.813	21
12	4	8	0.8	0.818	15

Another SAS program for two sample t-Test for mean differences was used to determine sample size, considering that each subject only completed either Phase I or Phase II of the test. The program was run for a 1:1 ratio and a 2:1 ratio between Phase I and Phase II. The mean differences that were considered were 6, 7, and 8, and standard deviations of 5, 6, 7, and 8. Tables 3 and 4 show the results from the two runs.

Table 3. 2:1 Ratio of Two Sample t-Test (Partial Results)

Computed N Total				
Index	Mean Diff	Std Dev	Actual Power	N Total
1	6	5	0.806	27
2	6	6	0.818	39
3	6	7	0.807	51
4	6	8	0.808	66
5	7	5	0.818	21
6	7	6	0.828	30
7	7	7	0.818	39
8	7	8	0.823	51

Table 4. 1:1 Ratio of Two Sample t-Test (Partial Results)

Computed N Total				
Index	Mean Diff	Std Dev	Actual Power	N Total
1	7	5	0.818	58
2	7	6	0.841	74
3	7	7	0.814	20
4	7	8	0.807	26
5	8	5	0.809	34
6	8	6	0.809	44
7	8	7	0.801	54

Discussion & Results

From the analysis of the literature, it was found that there are no specific criteria for determining the sample size for the Delphi study. Some studies experimented with fifteen subjects with 70% agreement as a consensus level. The Delphi technique was used in this study to determine if the designed questions were covering the seven types of tasks. For each question, a 70% consensus level among the participants was considered acceptable. The Delphi method is a multistage problem-solving method for reducing time and resources in order to design the questions; existing literature resources were used to determine the types of question used under each task type. The questions which did not receive a 70% consensus level were eliminated from the test. In the third stage, after the participants completed the test, they were asked for any suggestions for improving the test questions. Also participants were asked about their overall experience on the test design. The content validity results are shown in Figure 2. A total of sixteen people responded to this analysis. The initial expectation was to have a content validity rating of 6 or higher in defining 'How important the task is in daily life,' but the plot indicates that some of the question ratings fell below 6. Since the subjects participating in the test were from a wide range of professions, and some participated online, this variability was expected. The plot indicates that only ratings for a few questions fell between 5.6 and 6.

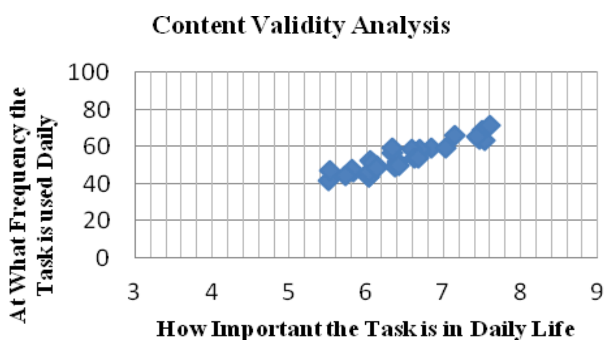


Figure 2. Content Validity Analysis

The test was conducted in a laboratory setting as well as in an online environment. A total of twenty seven subjects completed Phase I and Phase II of the test. Phase I of the test was completed by twelve subjects and Phase II of the test was completed by fifteen subjects.

The ratio of Phase I (including online and lab) and Phase II was approximately 2:1. The differences in mean and standard deviation were 7.25 and 0.47, respectively.

Table 6 shows the results from the sample t-Test SAS program for mean differences of 6 and 7 and standard deviations of 7 and 6. The SAS program considered for the case of 2:1 group ratio at power 0.8 and alpha 0.05. Since both the mean difference and standard deviation calculated from laboratory and online experiments was between 6 and 7, the average N value from Table 6 was considered as total subjects required for the test, which was approximately forty.

Table 5. Phase I Accuracy Analysis

Test Type	Number of Subjects	Mean Accuracy	Standard Deviation
Online Test Average	15	78.4	6.02
Laboratory Test Without Stress (Phase I)	12	78.3	6.6
Laboratory Test Without Stress (Phase II)	15	71.1	6.7

Table 6. SAS Two Sample t-Test

Computed N Total				
Index	Mean Diff	Std Dev	Actual Power	N Total
1	6	7	0.807	51
2	7	6	0.828	30

From the literature review on the effects of physical exertion on task performance, the number of subjects considered varied from ten to thirty two. From the analysis of the SAS results, it was reasonable to consider the total sample size of approximately forty for the study.

The NASA-TLX rating principle was utilized and modified to develop an overall performance chart to be rated by each subject, as shown in Table 7. The chart was required to be completed by the subjects after Phase I and Phase II of the test. The purpose of the subjective rating chart was to estimate the subject's evaluation of the test in terms of mental demand, temporal demand, performance, effort, and frustration level. The analysis of the report, as shown in Table 8, provides an overview for the test structure and the scope of future improvements for the test. The evaluation of the subjective rating indicates that participants were comfortable with how the questions were designed with a very low frustration level and a medium level of effort.

A short survey form, as shown in Table 9, was used to find how the subjects felt about the test design. The form was completed by the subjects after either Phase I or Phase II of the test. The evaluation report indicated that subjects were satisfied with the computer test model in terms of accessibility, navigation, readability, organization, and total time spend on the test.

Table 7. Overall Performance Chart

Title	Endpoints (1-10) scale	Descriptions
Mental Demand	Low / High	How much mental and perceptual activity was required?
Temporal Demand	Low / High	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred?
Performance	Poor / Good	How much do you think you were in accomplishing the goals of the task set by the experimenter?
Effort	Low / High	How hard did you have to work (mentally) to accomplish your level of performance?
Frustration Level	Low / High	How stresses versus relaxed did you feel during task?

Table 8. Summary of Subjective Rating on Test

Type	Rating (1-5) frequency	Rating (1-5) %	Rating (6-10) frequency	Rating (6-10) %
Mental Demand	12	37.5	20	62.5
Temporal Demand	12	37.5	20	62.5
Performance	3	9.5	29	90.5
Effort	15	47	17	53
Frustration Level	20	62.5	12	27.5

Table 9. Evaluation of Computer Test

Type	Rating (1-3) Frequency	Rating (4-5) Frequency
Accessibility	3	97
Navigation	0	68
Readability	9	91
Content Organization	6	94
Total Time spent on participating in the test	25	75

Conclusion

The focus of this study was to develop and standardize a task assessment test needed to evaluate individual task capacity and to determine the appropriate sample size to measure the effect that low-level physical stress may have on task performance. The Delphi method was considered as a tool to determine the needs and skills required in any specific work environment. The Delphi technique utilizes combined individual judgment to address any issue related to an incomplete state of knowledge. The consensus was reached above 70% agreement with eighteen subjects who completed the evaluation. The subjects participating in content validity were from a wide range of professions. The consensus level achieved was about 6 and above, in terms of "how important the task is in daily life". Thirty two subjects were considered for this study based on initial test results and statistical analysis. The number of subjects considered satisfied the research objective to determine if stress had any effect on task performance. The developed tool was capable of assessing the effect that low-level physical stress in various types of industries might have on performance. The assessment tool has the capacity to change its settings to incorporate different expertise levels or task types.

References

[1] Trent, W. C. (1985). *Understanding and Selecting Personnel*. Tyler: Gateway Press, Texas.

[2] Lazarus, R. S. (1990). Theory-Based Stress Measurement, *Psychological Inquiry*, 1(1), 3-13.

[3] Kroemer, K. H. E., Kroemer, H. B., & Kroemer-Elbert, K. E. (2003). *Ergonomics: How to Design for Ease and Efficiency.* (2nd ed.). Prentice Hall.

[4] Hancock, S., & McNaughton, L. (1986). Effects of fatigue on ability to process visual information by experienced orienteer. *Perceptual & Motor Skills*, 62, 491-498.

[5] Gawron, V. J., French, J., & Funke, D. An overview of fatigue. In P. A. Hancock & P.A. Desmond (eds.), (2001). *Stress, workload and fatigue* (pp. 581-595). Mahwah, NJ: Lawrence Erlbaum.

[6] Karim, R., & Farahmand, K. (2011). Test Battery for Evaluation of Task Performance and Situational Awareness. *International Journal of Engineering Research and Innovation*, 3(2), 54-60.

[7] Muckler, F. A. (1992). Selecting Performance Measures: Objective versus Subjective Measurement. *Human Factors*, 34 (4), 441-455.

[8] Faul, F., Erdfelder, E., Lang, A., & Buchner, A. (2007). G*Power 3: a flexible statistical power analysis program for the social, behavioral and biomedical

sciences. *Behavioral Research Methods*, 39(2), 175-191.

[9] Paas, F. G., & Adam, J. (1991). Human information processing during physical exercise. *Ergonomic* 34 (11), 1385-1397.

[10] Aks, D. J. (1998). Influence of exercise on visual search: Implications for mediating cognitive mechanisms. *Perceptual and Motor Skills*, 87, 771-783.

[11] Joyce, J., Graydon, J., McMorris, T., & Davranche, K. (2009). The time course effect of moderate intensity exercise on response execution and response inhibition. *Brain and Cognition*, 71, 14-19.

[12] McKenna, H. P. (1994). The Delphi Technique: a worthwhile research approach for nursing? *Journal of Advanced Nursing*, 19, 1221-1225.

[13] Hiral, A. S., & Tillman, T. S. (2008). An International Lean Certification Role Delineation Delphi Study Applied to Develop Graduate-level Curriculum in Lean Manufacturing, *Technology Interface Journal/ IAJC-IJME Conference*, Volume 9(1).

[14] Hasson, F., Keeney, S., & McKenna, H. (2000). Research Guideline for the Delphi Survey technique, *Journal of Advanced Nursing*, 32(4), 1008-1015.

[15] Powell, C. (2000). The Delphi technique: myths and realities, *Journal of Advanced Nursing*, 41(4), 376-382.

[16] Adler, P. S. (January-February, 1993). Time-and-Motion Regained. *Harvard Business Review*, 97-108.

[17] Farahmand, K., Karim, R., Srinivasan, R., Sajjadi, R., & Fisher, L. (2011). Lean Enterprise Principles Applied to Healthcare. *International Journal of Engineering Research and Innovation*, 3(2), 5-13.

[18] Miller, R. B. (1974). A Method for Determining Task Strategies. *American Institutes for Research in the Behavioral Sciences*. (Report no. APHRL-TR-74-26). Silver Spring, MD.

[19] Montgomery, D. C. (2001). *Introduction to Statistical Quality Control*. (4th ed.). Wiley.

Biographies

REZA KARIM completed his Ph.D. in Industrial and Manufacturing Engineering Department at North Dakota State University. He is currently teaching an undergraduate -level lab on Workstation Design and Time Motion Study and conducting research in improving Healthcare facilities design and management. His research interest is in the area of healthcare, simulation, product design, process analysis, lean application and human factor consideration. He has extensive work experience in the field of equipment design, process design, reliability engineering, Computational Fluid Dynamics (CFD) and project management. Mr. Karim may be reached at Reza.Karim@ndsu.edu

KAMBIZ FARAHMAND is currently a Professor at the Industrial and Manufacturing Engineering and Management at North Dakota State University. He is an internationally recognized expert in Productivity Improvement. Dr. Farahmand has over 28 years of experience as an engineer, manager, and educator. He is a registered professional engineer in the state of Texas and North Dakota. Professor Farahmand may be reached at Kambiz.Farahmand@ndsu.edu

A FAST ALGORITHM FOR SURFACE QUALITY COMPARISON AND ASSESSMENT IN ADVANCED AND AUTOMATED MANUFACTURING

E. Sheybani, S. Garcia-Otero, F. Adnani, G. Javidi, Virginia State University

Abstract

This study focused on providing image processing tools for comparison and assessment of a surface processed under different grades of a manufacturing process all the way up to optimal processing. The goal was to automate the task of surface quality inspection. Ability to measure the surface quality in real-time has many applications in manufacturing automation and product optimization, especially in processes in which the surface qualities such as roughness, grain size, thickness of coding, impurities size and distribution, hardness, and other mechanical properties are of importance. Surface analysis in manufacturing environments requires specialized filtering techniques. Due to the immense effect of rough environment and corruptive parameters, it is often impossible to evaluate the quality of a surface that has undergone various grades of processing.

The algorithm presented here is capable of performing this comparison analytically and quantitatively at a low computational cost (real-time) and high efficiency. The parameters used for comparison were the degree of blurriness and the amount of various types of noise associated with the surface image. Based on a heuristic analysis of these parameters, the algorithm can assess the surface image and quantifies the quality of the image by characterizing important aspects of human visual quality. An extensive effort was invested in order to obtain real-world noise and blur conditions so that the various test cases presented here could justify the validity of this approach. The tests performed on the database of images produced consistent and valid results for the proposed algorithm. This paper presents the description and validation (along with test results) of the proposed algorithm for surface image quality assessment.

Introduction

In this study an approach to surface image quality assessment for surface pattern and object recognition, classification, and identification is presented. This study aimed to assign a value to the visual quality of several surface finishes from the same object whose surface has undergone different grades of the same process. Ideally, this algorithm would be capable of discerning when an object is optimally processed. In doing so, some of the important parameters that can affect the quality of the surface and ways in which they can be measured quantitatively were identified.

Background

Surface quality assessment finds many industrial applications such as automated, advanced, and autonomous manufacturing processes. Given that in most industrial applications the surface quality cannot be known when the part is being machined, having a tool that can measure the quality of the surface in real time has a significant value. To add to the complication, in most industrial applications, the surface and, therefore, its image suffers from several physical phenomena such as noise—of several different kinds, e.g., Gaussian, salt and pepper, etc.—time shifts, phase shifts, frequency shifts, and other clutter caused by interference and speckles. Thus, the quality assessment tool should also be able to measure the level of deterioration of the surface due to these environmental effects. Therefore, evaluation of the quality of a surface is not an easy task and requires a good understanding of the processing methods used and the types of environmental processes affecting the surface. On the other hand, for a meaningful comparative analysis, some effective parameters have to be chosen and qualitatively and quantitatively measured across different settings and processes affecting the surface. Finally, any algorithm capable of handling these tasks has to be efficient, fast, and simple to qualify for the real-time applications.

In many advanced and automated industrial and manufacturing processes, image processing algorithms are employed in order to analyze object surfaces and use the information obtained to improve the quality of the product such as finish, texture, color, placement, temperature or cracks [1-3]. One major disadvantage of these techniques is that collective environmental noise, speckles, and other artifacts from different sensors, degrade the surface image quality in tasks such as surface pattern restoration, detection, recognition, and classification [4], [5]. While many techniques have been developed to limit the adverse effects of these parameters on image data, many of these methods suffer from a range of issues such as computational involvement of algorithms to suppression of useful information [6], [7]. Therefore, there is a great demand for a tool that could perform an accurate surface quality assessment. Since most surface defects in industrial environments look like clutter, noise, and/or phase/pixel shifts in imaging systems, the proposed surface quality assessment algorithm in this study was based on these parameters (noise and blurriness of surface image) [8], [9].

Furthermore, in order to achieve a comprehensive model and an algorithm that can handle a wide-range of surface imaging applications, adaptive parameters and thresholds that can be adjusted to the type of object surface, manufacturing process, and optimal grade of operation were proposed. In order to achieve the best set of data for assessment, comparison, and testing purposes, real surface images were corrupted with different grades of noise and blur. The noise in this case consisted of Gaussian, salt and pepper, and shot noise. The blur consisted of different levels of pixel displacement and angular rotation. A variety of the most prevalent techniques recommended in the literature to include noise and blur in the images were used [10], [11]. Wavelet transforms were employed for analyzing noise in image data, as suggested by other authors [12-15]. This study required several hardware and software components that set up the framework for image processing and analysis. The criteria for selecting these components was the optimum computing environment set by Mathworks, Inc. These include Matlab analysis and modeling software, a laptop equipped with at least 2GB of memory to run computationally intensive calculations, and programming (C/C++) environments to run programs and extract data. The digital signal-processing algorithms serve to manipulate data so that they would be a good fit for image processing and analysis. In these algorithms, a wavelet-based approach was considered for de-noising the image datasets.

Methodology

Figures 1 and 2 show the placement of the proposed algorithm in a given industrial image-processing setup and its functional block diagram. Ideally, the proposed algorithm should be able to look at an image received from the processing sensor of the manufacturing cell (which is cluttered with various noise and blur effects from the environment), compare it to the outcome of various processing levels of the same cell (A1, A2, and A3) for the same surface (image 1, Image 2, and Image 3), and decide which one is closer to the optimal threshold set for that particular process. As such, to validate the capability of the proposed algorithm in assessing and comparing the quality of different surfaces, it must be tested with known images compared to their cluttered and processed versions.

Figure 3 shows the block diagram of the validation approach combined with the details of the proposed algorithm from Figure 2. Consistency in quality measure figures is the key to the successful validation of this approach and its applicability to a wide range of surface images from different manufacturing processes. The objective was to have one algorithm that would work for different levels of surface processing cells. To show consistency in results, the tests were repeated with the original image (O), original image plus noise (O+N), original image plus blur (O+B), and original image plus noise and blur (O+N+B). The results for all cases are shown in Table 1. From Figure 2, the proposed algorithm consists of several modules, each unique in its design and purpose while applicable to a broad array of surface images. These modules are described below:

De-noising Filter Banks:
A surface image corrupted with noise can be simply modeled as $S(i,j) = f(i,j) + \sigma e(i,j)$, where S is a corrupted image with noise e, and σ is the noise level. To de-noise means to remove $\sigma e(i,j)$ and recover $f(i,j)$, the original (un-corrupted) surface/image. Noise is a wide-band phenomenon. Therefore, de-noising would require a delicate balance of high-, low-, and mid-band filters with proper thresholds that would minimize interference with the main signal. The proposed filters in this study used a combination of wavelet-based filter banks and Wiener/Gaussian filters as a means of multiband noise suppression and wide-band noise reduction, respectively.

The Wiener filters were specialized in (additive) noise smoothing (compression low-pass filter) and blur inversion (deconvolution high-pass filter), while reducing the mean square error. In the Fourier transform domain, the Wiener filters can be expressed as:

$$W(f_1, f_2) = \frac{H^*(f_1, f_2)\, S_{xx}(f_1, f_2)}{|H(f_1, f_2)|^2\, S_{xx}(f_1, f_2) + S_{nn}(f_1, f_2)} \qquad (1)$$

where $S_{xx}(f_1, f_2)$ and $S_{nn}(f_1, f_2)$ are power spectra of the original image and noise, respectively, and $H(f_1, f_2)$ is the blurring filter [16], [17].

The Gaussian filters perform signal smoothing by applying convolution (blurring), thereby removing high-frequency noise (mean filtering). The 2D Gaussian filter can be expressed as:

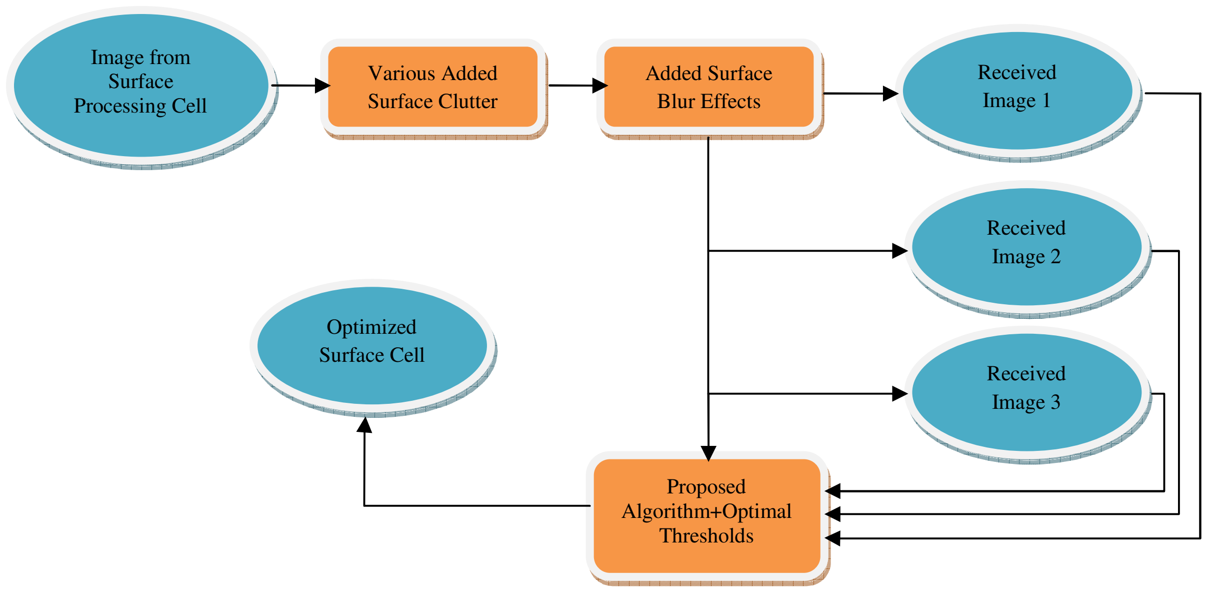


Figure 1. General Path for an Image from Processing Cell to Manufacturing Cell; Alternative Paths for Processing; and the Proposed Algorithm for Surface Quality Assessment

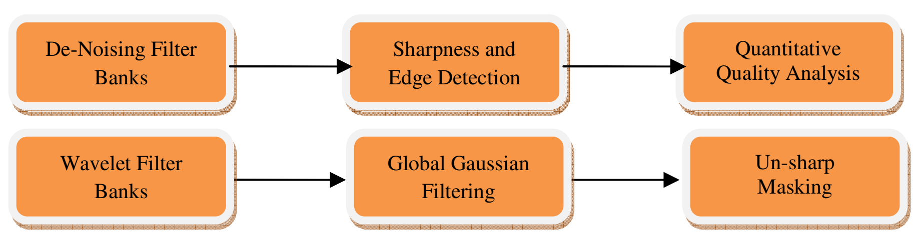


Figure 2. Components of the Proposed Algorithm for Image Quality Assessment and Details of the De-noising Filter Banks

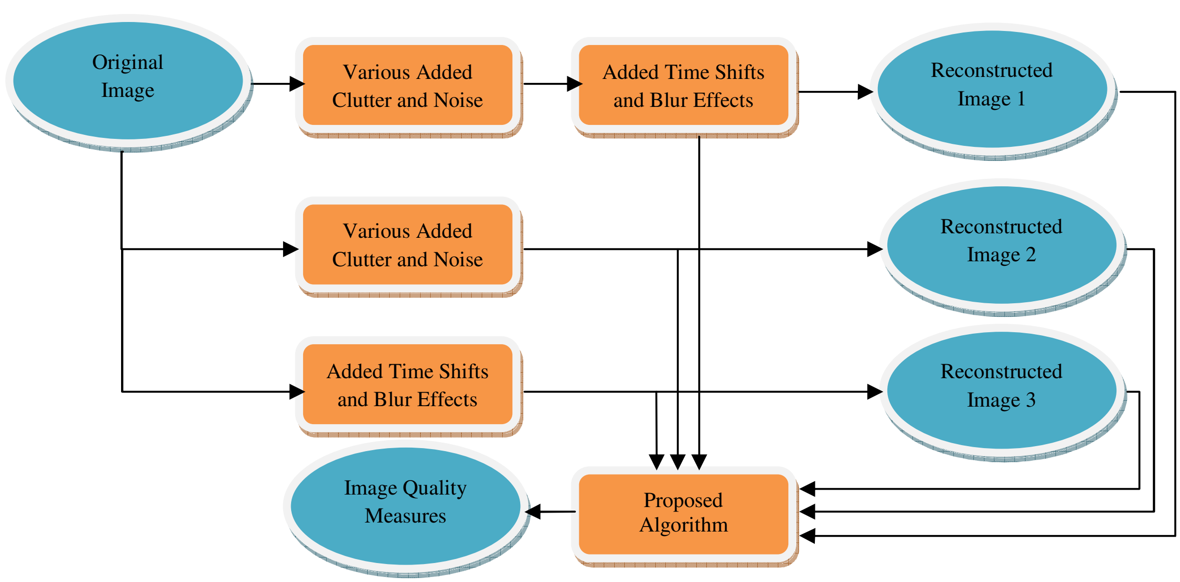


Figure 3. Validation-Approach Functional-Block Diagram for the Proposed Algorithm for Surface Image Quality Assessment

$$G(x,y) = \frac{1}{2\pi\sigma^2} e^{-[(x2 + y2)/2\sigma2]} \quad (2)$$

where the standard deviation (σ) determines the degree to which the image is smoothed. The Gaussian filters smooth the image more gently than the mean filter and preserve the edges better. Therefore, the Gaussian filter is not only better for edge detection due to its sharp cutoff frequency, but it also is the perfect pair for a Wiener filter as it neutralizes the blur effect of these filters and reduces the noise in bands that the Wiener filter cannot do effectively [16-19].

The wavelet de-noising method is proven to be one of the better methods [15-17]. This method involves three steps. First, a mother wavelet is used to generate the discrete wavelet transform (DWT) which, in turn, is employed to decompose the image. Then, hierarchical DWT representations of the image make it possible to determine the de-noising layer number by a proper soft threshold and threshold function algorithm. Finally, reconstructing the image by applying the threshold coefficients and inverse discrete wavelet transform (IDWT), reconstructs the de-noised image. Wavelet transforms are the result of translation and scaling of a finite-length waveform known as a mother wavelet. A wavelet divides a function into its frequency components such that its resolution matches the frequency scale and translation. To represent a signal in this fashion it would have to go through a wavelet transform.

Application of the wavelet transform to a function results in a set of orthogonal basis functions which are the time-frequency components of the signal. Due to its resolution in both time and frequency, wavelet transform is the best tool for decomposition of signals that are non-stationary or have discontinuities and sharp peaks. In this study, the wavelet transform was used to de-noise images. The approach consists of decomposing the signal of interest into its detailed and smoothed components (high and low frequency). The detailed components of the signal at different levels of resolution localize the time and frequency of the event. Therefore, the wavelet filter can extract the short-time, extreme value, and high-frequency features of the image. Usually, a subset of the discrete coefficients is used to reconstruct the best approximation of the signal. This subset is generated from the discrete version of the generating function:

$$\psi_{m,n} = a^{-m/2}\, \psi(a^{-m}\, t - nb) \quad (3)$$

where a and b are scale and shift, and m and n represent the number of levels and number of coefficients used for scaling and shifting of wavelet basis, respectively. Applying a subset of this set to a function x with finite energy will result in wavelet transform coefficients from which one can closely approximate (reconstruct) x using the coarse coefficients of this sequence [12], [13]:

$$x(t) = \textstyle\sum_{m \in Z} \sum_{n \in Z} \langle x,\psi_{m,n}\rangle \bullet \psi_{m,n}(t) \quad (4)$$

Sharpness and Edge Detection:
The proposed blind image quality assessment approach is based on immediate human visual factors such as lighting, contrast, tone, noise, and blurriness. These parameters were carefully simplified, filtered, merged, and optimized in order to yield a quantitative measure for quality of a broad range of images. As part of the filtering and simplification process, the edge detection and sharpening filters were employed.

The sharpness filtering or un-sharp masking can be used to remove uneven pixels and noise from an image while preserving the original data and avoiding deformity and shrinkage. This is done by applying linear or non-linear filters that amplify the high-frequency components of the image and, therefore, give the impression of an image with a higher resolution. The procedure requires setting thresholds that limit the sharpness of unwanted elements in the image (such as image grains). This technique increases the sharpness effect of an image by raising the contrast of small brightness changes. The image appears more detailed since the human perception is aligned to the recognition of edges and lines. Un-sharp masking could increase the detail contrast in general and amplify image interference of the original, resulting in very bumpy and unnatural image effects. In fact, too much masking could cause "halo" effects (light/dark outlines near edges). It can also bring in slight color shifts by emphasizing certain colors while diminishing others. The filters proposed in this study were carefully designed to optimize masking without causing “halo” effects and to emphasize luminance channel rather than color to avoid any color shift [20].

Edge detection is an essential part of any feature detection or extraction in image-processing or computer-vision algorithms. The technique consists of recognizing the points at which the brightness of a digital image changes abruptly (points of discontinuity). These changes could be an indication of important incidents in an image such as sudden changes in depth or surface orientation, properties of material, or illumination of the scene. Despite different techniques presented to solve this non-trivial problem, one of the earliest by Canny is considered to be the state-of-the-art edge detector [21]. In his approach, Canny considered an optimal smoothing filter given the criteria of detection, localization, and minimizing multiple responses to a single edge. He proved that this filter can be implemented as the sum of four exponential terms and approximated by first-order derivatives of Gaussians. He used central differences as a gradient operator to estimate input image gradients [21], [22]:

$$L_x(x, y) = -\tfrac{1}{2} \cdot L(x-1, y) + 0 \cdot L(x, y) + \tfrac{1}{2} \cdot L(x+1, y) \quad (5)$$

$$L_y(x, y) = -\tfrac{1}{2} \cdot L(x, y-1) + 0 \cdot L(x, y) + \tfrac{1}{2} \cdot L(x, y+1) \quad (6)$$

The gradient magnitude and orientation can then be computed as

$$|\nabla L| = \sqrt{L_x^2 + L_y^2} \quad (7)$$

$$\Theta = Atan2(L_y, L_x) \quad (8)$$

Quantitative Quality Analysis:
For the purpose of comparison and assessment of various surface images from a processed object, it is desired to have a quantitative measure based on parameters involved in visual quality. In this study, the ideal quantitative measure was analytically calculated based on a delicate balance between the signal to noise ratio (SNR) and norm of the reconstructed image. Furthermore, important factors in human visual system such as scene lighting, contrast, and edges were considered in order to come up with these parameters. The Matlab analysis and modeling software, a laptop equipped with at least 2GB of memory to run computationally intensive calculations, and programming (C/C++) environments to run programs and extract data were employed to process and validate the algorithms for this study. As depicted in Figure 2, a cluttered image was de-noised to an optimal level (measured by SNR) and then, using the un-sharp masking, its useful information was extracted in order to realize a factor that was an indication of the portion of the true image that was embedded inside the cluttered version. The closer this number is to one, the higher the portion of the true image inside the reconstructed version. A number larger than one (as shown in the case of exceptional images in Table 3) is an indication that the image has picked up a few extra pieces beyond what was intended in the original image.

SNR is a measure of how well a signal is preserved as it travels through a noisy environment. It is the ratio of signal power to background noise power, measured in dB. It is calculated as follows:

$$SNR = 10 \log_{10}(P_s/P_n) = 20 \log_{10}(A_s/A_n) \quad (9)$$

where P_s and P_n are signal and noise power, and A_s and A_n are signal and noise amplitude, respectively.

Since all data-acquisition systems suffer from environmental noise, SNR can be partially improved by limiting the amount of noise injected into the system from the environment. This can be done by reducing the sensitivity of the system and/or filtering out the noise. Another type of noise (additive noise) is introduced to the system at the quantization phase. This type of noise is non-linear and signal-dependent and, therefore, requires more selective filtering for noise cancellation. The filters used in this study for noise reduction were a delicate balance between Weiner, Gaussian, and wavelet filter banks, which optimally adjust themselves to the level of noise in signal and noise frequency bands for maximum noise cancellation and minimum signal deterioration [23].

Thinking of an image as a two-dimensional matrix, norm can be used to measure the "size" of the image or the "distance" or "difference" between two images. 1-norm of a vector is given as

$$\|\vec{X}\|_1 = \sum_{i=1}^{n} |x_i| \quad (10)$$

Accordingly, 1-norm of a matrix would be

$$\|A\|_1 = max_j \left(\sum_i |a_{i,j}| \right) \quad (11)$$

This amounts to the maximum of column sums. Following the same pattern, the 2-norm of a vector is

$$\|\vec{X}\|_2 = \sqrt{\sum_{i=1}^{n} |x_i|^2} = \sqrt{\langle \vec{X}, \vec{X} \rangle} \quad (12)$$

which amounts to matrix 2-norm being

$$\|A\|_2 = \sqrt{Largest\ eigenvalue\ of\ A^*A}$$

otherwise known as singular values of matrix *A* [24].

Results and Future Work

Table 1 shows examples of images from the image database used for this experiment. Figure 4 shows examples of the validation results for this study. Figure 5 shows examples of the results for images with exceptions, where the anomalies in results show up as quality measures for surface images that do not converge to an optimal value.

As shown in Figure 3, the images for this experiment were cluttered in 3 different ways (Table 1) and all processed with the proposed surface image quality assessment algorithm. Quantitative results proved to be consistent for

Table 1. **Examples of Images used for Validation of the Proposed Algorithm for Surface Image Quality Assessment and Tested with Original Image (O), Original Image plus Noise (O+N), Original Image plus Blur (O+B), and Original Image plus Noise and Blur (O+N+B). Also shown are Examples of Images with Exceptional Conditions.**

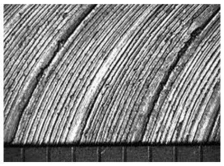
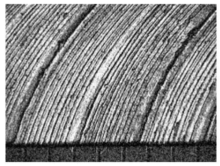
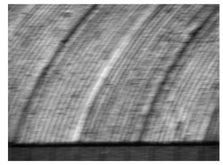
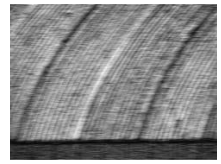
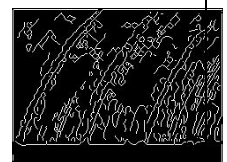
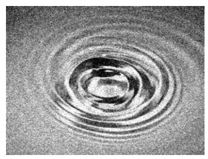
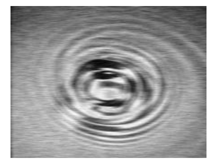
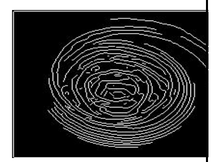
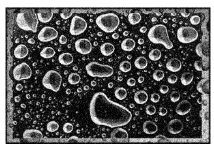
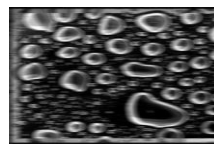
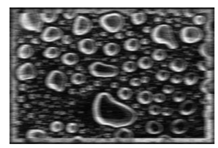
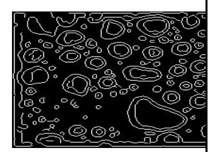
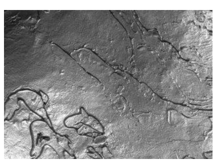
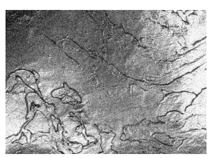
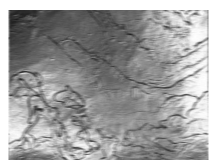
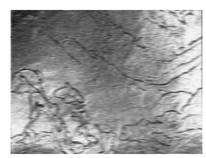
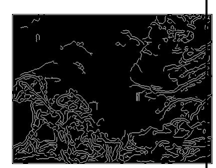
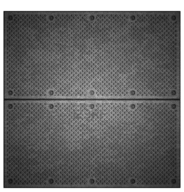
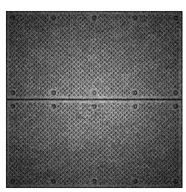
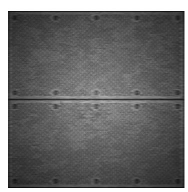
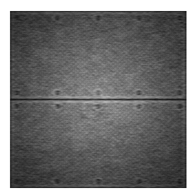
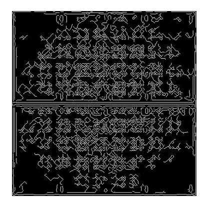
Examples of Images	O	O+N	O+B	O+N+B	O Image Edge
Surface1					
Surface2					
Surface3					
Exception1					
Exception2					

Figure 4. Examples of the Normalized Validation Results for the Proposed Algorithm for Surface Image Quality Assessment—Tested for Original Image (O), Original Image plus Noise (O+N), Original Image plus Blur (O+B), and Original Image plus Noise and Blur (O+N+B)

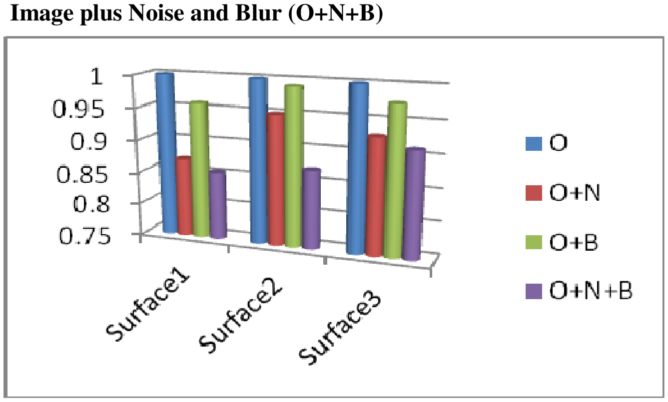
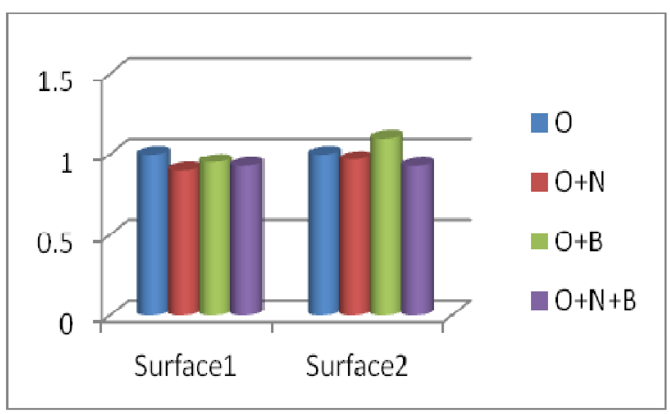


Figure 5. Examples of Normalized Test Results for the Images with Exceptions—the Proposed Algorithm Deviates from the Normal Trend



each and every image type tested. Here are some observations from these test results:
a. The algorithm consistently rates the original better than the noisy (O+N), blurry (O+B), and noisy-blurry (O+N+B). In most cases, as the quality of the image was degraded (by introducing more clutter such as noise and blur or both), the quality measure continually decreased. The lack of consistency here remains a question until further improvements to the algorithm and a comparison to human visual system (HVS) can be performed.

b. The exceptional images shown in Table 1 with results in Figure 5 were deliberately corrupted with anomalies (such as extra and non-homogeneous lighting, text, lines, edges, etc.) added to the image. The inconsistency in results for these images are shown in Figure 5. This is another strong point about the proposed algorithm as it picks out images with irregularities.

c. The results also indicate that the proposed quality assessment figure is a robust and reliable measure based on limited visual parameters for a fast convergence suitable for real-time applications with limited sensor data. The measure proved to be able to differentiate between different grades of processing of the same object (surface images) very accurately. Accordingly, it can also detect anomalies in the image in the same way that the human eye can.

The authors further examined the validity of this algorithm in comparison to human visual system (HVS). This is rather an important task as it finds applications in many automated systems in which human observation and validation is part of the process (CIM cells, manufacturing, etc.). The successful results of this study will be reported in a future paper. The algorithm can now be matched to relevant applications in the real world. Another step in improving this work is the hardware implementation of the algorithm. Currently, the authors are teaming up with NASA partners to program the proposed algorithm in an FPGA.

Conclusion

The long-term goal of this research project is to enable increased autonomy and quality of image-processing systems, with special emphasis on automated processing, validation, and reconfiguration. The overall theme of this work is automatic extraction and processing of high-resolution surface images by adding a real-time surface image quality assessment algorithm. Wiener, Gaussian, un-sharp masking, and Multi-resolution wavelet filter banks were proposed to enable an efficient and fast solution to this problem. A delicate balance of these filters in the proposed algorithm is capable of recognizing the quality of an optimal surface (image) in comparison to unfinished versions of it.

This effort has led to accelerated research in theories, principles, and computational techniques for surface quality assessment in image processing. The results indicated that the proposed algorithm can effectively assess the quality of any given surface from a wide range of variations in finish. Furthermore, the algorithm can differentiate between a regular surface image corrupted with noise, blur, and other clutter, versus one corrupted with artificial anomalies such as extra lighting or edges. This further validates the functionality and accuracy of the proposed algorithm. Additionally, due to the nature of the components used in this algorithm [11-13], the proposed algorithm is faster, more efficient, and more robust—when compared to existing algorithms in the field—and can be implemented in hardware for real-time applications. Object surface image extraction, recognition, and processing are of great interest to many industrial and manufacturing fields such as surface detection, smoothness, finish, and classification.

Some of the limitations of this study have to do with the constraints imposed by industrial environments in obtaining real-time images of objects whose surface is undergoing processing. In many manufacturing or industrial applications, due to the roughness of the processing cells, gathering data or images from the surface of an object may not be feasible in a straightforward manner and may require additional computational algorithms.

Acknowledgements

The authors would like to acknowledge the Commonwealth Center for Advanced Manufacturing (CCAM), as well as NASA CIPAIR, NSTI, and fellowship grants for their financial support of this research.

References

[1] Maxwell, J. D., Qu, Y., & Howell, J. R. (2007). Full Field Temperature Measurement of Specular Wafers During Rapid Thermal Processing. *IEEE Transactions on Semiconductor Manufacturing,*20(2, 137-142.

[2] Huang, K-C., Chang, C-L., & Wu, W-H. (2011). Novel Image Polarization Method for Measurement of Lens Decentratio. *IEEE Transactions on Instrumentation and Measurement,*60(5), 1845-1853.

[3] Cheng, Y., & Jafari, M. A. (2008). Vision-Based Online Process Control in Manufacturing Applica-

tion. *IEEE Transactions on Automation Science and Engineering,*5(1), 140-153.

[4] Tsai, D-M., & Luo, J-Y. (2011). Mean Shift-Based Defect Detection in Multicrystalline Solar Wafer Surface. *IEEE Transactions on Industrial Informatics,*7(1), 125-135.

[5] Bernardini, F., Martin, I. M., & Rushmeier, H. (2001). High-quality texture reconstruction from multiple scan. *IEEE Transactions on Visualization and Computer Graphics,*7(4), 318-332.

[6] Pluim, J. P. W., Maintz, J. B. A., & Viergever, M. A. (2003). Mutual-information-based registration of medical images: a surve. *IEEE Transactions on Medical Imaging,*22(8), 986-1004.

[7] Reed, S., Ruiz, I. T., Capus, C., & Petillot, Y. (2006). The fusion of large scale classified side-scan sonar image mosaic. *IEEE Transactions on Image Processing,*15(7), 2049-2060.

[8] Sheikh, H. R., & Bovik, A. C. (2006). Image information and visual qualit. *IEEE Transactions on Image Processing,*15(2), 430-444.

[9] Wang, Z., & Bovik, A. C. (2002). A universal image quality inde. *IEEE Signal Processing Letters,*9(3), 81-84.

[10] Samadani, R., Mauer, T. A., Berfanger, D. M., & Clark, J. H. (2010). Image Thumbnails That Represent Blur and Nois. *IEEE Transactions on Image Processing,*19(2), 363-373.

[11] Mignotte, M. (2007). A Post-Processing Deconvolution Step for Wavelet-Based Image Denoising Method. *IEEE Signal Processing Letters,*14(9), 621-624.

[12] Chappelier, V., & Guillemot, C. (2006). Oriented Wavelet Transform for Image Compression and Denoisin. *IEEE Transactions on Image Processing,*15(10), 2892-2903.

[13] Balster, E. J., Zheng, Y. F., & Ewing, R. L. (2005). Feature-based wavelet shrinkage algorithm for image denoisin. *IEEE Transactions on Image Processing,*14(12), 2024-2039.

[14] Sheybani, E. (2011). Enhancement of Data in Integrated Communications, Navigation, and Surveillance Systems. *Proceedings of NASA/IEEE/AIAA ICNS 2011*, Washington, DC.

[15] Pramod, N. C., & Anand, G. V. (2004). Nonlinear Wavelet Denoising for DOA Estimation by MUSIC. *2004 International Conference on Signal Processing & Communications (SPCOM),* Bangalore, India, (pp. 388-392).

[16] Davies, E. (1990). *Machine Vision: Theory, Algorithms and Practicalities.* Academic Press.

[17] Gonzalez, R., & Woods, R. (1992). *Digital Image Processing.* Addison-Wesley Publishing Company.

[18] Haralick, R., & Shapiro, L. (1992). *Computer and Robot Vision.* Addison-Wesley Publishing Company.

[19] Jin, F., Fieguth, P., Winger, L., & Jernigan, E. (2003). Adaptive Wiener Filtering of Noisy Images and Image Sequesnces. *Proceedings of IEEE ICIP 2003*, Barcelona, Spain.

[20] LaserSoft Imaging, (2011). *SilverFast Unsharp Masking*, Manual: SilverSoft USM, Retrieved November 10, 2011, from http://www.silverfast.com/highlights.

[21] Ziou, D., & Tabbone, S. (1998). Edge detection techniques: An overview. *International Journal of Pattern Recognition and Image Analysis*, 8(4), 537-559.

[22] Canny, J. (1986). A computational approach to edge detection. *IEEE Trans. Pattern Analysis and Machine Intelligence*, 8, 679-714.

[23] Signal-to-Noise Ratio. (2011). In *Wikipedia*. Retrieved November 10, 2011, from http://en.wikipedia.org.

[24] Stensby, J. (2011). Notes on Matrix Norms. In *Wikipedia*. Retrieved November 10, 2011, from http://www.ece.uah.edu

Biographies

EHSAN SHEYBANI has earned a BSEE, MSEE, and Ph.D EE from University of Florida, Florida State University, and University of South Florida, respectively. He is currently an Associate Professor of Computer Engineering at Virginia State University, with a research interest in Communications and Signal Processing. Dr. Sheybani may be reached at esheybani@vsu.edu

SINGLI GARCIA-OTERO received her M.S. and Ph.D. degrees in the electrical and computer engineering from the University of Missouri- Columbia in 1985 and 1992, respectively. Currently, she is a professor of computer engineering program at the Virginia State University. Dr. Garcia may be reached at sgarcia-otero@vsu.edu

FEDRA ADNANI received her M.S. and Ph.D. degrees in the Biomedical Engineering from Virginia Commonwealth University in 2003 and 2006, respectively. Currently, she is assistant professor of computer engineering program at Virginia State University. Dr. Adnani can be reached at fadnani@vsu.edu

GITI JAVIDI holds BS in Computer Science from University of Central Oklahoma, MS in Computer Science and Ph.D. in IT with an emphasis on Computer Science, both from the University of South Florida. She currently serves as an Associate professor of Computer Science at Virginia State University, where her main research interest is information visualization, multimodal human computer interac-

COORDINATE MEASUREMENT TECHNOLOGY: A COMPARISON OF SCANNING VERSUS TOUCH TRIGGER PROBE DATA CAPTURE

Troy E. Ollison, Jeffrey M. Ulmer, Richard McElroy; University of Central Missouri

Abstract

Manufacturers in the United States utilize coordinate measurement machines to ensure part compliance with specifications. While component material may affect actual results, this study attempted to determine if there was a difference between 3D-printed rapid-prototyped parts using different probes and part contact methodologies. Through the use of a coordinate measurement machine and ZCast® parts for measurement, it was determined statistically that there is a difference in cylindricity accuracy between scanning and touch trigger probe technology.

Introduction

Coordinate measuring machines (CMMs) are widely used in industry to precisely measure parts for inspection or quality control. This study utilized a CMM to measure cylindricity and assess accuracy results between scanning and touch trigger probe technologies on rapid-prototyped (RP) parts that were 3D printed using ZCast® build material and a ZCorp 310 printer. Since no prior studies were found that compared scanning and touch trigger probes, this study sought to evaluate these measurement devices and their potential measurement variances to aid both academic and industrial metrology practitioners.

Review of Coordinate Measuring Machines (CMM)

A coordinate measuring machine (CMM) is used to accurately record part geometry data through the use of a contact probe and a mechanism which can position the probe relative to surfaces and features of a work part [1]. A direct computer-controlled coordinate measuring machine (DCC/CMM) is a programmable, computer-controlled coordinate measuring machine. They are different from manual CMMs because DCC units are computer numerically controlled (CNC) machines with precise motors that can accurately control the movements of the CMM [2]. CMMs are widely used in industry today. They are versatile enough to be used for inspection and statistical process control for virtually any geometric shape [3], [4]. Due to the CMM's versatility, speed, and high accuracy, it is considered a suitable measurement device for RP parts [5]. The DCC/CMM can carry out a variety of automatic measurements to determine dimensional and shape errors. This automatic feature minimizes inconsistencies that would be incurred with manual measurements using a non-DCC CMM [5], [6].

Coordinate Measuring Machine Errors and Probe Types

Coordinate measurement machine errors generally occur through two sources: machine structure errors and probe errors. The machine structure errors include geometric errors, dynamic errors, and thermal errors. Probe errors include mechanical lobbing error and delays in the touch detection circuitry [7], [8]. All CMM probes, including optical probes, induce a certain amount of systematic error [9], [10]. Probe pre-travel or lobbing error is the distance between the point at which the probe touches the workpiece and the point at which the trigger is registered [8]. Cosine error occurs when there is a lack of squareness between the part being measured and the contact surface of the CMM probe [11]. Other factors such as temperature and vibration can have a large effect on measurement accuracy. Thermal errors can originate from a wide variety of sources which include: room temperature, lights, and pneumatics [9]. Most manufacturers of CMMs suggest 68ºF as the best precision measuring temperature. Also, temperature variation should be kept to less than 0.2ºF per hour and no more than 1ºF per eight hours [12]. The temperature of the part is just as important as CMM environment temperature. Controlling part temperature can be accomplished through acclimating the part for 15-30 minutes in the CMM's environment [13].

One of the disadvantages of using many CMMs is that they acquire point-by-point data (discrete measurements) which then need to be analyzed so that a substitute geometry can be developed for the part [9], [14]. There are some inherent problems with evaluating geometric errors with discrete measurement points. These problems include: proper definition of geometric errors, proper sample size to evaluate the error, method used to evaluate geometric error, and method used to interpret a given geometric error specification [14]. Most CMMs utilize the least-squares method to calculate these substitute features. The least-squares algorithm is used to fit an ideal form to coordinate data by minimizing the sum of the squared deviations. [3], [4]. However, the point-by-point sampling procedure performed by most CMMs will not determine all of the form deviations of the part, but rather they simply sample the fixed data points. Therefore, the sampling strategy using a CMM (the selection of the number and position of points) can influence the test results [4], [15].

Common probe types include kinematic touch probe (incorporates an internal strain gauge to indicate measurement), optical digitizer probe (utilizes high-quality optics and light to discriminate measurements), analog probe (varying signal style), and force probe (small springs with contact switches). The most popular is the kinematic touch probe which is designed to sense the mechanical contact of the part by closing electrical switches—in tandem with internal strain gages—when force is applied to the probe [7], [8], [10], [16].

Active scanning probes are a relatively new style of probe which is becoming increasingly popular. Active scanning probes have many advantages over conventional touch trigger probes such as increased data acquisition, decreased measurement time, and the elimination of many errors common in conventional probes. There are some major differences in how active scanning probes work compared to touch trigger probes. The main difference with active scanning probes is the use of electrical springs, small linear drives, which generate their probing force electronically instead of mechanically like touch trigger probes. This allows for constant and consistent contact pressure as well as a larger measurement range. This also allows contact pressure to be adjusted, depending on the measurement application. Active scanning probes obtain measurement samples by measuring the deflection of the probe electronically, which virtually eliminates many conventional probe errors. In addition to better accuracy, active scanning probes can collect thousands of sample points in a matter of seconds, which might take conventional touch trigger probes hours [17], [18].

Measuring Cylindricity with a Coordinate Measuring Machine

Cylindricity is defined as a condition of a surface of revolution in which all points of the surface are equidistant from a common axis [19]. When measuring cylindricity, the entire surface is one tolerance zone where the surface must not only be round but also be straight [20]. The three most common ways to measure cylindricity is through the use of air, mechanical, or optical gaging [21].

Throughout the literature, sampling issues are heavily represented. Sampling issues that can affect validity of results deal mainly with the location and number of the sampling points. Careful planning is essential when writing an inspection program for a computer-controlled CMM. Considerations such as number of sample points, location of sample points, path planning, and probe qualification are very important. The higher the number of sampling points taken, the more accurate the results. However, this increase in sampling is directly related to measurement time and data processing costs [6], [14], [22]. CMM inspection techniques may affect the geometric shape of the sample and ultimately part measurements. This is especially true in the presence of unknown part forms and unknown measuring machine errors. Therefore, a much higher number of data points must be taken, especially in the presence of unknown form error [9]. The optimum number of sampling points for cylindricity measurement is still somewhat of a question. However, according to statistical rules, if too few points are taken, the measurement uncertainty will increase. By the same token, if too many points are measured, the cost of measurement will increase [23].

The conventional practice of measuring cylindricity with a CMM is to measure a dense set of points evenly spaced around the circumference at two or three axial locations [24]. The review of literature conveyed a wide range of ideas pertaining to the number of sample points and axial locations that should be measured for determining cylindricity. In industry, it is common to keep the sample size as small as possible such as 4-8 points for cylinder features, whereas most CMMs use six measurement points to determine diameter and cylindricity [3]. However, when using this number, there is a risk of accepting an out-of-specification part [23]. According to the Weckenmann et al. [15], for thorough analysis of the maximum inscribed circle and least-squares circle, 10-20 points are required for accurate measurement data. This correlates with the Jiang & Chiu study [23] which suggests that when the number of measurement points on a cylinder is greater than eight, the confidence interval of 95% is achieved. Also, surface roughness has a great effect on the number of points required for an accurate measurement of form error [9].

The number of axial planes that should be measured on a cylinder is another issue which is very important for the measurement of cylindricity. Again, the literature conveyed a wide range of ideas in this area. For the most part, studies pertaining to the measurement of cylindricity use between 2 -4 axial planes. Jiang & Chiu [23] used three axial measurement planes while Summerhays [24] used four axial measurement planes.

Rapid Prototyping Fundamentals

In the late 1980s, new and faster ways of producing a prototype were developed. These new technologies are considered rapid prototyping (RP). RP is a term used to denote a class of additive processes by which complex, three-dimensional (3-D) objects are created from a computer-generated database [25]. RP techniques use a layer-by-layer process of building a part. The parts that can be produced range from artificial limbs, hearing aids, and filtering devices to cell phone covers and almost anything which can be created in a three-dimensional digitized format. The three-dimensional printing (3DP) process implemented by ZCorp uses ink-jet technology to produce parts for direct manufacturing as well as for rapid prototyping. The process begins by spreading a layer of powder build material at the top of the fabrication chamber to a precise thickness. The jetting head then deposits a liquid adhesive in a two-dimensional pattern, specified by the program, onto the layer of powder. This process is repeated layer after layer until a three-dimensional part is developed.

One of the more recent developments of ZCorp is the material called ZCast® which is engineered for the purpose of producing mold cavities and cores to be used in the casting of many non-ferrous metals. By using ZCast®, companies have the ability to make low-production runs or functional prototypes of castings and cores in a very short period of time. Traditionally, developing a mold or core could take weeks, depending on its complexity. Also, many geometric shapes and attributes, which are not possible with traditional molding techniques, can be accomplished easily with 3DP. However, the accuracy of printed molds and cores can be a limitation. There is a need to develop functional prototypes that are cost effective for the designer and are representative of production castings [26].

Problem Statement

Using a coordinate measurement machine and ZCast® parts for measurement, is there a difference in cylindricity accuracy between scanning and touch trigger probe technology for measurement of rapid-prototyped components?

Hypothesis Statements

Null Hypothesis: There will be no statistically significant difference in the cylindricity accuracy between scanning and touch trigger probe measurements of 3D-printed parts about the X axis at the 0.05 level of significance.

Alternative Hypothesis: There will be a statistically significant difference in the cylindricity accuracy between scanning and touch trigger probe measurements of 3D-printed parts about the X axis at the 0.05 level of significance.

Assumptions of the Study

To obtain sufficient measurement variation, calibration standards were not used in this study. Manufactured rapid-prototyped parts appeared to be the best option to achieve the variance needed. For the purpose of this study the following assumptions were applied in an attempt to improve the feasibility of this study.

1. The build and measurement process did not affect the specimen cylindricity.
2. Cylindricity was not related to the mix consistency of virgin and recycled powder.
3. Build location within the build chamber did not have an effect on measurements.
4. Powder consistency was not affected by age or chemical separation.
5. Variations in material shrinkage did not exist.
6. Variations in layer thickness did not exist or have an effect on the specimens.
7. After a one-hour cure time, variations in natural cure time did not exist between batches.
8. Variations in oven cure time and temperature did not exist between batches.
9. CMM geographical locations far from any major highways or industrial facilities did not produce vibrations that might affect the accuracy.
10. Preparation of the 310 Printer and the ZD4i depowdering station was sufficient.
11. The "purge" command did not adversely wear the printhead.
12. Each specimen was located in the same position in the measurement envelope of the CMM during measurement by a fixture to reduce volumetric error.
13. The CMM used to measure cylindricity was in good working order, certified, and calibrated before measurement began.
14. Two individual measurement programs—one at a diameter of 1" and another at a diameter of 0.75"—were used for all measurement cycles.
15. Observations were paired and dependent.
16. Pairs were normally distributed with approximately the same variance.

Limitations of the Study

For the purpose of this study, the following limitations apply.

1. The 310 Printer had been maintained and had not been used excessively over the past four years.
2. The CMM used was capable of measuring to an accuracy of at least 0.00002” but other minute errors may have been present below this measurement threshold.
3. Each specimen in each batch was a copy of one original STL file created by SolidWorks version 2006. However, minute tessellation errors existed in all STL files.
4. The CMM utilized Zeiss Calypso® software and implemented a best-fit calculation in order to determine the attributes of a circle. This calculated geometry may not have been the “true” geometry measurement.
5. All measurements were obtained in a semi-controlled temperature and humidity environment.
6. A calibration of the ZCorp 310 printer used in this study was not performed.
7. The surface finish of the 3DP parts may have had variations of surface finish depending upon the part’s build orientation.
8. The temperature and humidity were not precisely controlled during the build of the specimens.
9. The 8mm ball could come into contact with larger crevasses and create erroneous data.
10. Fifteen measurement points at three axial levels were used.
11. Both virgin and recycled build powder was sifted through a screen with openings of approximately 1mm to separate any large granules and prevent them from entering the build chamber of the 310 Printer. However, grains small enough to pass through the screen, yet large enough to affect eventual measurement, could have been introduced into the specimen build chamber.
12. Due to the cost of the ZCast® build material and zb56 binder, only a limited number of samples were made. Only eleven batches of twelve specimens (132 parts) were produced with existing materials.

Experimental Design and Data Collection

Specimens were designed in Solid Works, built in a ZCorp 310 printer, cured in a convection oven at approximately 375ºF for four hours, and placed in sealed containers prior to measurement. Laboratory measurement temperature varied from 71.44ºF to 80.78ºF. Sealed-container specimen humidity varied from 44 to 75% relative humidity.

All specimens were allowed to stabilize at the DCC/CMM room temperature and humidity for at least 1 hour before measurement occurred. Prior to measurement, all specimens were cleaned by low-pressure compressed air to remove any loose particles that might affect measurement accuracy. Eleven total batches, with each batch consisting of 12 total specimens (132 total specimens) at 3 different build orientations and 2 different diameters, were measured. A certified Zeiss Contura® G2 DCC/CMM with a VAST XXT passive scanning head, 125mm carbon-fiber shaft probe, and 8mm synthetic ruby was used to collect measurement data. A steel fixture held the specimens vertically as well as indexed the specimens in the same location relative to X-axis rotation while the measurement occurred. Figure 1 provides the specimen prints for the 1"- and 0.75"-diameter specimens used in the study. Figure 2 depicts the measurement planes. Figure 3 illustrates how specimens were secured for measurement.

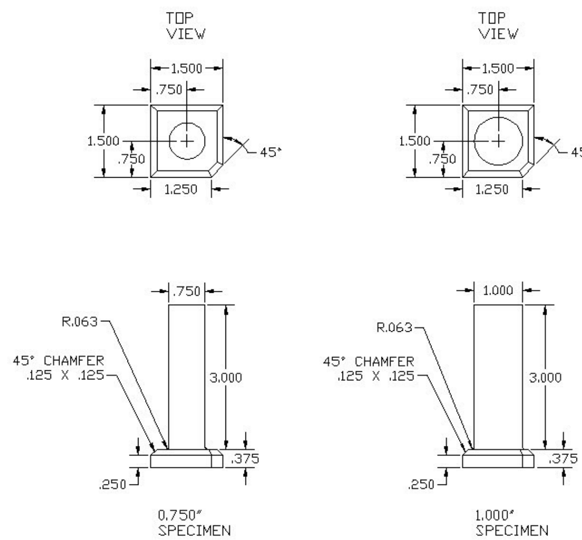


Figure 1. Specimen Prints

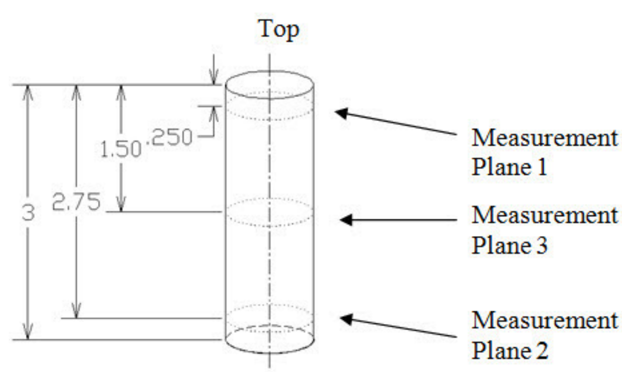


Figure 2. Axial Measurement Planes

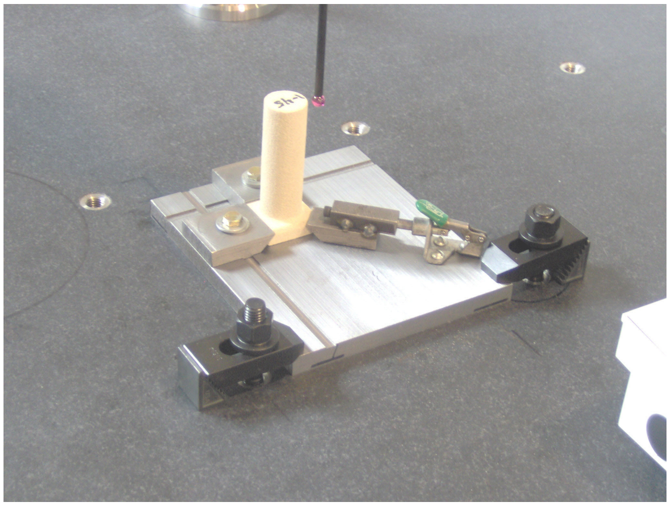


Figure 3. Specimen Measurement Fixture

One DCC/CMM program was written for each specimen diameter measured (one at a diameter of 1” and another at a diameter of 0.75”). Temperature and humidity readings were recorded during the testing of each specimen. After each specimen was measured, the fixture was cleaned using compressed air to remove any particles that might affect measurement results. Each specimen in each batch was tested. Three vertical axial measurement planes acquired measurements with 15 points (Touch Trigger), and continuous scanning, around the cylinder specimen. Figure 4 is provided as a reference for the measurement equipment.

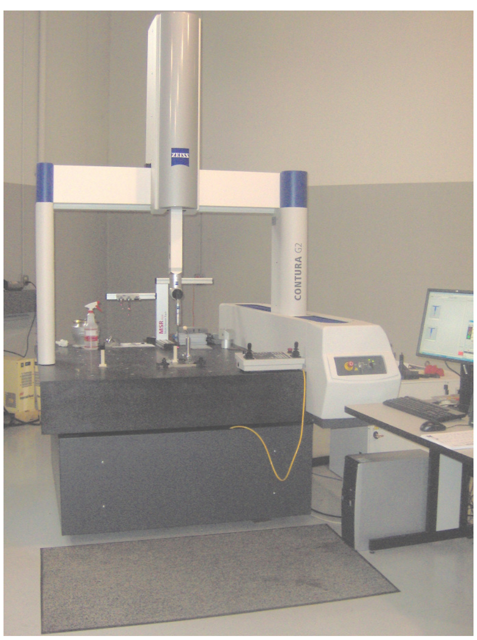


Figure 4. Zeiss Contura® G2 DCC/CMM

Variables and Data Recording Information

The dependent variable in this study was the cylindricity of the 3D-printed part as measured by a probe using either Scanning or Touch Trigger. Units for the measurements were in inches, carried out to six places (0.000000).

Specimen Creation and Handling Details

The cylinder models, which were used in this experiment, were initially generated with SolidWorks version 2006. The design of the specimens incorporated a base design which allowed all specimens to be fixtured consistently and in reference with each specimen’s X axis of rotation when measurement occurred. From this 3D model, an STL file was generated using default values. The STL files of the 1” and 0.750” specimens were then imported into the ZPrint® 6.2 software. Once the cylinder files were loaded into the ZPrint® software, they were copied and rotated. The cylinders being printed were located in different locations in the build chamber in order to account for any variation in build accuracy due to a cylinder’s location in the build chamber. The specimens were only rotated at 0º, 45º and 90º about the X axis of the 310 Printer. The single axis and limited rotations were chosen largely because of the extremely high cost of the ZCast® build material and the extended period of time it would take to build and test all axes at an increased number of rotation angles. A 3” (overall length) specimen was utilized with dimensions of 0.25”, 1.50”, and 2.75” from the top of the specimen while it was held in the measurement fixturing.

Statistical Analysis and Results

In this study, a Dependent Paired T-Test using SPSS 19 was chosen because of the continuous variable output values of cylindricity. One hundred and thirty two values were obtained for cylindricity through both the scanning and touch trigger probe acquisition modes. The variable for scanning was termed “CYLSCAN” and the variable for touch trigger probe was termed “CYLTTP.” To meet the normality assumption of a Paired T-Test, a Normal Q-Q Plot was created for both CYLSCAN and CYLTTP (see Figure 5). While the Anderson-Darling statistics did not support normality (CYLSCAN: $p = <0.005$, $AD = 2.986$; CYLTTP: $p = <0.005$, $AD = 1.893$), approximate normality for both variables was obtained, as illustrated in Figure 5. Equal variance was present between CYLSCAN and CYLTTP.

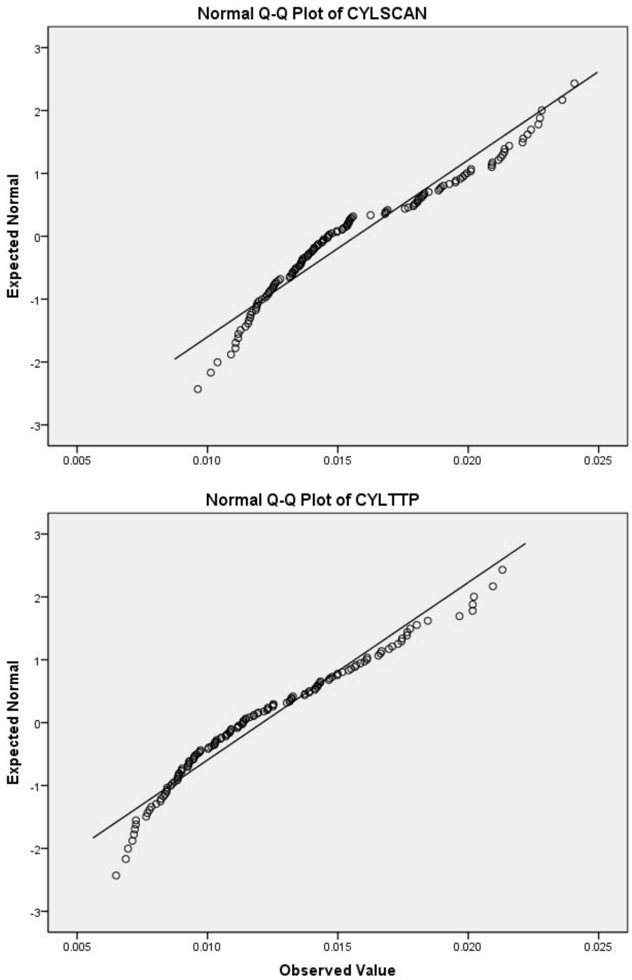


Figure 5. Q-Q Plots of CYLSCAN and CYLTTP

Hypothesis Results and Conclusion

On average, Cylindricity Scanning (CYLSCAN: M = 0.01568, SD = 0.00355) has experienced a significant difference compared with Cylindricity Touch Trigger Probe (CYLTTP: M = 0.01210, SD = 0.00354) with Dependent Paired T-Test results of M = 0.00358, SD = 0.00138, R^2 = .924, $t(131) = 29.694$, p = .000 (two-tailed). Therefore, the null hypothesis was rejected indicating there was a statistically significant difference in the cylindricity accuracy between scanning and touch trigger probe measurements of 3D-printed parts about the X axis at the 0.05 level of significance. A Boxplot between CYLSCAN and CYLTTP is provided in Figure 6.

Using a coordinate measurement machine and ZCast® parts for measurement, it was determined statistically that there was a difference in cylindricity accuracy between scanning and touch trigger probe technology. Both measurement technologies have found a place in industry and academia. It is significant that parts measured in one manner, using one technology, can be significantly different from that of a similar measurement technology using the same machine.

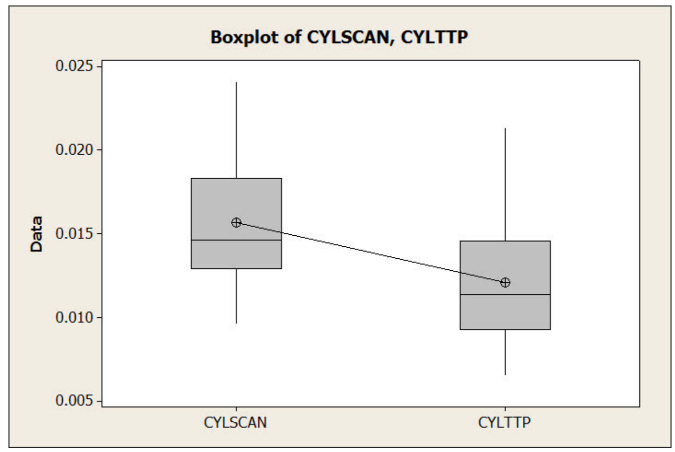


Figure 6. Boxplots of CYLSCAN and CYLTTP

The statistical significance of this study could be attributed to the inherent errors associated with touch trigger probes through mechanical action and/or deformation of the rapid-prototyped parts, whereas the scanning probe possesses miniaturized linear actuators which provide increased data acquisition (a higher number of data points), decreased measurement time, and the elimination of many errors common in conventional probes. One potential limitation affecting study results, and possible application to other such studies, could be variations in temperature and humidity. While extensive measures were taken to control these variables, ambient temperature and humidity may still have had an effect on the measurement results.

Rapid-prototyped parts using the ZCast® material may potentially change the results of this test if components were fabricated using machined steel, forged metal, or possibly another type of powdered rapid-prototyping material. While this may not be a substantial limitation, other materials could have changed the results of the study. The interesting part of this study was that identical components were measured using the same method, using two types of measurement technologies, and yet yielded a statistically significant difference.

Recommendations for Further Research

The study should be replicated using a different material with parts that have intentional variance in cylindricity to build a body of knowledge of how different materials are affected by these measurement techniques. The measurements taken by both the scanning and touch trigger probe could also be expanded to include other geometric aspects such as roundness, flatness, and straightness. Results of research such as this will greatly expand the knowledge base pertaining to this branch of metrology. Additional studies could be conducted on the optimal level of automation comparing scanning and touch trigger probe component measurement. Basically, to determine which method is best optimized for minimal waste in time and effort.

Lean Automation requires the efficient use of all available resources [27]. The Six Sigma methodology could also be investigated in terms of DMAIC (Define, Measure, Analyze, Improve, Control) in an applied metrology environment using both scanning and touch trigger probe DCC/CMM technology. The basic application of the Six Sigma methodology is well illustrated in an article by Farahmand et al. [28]. In tandem with this study, analysis of DCC/CMM reliability should be investigated to validate DCC/CMM measurement results [29].

References

[1] Groover, M. (2007). *Fundamentals of Modern Manufacturing*. (3rd ed.). New Jersey: John Wiley & Sons, Inc.

[2] Berisso, K. (2003). A comparison of measurement variations for selected probe head configurations for coordinate measuring machines. *Dissertation Abstracts International*, (64)8, 3989. (UMI No. 3102997)

[3] Dowling, M. M., Griffin, P. M., Tsui, K. L., & Zhou, C. (1997). Statistical issues in geometric feature inspection using coordinate measuring machines. *Technometrics,* 39, 3-17.

[4] Weckenmann, A., Eitzert, H., Garmer, M., & Weber, H. (1995). Functionality-Oriented Evaluation and Sampling Strategy in Coordinate Metrology. *Precision Engineering*, 17, 244-252.

[5] Mahesh, M., Wong, Y. H., Fuh, J. Y. H., & Loh, H. T. (2004). Benchmarking for comparative evaluation of RP systems and processes. *Rapid Prototyping Journal*, 10(2), 123.

[6] Jackman, J., & Park, D. (1998). Probe Orientation for Coordinate Measuring Machine System Using Design Models. *Robotics and Computer-Integrated Manufacturing*, 14, 229-236.

[7] Lu, E. (1992). Improvement of CMM throughput using path planning, dynamic lobing error compensation, and structural vibration control. *Dissertation Abstracts International,* 53, 5, 2506. (UMI No. 9226959)

[8] Shen, Y., & Springer, M. E. (1998). A robust pretravel model for touch trigger probes in coordinate metrology. *Journal of Manufacturing Science and Engineering,* 120(3), 532-539.

[9] Hocken, R. (1993). Sampling Issues In Coordinate Metrology. *Manufacturing Review*, 6(4), 282-294.

[10] Shen, Y., & Zhang, X. (1999). Pretravel Compensation for Horizontally Oriented Touch Trigger Probes with Straight Styli. *Journal of Manufacturing Systems,* 18(3), 175-185.

[11] Marsh, B. (1996). An investigation of diameter measurement repeatability using a coordinate measuring machine and a multi-baseline repeatability assessment methodology. *Dissertation Abstracts International,* 57(8), 5251. (UMI No. 9701107)

[12] Gazdag, W. (December, 1992). High-Accuracy CMMs. *Quality,* 20-26.

[13] Adams, L. (2000). CMMs don't like it hot. *Quality,* 39(8), 36-39.

[14] Chang, S. H. (1991). *Statistical Evaluation and Analysis of Form and Profile Errors Based on Discrete Measurement Data.* Published doctorial dissertation, The University of Michigan, Ann Arbor.

[15] Weckenmann, A., Heinrichowski, M., & Mordhorst, H. J. (1991). Design of Gauges and Multipoint Measuring Systems Using Coordinate-Measuring-Machine Data and Computer Simulation. *Precision Engineering*, 13(3), 244-252.

[16] Innovations in Touch-Trigger Probe Sensor Technology. (2003). White Paper. Retrieved April 1, 2004, from http://www.renishaw.com

[17] Knebel, R. (1999). Better Math Makes Scanning Stronger. *Modern Machine Shop Online,* Retrieved from http://www.mmsonline.com/articles/109905.html

[18] Imkamp, D., & Schepperle, K. (2006). The Application Determines the Sensor: VAST Scanning Probe Systems. *Innovation SPECIAL Metrology*, 8, 30-33.

[19] Gooldy, G. (1995). *Geometric Dimensioning and Tolerancing*. Prentice-Hall, Inc. Englewood Cliffs, New Jersey.

[20] Owen, J. (1992), Roundness Roundup. *Manufacturing Engineering*, 108(4), 72-78.

[21] Knight, P. (2000). Measurement of Cylindrical Parts. *Dissertation Abstracts International,* 61, 8, 4360. (UMI No. 9982444)

[22] Choi, W., Kurfess, T. R., & Cagan, J. (1998), Sampling uncertainty in coordinate measurement data analysis. *Precision Engineering,* 22(3), 153-163.

[23] Jiang, B., & Chiu, S. (2002). Form Tolerance-Based Measurement Points Determination With CMM. *Journal of Intelligent Manufacturing,* 13, 101-108.
[24] Summerhays, K. D. (2002). Optimizing Discrete Point Sample Patterns and Measurement Data Analysis on Internal Cylindrical Surfaces With Systematic Form Deviations. *Precision Engineering,* 26, 105-121.
[25] Dimitrov, D., & de Beer, N. (2002). *3-D Printing-Process Capabilities and Applications.* Issue 212 of Technical paper // SME, Society of Manufacturing Engineer.
[26] Metalcasting Industry Technology Roadmap: Pathway for 2002 and Beyond. *Cast Metals Coalition*, October 2003. Retrieved from www.eere.energy.gov/industry/metalcasting/pdfs/67443_new.pdf
[27] Jackson, M., Hedelind, M, Hellstrom, E., Granlund, A., & Friedler, N. (2011, Fall/Winter). Lean Automation: Requirements and Solutions for Efficient Use of Robot Automation in the Swedish Manufacturing Industry. *International Journal of Engineering Research & Innovation*, 3(2), 36-43.
[28] Farahmand, K., Marquez-Grajales, J. V., & Hamidi, M. (2010, Fall/Winter). Application of Six Sigma to Gear Box Manufacturing. *International Journal of Modern Engineering,* 11(1), 12-19.
[29] Shah, B., & Redkar, S. (2010, Fall/Winter). Design and Development of a Durability Testing Machine. *Technology Interface International Journal,* 11(1), 14-20.

Biographies

TROY E. OLLISON, Ph.D., is an Associate Professor of Engineering Technology at the University of Central Missouri teaching both graduate and undergraduate courses. His research interests include: rapid prototyping, learning methodologies, materials and manufacturing processes. In addition, Dr. Ollison is a member of the Society of Manufacturing Engineers and the Association of Technology Management and Applied Engineering. Dr. Ollison may be reached at ollison@ucmo.edu

JEFFREY M. ULMER, Ph.D., is an Associate Professor of Technology, Engineering Technology, and Industrial Management at the University of Central Missouri in Warrensburg, Missouri, teaching both undergraduate and graduate students. Ulmer is an American Society for Quality Certified Manager of Quality & Organizational Excellence and a Certified Six Sigma Black Belt. He is also a trained Lean Six Sigma Black Belt (from the Regal-Beloit Corporation) and has worked for 25 years in industry in the areas of product engineering, quality assurance / control, and production management. Dr. Ulmer may be reached at julmer@ucmo.edu

RICHARD McELROY, Ed.D, is an Assistant Professor of Elementary and Early Childhood Education at the University of Central Missouri teaching both graduate and undergraduate students. He is a published author of numerous peer reviewed articles, two children's books, and a novel. Dr. McElroy may be reached at mcelroy@ucmo.edu

PROPOSED INSTRUCTIONAL DESIGN STRATEGIES FOR MATCHING OPERATOR LEARNING PREFERENCES WITH INSTRUCTIONAL FORMATS: A PRELIMINARY STUDY

Yi-hsiang Chang, University of North Dakota; Thomas R. Klippenstein, Andros Engineering

Abstract

Work instructions for manual assembly operations are basic to the activities of many industries. They are essential for completing a set of tasks in a correct sequence, making an assembly "complete." These instructions may be used to repair equipment, assemble components, or operate a machine. In today's manufacturing environment, one of the keys to success is rapid change to meet customer demands through mass customization. Workers must be flexible by learning a multitude of tasks, oftentimes through comprehending given work instructions, at a fast rate, including assembly of multiple types of parts during their shift or changing a machine's configuration to produce different parts. This paper reports a preliminary study to be used as a pilot or trial run on the test materials for a future, more comprehensive experiment. Other than just finding errors, missing information, or unanticipated consequences, a mixed method approach was utilized to investigate the interaction between the operator and given work instructions through both qualitative and quantitative data.

Introduction

To maintain their competitive advantage, manufacturers are moving toward a market where customization is key [1] and moving away from the mass production model. With this move, the need for rapid adaptability becomes crucial. Human labor is ideal for this rapid adaptability and, quite often, rapidly configurable automated processes can be impossible and/or not economically feasible. The close customer-manufacturer relationship in pre-manufacturing and post-sale activities, such as customer co-design process of products and services [2], increases the intricacy of business process planning. Along with product design and configuration [3], lifecycle activities for planning, manufacturing, and sustaining products and services need to be customized. Efficient data management is no longer the only key factor for successful mass customization; effective knowledge management throughout the product lifecycle [4] is now a key factor as well.

Manual assembly operation, an essential component in the mass customization environment, contains an inherent problem: "Expert" assemblers or technicians require a long learning curve and training, which can be expensive, particularly for processes that require problem-solving skills [5], [6]. It can also take months or years for a novice to develop the knowledge for high-complexity assembling processes. Moreover, even expert-level assemblers often must refer to instructions for infrequently performed or highly-complex procedures. In mass customization, field technicians and assemblers are challenged by frequently changing processes. To train assemblers each time assembly processes are changed is impractical and costly, especially with the fast pace of market competition [7]. One efficient way to solve this problem is having human manual assemblers cross-trained on different tasks to develop a deeper understanding of the whole process. Another solution is designing-for-assembly to reduce the skill level needed and cost of assembly. This concept has gained acceptance in mass production but it trades off flexibility and modularity, which may not be suitable for mass customization [8].

The quality of assembly operations relies on the experience of the assembler and the proper execution of the well-defined work instructions. The current practice for designing work instructions is not a collaborative effort between the job designer and the job executor and as a result no real-time feedback is available. General assumptions are often made about the needs of the job executor. Some research has been done to eliminate possible communication errors due to individual differences. Japanese researchers examined the use of language in the design of assembly instructions to accommodate a user's preference [9]. A study done by Matsumoto et al. [10] in Japan investigated the performance difference of novice workers using two different types of operating manuals of a facsimile machine: understanding-oriented and operation-oriented. The group of novice workers obtained a more favorable learning result using the understanding-oriented, or operator-centered, manual. Stanford University researchers contend that operator-centered instruction works better in practice through a study using the assembly instructions for a commercial television stand based on cognitive design principles [11]. The results indicated that cognitive design principles used in the assembly instructions reduce assembly time by an average of 35% and errors by 50%. Both studies of novice workers' behavior resulted in specific guidelines for creating effective help materials.

Incorporating individual differences into the design of assembly work instructions requires special attention to the learning and cognitive styles of the operator. Learning style refers to the learner's preference of instruction methods while cognitive style refers to the learner's approach to organize and retrieve knowledge [12]. Among numerous instructional theories, teaching according to the learner's learning style has shown effectiveness in practice for improving student learning [13]. There are four major learning style measurements that have effectively been used in education, namely the Myers-Briggs Type Indicator [14], Herrmann Brain Dominance Instrument [15], Kolb's Learning Style Model [16], and the Felder-Silverman Learning Style Model [13]. These instruments share the notion that teaching strategies can be used to improve learning outcome; however, classroom teaching of students is different from typical instructions received by industry workers. The most significant difference is the delivery means of instructional materials. In a classroom setting, the teacher may design and deliver the instructions based around the students' learning preferences, and may receive feedback before and after the activity from the students. For the trainers in industry, communication is typically one-way; special intervention covering individual differences cannot be available without the expert's presence. As a result, instructional design for the asynchronous learning environment is more challenging than that used in the classroom [17], [18].

One issue that has received relatively less attention in work instruction design is how the operator interacts with the instructional materials. When the job executors first receive instructions, they usually go through the "first run" phase as a mental mapping process [19]. First run refers to a situation where the operator is given a task similar to a previous task but not exactly the same. This situation can be found in mass customization production lines, product maintenance, and on-the-job training. Research on object assembly of mechanical systems [20] suggests that there are two phases of object assembly. When operators are exposed to a new assembly task, they first attempt to comprehend the basic assembly task to construct a mental model [21], and then execute the actual assembly process according to their mental model [22]. Operators continuously gather information from two major sources during the task comprehension process—work instructions or parts ready for assembly. The information of the given task may be delivered in different forms: either in visual, textual, or auditory forms presented by the work instructions, or in visual, auditory, or tactile forms presented by the objects. The construction of the initial mental model has mainly relied on visual information from both the work instructions and the objects, the textual description from the work instruction, and auditory if available. Tactile information may be used more often for mechanical assembly tasks as confirmation of visual and textual information [23], or for the verification and modification of the mental model through trial and error [24].

Studies done at the University of California, Santa Barbara, [25] concentrated on operator perceptions of work instructions. Those studies involved a human's understanding of a mechanical device and the role diagrams play in communicating this information. A cognitive model of how people read text and inspect an accompanying diagram was developed. This model indicated that people inspect diagrams for three reasons: to form a representation of information read in the text; to reactivate information that has already been represented; and/or to encode information that is absent from the text. Using data from participants' eye fixations while they read a text and inspected an accompanying diagram, Hegarty & Just [21] found that low spatial ability participants needed to inspect diagrams more often than the text. The data also suggested that knowledge of relevant information in a diagram might be a prerequisite for encoding new information from a diagram.

To summarize, as operators in mass customization production environments must continually learn new tasks, applying the principles of instructional design to address individual differences and, thus, enhance the instruction comprehension activity in manual assembly operations, will be beneficial. Previous studies have looked at the relationship between particular instruction and learning styles, operator experience, and cognitive ability. However, the objective of these studies focused mainly on collecting quantitative data, e.g. task performing speed and accuracy; how individuals interacted and responded to specific instructional types had not been thoroughly studied. This preliminary study employed a mixed method to better understand such phenomenon during manual assembly operations, with the intention of serving as a pilot study for a future, expanded experiment. The design of the testing materials and the experiment was described in detail. The finding of this study revealed rich information that had not been presented elsewhere and which not only helped identify issues of designed treatments, but also provided insight overlooked by other researchers. It was conducted to fine-tune the testing materials for future research by carefully examining operation-instruction interaction.

Development of Instructional Materials

To capture the essence of manual assembly tasks in industry, three of the most commonly used instructional formats were selected for this study: Step-by-Step, Exploded Diagram, and Demonstration Video. These formats were quite often used in conjunction with one another but, for this study, they were separated in order to observe the interaction between learning preferences and instructional formats.

The assembling of a battery-powered screwdriver, the 6V Tiger Driver, shown in Figure 1, was used as the context. There was an external lock for the bottom battery door; the trigger was to turn the screwdriver on and off; and, the switch on the top is to control the direction of rotation. This screwdriver, while inexpensive, possessed a certain level of complexity relevant to the common operations in an industry setting. The screwdriver was first disassembled, and eleven components were selected to design an assembly activity; the assembling of the harness, springs for battery contact, and screws holding the housings were not included as they required different work skills and instructions which were not the focus of this study. Through reverse engineering, a computer model of the 11-component screwdriver was built in SolidWorks to generate illustrations required by different instructional formats.

Figure 1. The battery powered screwdriver used in this study

A ten-step Step-by-Step set of instructions was first created based on the assembly process plan derived previously. Each step included text to describe the actions needed to complete the step along with corresponding illustrations showing how the part should be assembled. The Step-by-Step instructions, oftentimes in the form of training or maintenance manuals, is the most commonly used in industry and by the do-it-yourself enthusiasts for assembling and repairing products, as well as many other complex tasks. It seems to contain the greatest amount of information and is preferred by the visual learner who favors reading and studying the subject in a text and illustration format while performing a task.

An Exploded Diagram, commonly used in conjunction with Step-by-Step instructions, was created next. Shown in Figure 2, it did not have the number indicator and name for individual parts nor a Bill of Materials, which were provided in a separate instruction sheet for all participants. This instructional format shows part orientation and placement relative to other parts in the assembly; it does not indicate a particular order of assembly but implicitly indicates the parts closer to the center of the diagram are assembled first with subsequent parts being assembled in relative order of distance from the center. In the experiment, the Exploded Diagram was in the form of a single Letter size sheet of paper showing three views: exploded parts, assembled showing internal parts, and assembled showing the outside cases of the screwdriver.

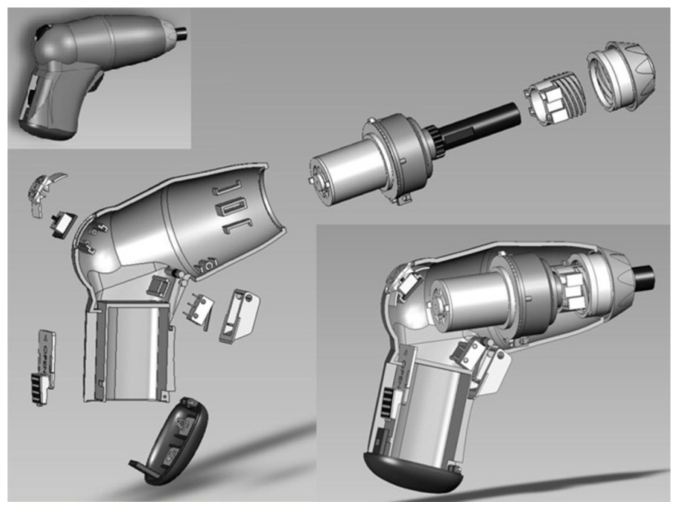


Figure 2. The Exploded Diagram used for the experiment

The Demonstration Video was developed from the Step-by-Step instructions using the animation function of SolidWorks, in the same assembly sequence to ensure that the same information was provided but in a different format. This instructional format is typical of on-the-job training and usually consists of an instructor demonstrating an assembly sequence to a learner. The learner, however, may or may not follow along with his or her own assembly what the video is demonstrating. Demonstration videos may be formal or informal, formal containing audio and onscreen notation, and may be slightly different each time it is performed. An animated set of instructions was used in this study as a surrogate for a live demonstration to make exactly the same information available to each participant. The video clip used did not have accompanying audio or onscreen notation.

There were a few alternatives, such as live physical demonstrations, a recorded video, or computer-based instruction, which could be used but were not chosen due to concern of treatment consistency, time, and facility constraints. For example, the trainer from a live physical demonstration might provide different participants additional or inconsistent information. A recorded video of a live demonstration, on the other hand, does not have the consistency issue; still, the time and cost to produce a good live demonstration video is fairly significant and was not suitable for this preliminary study. A digital form of the Step-by-Step instructions and Exploded Diagram in either PowerPoint or Adobe Acrobat File was also considered but not used because it changed the interface and interaction between the learner and instructional materials from the common printed media currently used.

Experiment

Ten undergraduate students from a four-year university on the West Coast of the United States were recruited from various Industrial Technology classes as participants. These students were of different major courses of study such as Technology, Engineering, and Business disciplines. Participants were invited knowing that they possessed certain skills and experience in manual assembly operations similar to that of those field assemblers in the "first run" situation. The experiment was conducted in a lab setting with the participants sitting at work benches during normal school hours. Noise and interruptions were minimal and lighting conditions were similar to typical industry settings. Basic information was given by the proctor for the purpose of the experiment and the progression of the experiment (Pre-test Survey, manual assembly activity, Post-test Survey). A verbal disclaimer stating their participation in this experiment was voluntary and in no way connected to their academic curricula was also delivered. The participants in return acknowledged with a verbal answer. The proctor also explained the need for their critique or feedback on the materials presented. No other information was given during the test. If a question arose about the assembly operations, the participant was asked to make a note and move on. This was done to ensure that all participants were given equal amounts of information and to expose errors in the materials.

A multiple-choice, self-assessing pre-test survey was presented to the participants prior to their actual manual assembly tasks to collect information on their level of experience in manual assembly, self-assessment of their skill level in assembly, learning preferences (reading-writing, visual, and tactile) and preferred instructional format. The information gathered was then used to make a determination on the type of instructional material provided. Specific instructional material was then given to the participants along with a bag of eleven power screwdriver parts, as shown in Figure 2; no extra parts were provided.

The participants began the assembly activity and worked until completion. The participants were timed without notification while assembling the components in order to determine if their time to completion correlated with any other data collected. The timing started when the participant began following the instructional materials provided and stopped when the participants decided the assembly was complete. A multiple-choice, self-assessing post-test survey was then used to collect participants' feedback on the difficulty of the exercise, clarity of the instruction (to help identify missing information, unclear illustrations, improper sequences, etc.), and whether the specific instructions enhanced or had no effect on their task performance. The results of the post-test survey and overall impressions were then discussed for clarification of any issue and to ensure that all suggestions were documented. After the post-experiment discussion, the assembled electric screwdrivers were disassembled and inspected for completeness and errors in assembly. The surveys, task completion times, and assembly errors were then compiled to ensure that individual participant's data was kept together. For anonymity, and to elicit honest feedback, the participants' names were not recorded, nor was any system used to identify a specific individual's survey after it was submitted.

Pre- and Post-test Survey Results

Table 1 shows the results of the pre- and post-test surveys of individual participants as well as the time used to complete the task and number of errors they made. For the pre- and post-test surveys, individual answers were personal opinions and were not measured or verified by any test instrument. In the pre-test survey, six out of ten participants felt they were "very experienced" in assembling parts, while three reported that they had "some experience", and one participant claimed "little to no experience". The reported experience level, however, did seem to match the skill level indicated by the individuals, with four out of the six "very experienced" participants claiming that they had a "high skill level", while all of the "some experience" participants indicated having "mid skill level." The only "little to no experience" participant reported a corresponding "low skill level", who could be considered as a typical example of participants in some previous research.

Table 1. Data collected from Pre-test Survey, Post-test Survey, and Test Outcome

	Pre-test Survey			Post-test Survey					Test Outcome	
Participant	Experience Level	Skill Level	Preferred Instruction	Instruction Provided	Instruction Match?	Exercise Difficulty	Instruction Easy to Follow	Effect on Performance	Time to Complete (minutes)	Number of Errors
1	Some	Mid	Step-by-step	Step-by-step	Yes	No	No	Enhanced	10:15	1
2	Some	Mid	Step-by-step	Exploded Diagram	No	No	No	Enhanced	3:20	2
3	Some	Mid	Demonstration	Step-by-step	No	Yes	Yes	No Effect	7:50	2
4	Very	Mid	Demonstration	Step-by-step	No	Yes	Yes	No Effect	11:00	3
5	Very	High	Demonstration	Demonstration	Yes	No	Yes	Enhanced	8:15	3
6	Very	High	Exploded Diagram	Demonstration	No	No	Yes	**Lowered**	10:45	1
7	Very	High	Demonstration	Exploded Diagram	No	Yes	Yes	Enhanced	6:30	3
8	Very	High	Demonstration	Demonstration	Yes	Yes	Yes	No Effect	12:55	1
9	Very	Mid	Exploded Diagram	Exploded Diagram	Yes	No	Yes	Enhanced	6:30	2
10	Little	Low	Demonstration	Step-by-step	No	Yes	Yes	No Effect	13:15	2

Six participants preferred the Demonstration instruction method to learn about the subject, while Step-by-Step and Exploded View Diagrams were preferred an equal amount (two each). All of the participants classified themselves as tactile learners, needing physical hands-on experience to comprehend the assembly process. This dominant learning style may be due to the convenience sampling strategy of participants from technically related courses in college. In the planned future expanded experiment, a larger sample size with more diverse backgrounds should create a greater variation in all of the survey data, specifically the Learning Preference category.

As shown in Table 1, four of the participants received materials of an instructional format matching their preferred format, while six did not receive their preferred instructional type. The participants were evenly split when asked if the exercise was challenging. Eight of the participants reported the instruction provided was “easy to understand.” One of the two participants who rated the instructions as not “easy to understand” was provided with a matched instructional format, while the other was not.

Five out of ten participants believed that the instructional material “enhanced” their manual assembly performance, while the other four reported “no effect,” and one felt it actually "lowered" his or her performance. Comparing the Instruction Type Match to Effect on Task Performance revealed a relatively even spread of results. It should be noted that the preferred instruction type was self-reported by participants, who might or might not be aware of the distinction between different ones at the time of filling out the pre-test survey. By showing them examples of different instruction types at that point would have resulted in more accurate data. Similarly, individual Skill Level and Effect on Performance were based on the participants' subjective opinion. By providing a pre-test training activity, a more equal baseline among the participants in terms of task enhancement via work instructions could be achieved. In the meantime, individual skill level could also be assessed in a more objective manner.

Time to Complete

The Demonstration Video instruction used in the study lasted 6 minutes and 30 seconds; if the participants followed the video closely without shortcutting or fast forwarding, they would require a longer time to complete the task. The other two forms of instructional materials could be completed as quickly as the participants felt was needed. Shown in Table 1, the participants with Exploded Diagram instructions completed the task faster than participants with either the Step-by-Step or Demonstration Video instructions, whether or not the instructional type matched their learning preference. One explanation for this phenomenon was that an exploded diagram provided the least amount of explicit information for the participants to follow. It allowed the participants to assemble the components in the order they desired and did not make them read through text instructions or follow a demonstration.

Errors in Assembly

Errors in assembly tasks by individual participants were identified after the experiment. There were approximately twenty potential ways to assemble the components incorrectly. Inserting a part upside down or backwards would be an example of such errors. Table 2 shows the errors made by the participants, along with the individuals' time to complete the assigned task, instructional preference match, and claimed performance enhancement by the instruction provided. Out of the approximately twenty potential ways to make an error, only five types of assembly errors were observed:

- Type 1 Error: Motor/Shaft assembly and Front Knob/Threaded Collar assembly were installed outside of Left Side Housing.

Table 2. Summary of Participant Errors, Time to Complete, Preference Match, and Claimed Performance Enhancement by Instructional Materials Provided

Participant	Match	Enhanced	Time used (minutes)	Error Count	Error Type				
					1	2	3	4	5
1	Yes	Yes	10:15	1					X
2	No	Yes	3:20	2				X	X
3	No	No	7:50	2				X	X
4	No	No	11:00	3			X	X	X
5	Yes	Yes	8:15	3		X		X	X
6	No	Rev	10:45	1				X	
7	No	Yes	6:30	3	X			X	X
8	Yes	No	12:55	1				X	
9	Yes	Yes	6:30	2				X	X
10	No	No	13:15	2				X	X
Error Count Subtotal					1	1	1	9	8

- Type 2 Error: Direction Switch was upside down
- Type 3 Error: Front Knob was assembled into Left Side Housing incorrectly
- Type 4 Error: Front Knob and Threaded Collar were assembled incorrectly
- Type 5 Error: Trigger Spring position was incorrect

Errors made in the assembly might indicate missing or incorrect information, or too much information in that particular step in the instructional materials. Two types of error out of approximately twenty possible types during assembly accounted for over 80% of the assembly errors. The remaining three types of assembly errors occurred one time each, which might indicate an oversight on the part of the participant during assembly, but did warrant further investigation of the instructional material to determine if those assembly errors could be eliminated through revisions.

Feedback on Instructional Material

The participants were asked to provide feedback on all aspects of the experiment as well as the treatments. Overall, the comments were positive and many of the participants reported that the test was fun. The feedback reflected some of the assembly errors and a majority of the participants made the same comments. The most common issue was to add a definition of the components needed for each step at the beginning of the step. Other comments reflected the lack of accurate Trigger Spring position instructions and the spatial relationship of how the components fit together. Some of these comments were due to the inherent way a specific instructional form presented the information, such as how an Exploded Diagram would not show explicitly where or how the components fit together.

None of the participants using the Demonstration Video paused or rewound the video, indicating that the video clip progressed at a reasonable speed, or the participants did not feel the need to double check their work. Participants typically did not pick up the few components needed for specific step before beginning the instruction, so they tended to have to scramble in order to find components in the pile. All of the participants were surprised when their assembly was incorrect, and all believed that theirs was assembled correctly according to the instructions, although some areas were difficult to understand.

There were issues caused by specific instructional formats. The materials were functionally sound but contained a few easily correctable details in the procedure. The results of the participants' performance ratings in Table 2 indicated that two main errors were made during assembly regardless of the format of instruction provided, namely how the Front Knob was assembled to the Threaded Collar, and what was the proper position of the Trigger Spring. Due to its inherent lack of detail, the Exploded Diagram gave no indication of how those two steps could be accomplished; thus, it was typically used as a supplemental source in conjunction with the other instructional formats such as Step-by-Step.

The Exploded Diagram instruction used in this experiment consisted of a letter-size sheet with three illustrations. The main illustration displayed the parts exploded while the other two denoted the parts assembled without the Right Side Housing and assembled completely with no text instructions. To better serve its purpose, the Exploded Diagram should be expanded to three pages to provide a greater amount of information to the participants. The first page should consist of a Bill of Materials with illustrations for all of the individual parts and their respective nomenclature. The second page should display the parts in the exploded view with detailed callout illustrations for the Trigger Spring position and Front Knob to Threaded Collar assembly steps. Concise text notes should be added to each callout illustration to clarify assembly details. The third page should consist of two illustrations; one displaying the parts assembled into the Left Side Housing only and the other with all parts and both housings completely assembled. By implementing these changes, the Exploded Diagram could provide enough detail for the participants to correctly assemble the parts.

The Step-by-Step instructions used in this experiment were the basis for the other two instructional formats and contained some issues that might have affected individual assembly accuracy or caused confusion. The participants indicated that it was problematic to read the text, interpret the illustrations, compare the physical components, assemble the components in a single step, and then repeat the cycle. They tended to focus on only one aspect at a time and often skipped subsequent information presented in the same step of the instruction if they felt that portion had been completed. Such observations indicated that the amount of information and order of information in a given step was essential in fine-tuning the Step-by-Step instructions.

The Demonstration Video instruction was based on the Step-by-Step in illustrations and parts assembly progression; therefore, it contained the same errors as the Step-by-Step instructions. It should be revised to reflect the same part assembly order as the revised Step-by-Step instructions. The Demonstration Video instruction contained two technical issues that need correction. The video clip's resolution did not match a standard 4:3 monitor, so the participants were required to resize the video player window to fit individual video segments. Moreover, the video clips would only play on the QuickTime video player while they were supposed to be compatible with Windows Media Player. The school computers commonly available to students did not contain the proper plug-ins or add-ons, so all of the testing had to be done with a laptop not owned by the school; an experiment with more than one participant could be problematic.

Conclusions and Recommendations

A preliminary study utilizing a mixed method to investigate the interaction between the operator of a manual assembly activity and the given instructional materials was presented. The objective of this study was to explore the operator-instruction interaction through both quantitative and qualitative data, and serve as a pilot study for a future expanded quantitative study on whether a specific instructional format that matched the operator's learning preference would affect the speed and accuracy of manual assembly performance. Being a preliminary study, the intent of this paper was to report the qualitative data often neglected in previous studies and compare it with the quantitative data of the individual participant's task performance speed and accuracy.

The main limitation in this study came from the small sample size of ten participants, which was not large enough to have a high statistical power; thus, no correlation between variables or further statistical analyses were performed. The qualitative-centric results were only suitable for evaluating the instructional materials as well as the pre- and post-test surveys, and identifying possible reactions from the participants. Diversity of participants was another issue with this particular sample. For further research, a better screening process should be used to add variety or randomness to the participants recruited for the experiment, along with a significantly larger sample size. A power analysis prior to the experiment should be performed in order to determine the ideal number of participants.

One way to increase the diversity among participants would be to revise the pre-test survey and corresponding recruitment strategies. Besides soliciting participants' opinion of themselves regarding manual assembly related experience level, skill level, instruction preference, and learning style, more in-depth questions should be asked along with examples of different instruction types to determine actual preferences, making the data much more accurate and representative. For example, individuals might believe that they prefer the Step-by-Step instructional format, but a formal instrumental process would determine that these participants actually prefer the instruction in the Demonstration Video.

Running a similar experiment on a larger scale will require a large amount of data collection and analysis. By incorporating all of the materials into a digital format, potentially web-based, the data could be collected and analyzed quickly. The survey and the various instructional formats could be placed on a website connected to a database where the participants would follow on-screen instructions for all aspects of the experiment. The test results (errors in assembly) could then be logged by the proctor. However, it should be noted that the caveat to presenting all of the materials in digital format is whether or not it would change the perception as well as the task performance of the participants due to the interaction between the operator and the printed media, which might be different from that between the operator and the computer interface.

Some participants indicated difficulty in reading the text, interpreting the illustrations, comparing and assembling the physical parts, and then repeating the cycle. They tended to focus on only one area and skip over information that appeared previously accomplished when it had, in fact, not been. Further research into factors such as ratio of text or illustrations to actions per step, sequence of operations, order of illustrations, and any other aspects in the structure of the work instructions which may enhance the understanding of the instructions, will be another area for future investigation. The findings from any follow-up study will likely offer valuable suggestions for improving types and quality of instructional material used by technical trainers.

References

[1] Tseng, M., & Jiao, J. (2001). Mass Customization. In G. Salvendy (Ed.), *Handbook of Industrial Engineering* (3rd ed.). New York: Wiley.

[2] Piller, F. (2004). Mass Customization: Reflections on the State of the Concept. *International Journal of Flexible Manufacturing Systems*, 16, 313-334.

[3] Siddique, Z., & Boddu, K. R. (2004). A Mass Customization Information Framework for Integration of Customer in the Configuration/Design of a Customized Product. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, 18(1), 71-85.

[4] Smirnov, A. V., Pashkin, M., Chilov, N., & Levashova, T. (2003). Agent-based Support of Mass Customization for Corporate Knowledge Management. *Engineering Applications of Artificial Intelligence*, 16(4), 349-364.

[5] MacDuffie, J. P. (1997). The Road to "Root Cause: Shop-Floor Problem-Solving at Three Auto Assembly Plants. *Management Science*, 43(4), 479-502.

[6] O'Hara, K. P., & Payne, S. J. (1998). The Effects of Operator Implementation Cost on Planfulness of

Problem Solving and Learning. *Cognitive Psychology*, 35, 34-70.
[7] Hopp, W., & Oyen, M. (2004). Agile Workforce Evaluation: A Framework for Cross Training and Coordination. *IIE Transactions*, 36(10), 919-940.
[8] He, D. W., & Kusiak, A. (1997). Design of Assembly Systems for Modular Products. *Robotics and Automation, IEEE Transactions on*, 13(5), 646-655.
[9] Abe, N., Tanaka, K., & Taki, H. (1999). Understanding of Mechanical Assembly Instruction Manual by Integrating Vision and Language Processing and Simulation. *Robotics and Automation 1999 Proceedings. 1999 IEEE International Conference on* 02/1999; 4:3091-3096 vol.4.
[10] Matsumoto, F., Ueda, Y., Takeda, K., & Mizunashi, S. (1994). Understanding-oriented Manual vs. Operation-oriented Manual. *Proceedings of the 10th Symposium on Human Interface*.
[11] Heiser, J., Phan, D., Agrawala, M., Tversky, B., & Hanrahan, P. (2004). Identification and Validation of Cognitive Design Principles for Automated Generation of Assembly Instructions. *Proceedings of the Working Conference on Advanced Visual Interfaces*, Gallipoli, Italy.
[12] McLoughlin, C. (1999). The Implications of the Research Literature on Learning Styles for the Design of Instructional Material. *Australian Journal of Educational Technology*, 15(3), 222-241.
[13] Felder, R. M., & Silverman, L. K. (1988). Learning and Teaching Styles in Engineering Education. *Journal of Engineering Education*, 78(7), 674-681.
[14] McCaulley, M. H. (1990). The MBTI and Individual Pathways in Engineering Design. *Journal of Engineering Education*, 80, 537-542.
[15] Lumsdaine, M., & Lumsdaine, E. (1995). Thinking Preference of Engineering Students: Implications for Curriculum Restructuring. *Journal of Engineering Education*, 84, 193-204.
[16] Kolb, D. A. (1984). *Experiential learning: Experience as the Source of Learning and Development*. Englewood Cliffs, NJ: Prentice-Hall.
[17] Aragon, S. R., Johnson, S. C., & Shaik, N. (2001, July 8). A Preliminary Analysis of the Influence of Learning Style Preference on Student Success in Online vs. Face-to-face Environments. *Eighth International Literacy and Education Research Network Conference on Learning*, Spetses, Greece.
[18] Neuhauser, C. (2002). Learning Style and Effectiveness of Online and Face-to-face Instruction. *American Journal of Distance Education*, 16, 99-114.
[19] Golledge, R. G. (1999). *Wayfinding Behavior: Cognitive Mapping and Other Spatial Processes*. Baltimore, MD: Johns Hopkins University Press.
[20] Novick, L. R., & Morse, D. L. (2000). Folding a Fish, Making a Mushroom: The Role of Diagrams in Executing Assembly Procedures. *Memory and Cognition*, 28(7), 1245-1256.
[21] Hegarty, M., & Just, M. A. (1993). Constructing Mental Models of Machines from Text and Diagrams. *Journal of Memory and Language*, 32, 717-742.
[22] Hegarty, M., & Sims, V. K. (1994). Individual Differences in Mental Animation during Mechanical Reasoning. *Memory and Cognition*, 22, 411-430.
[23] Jayaram, S., Jayaram, U., Wang, Y., Tirumali, H., Lyons, K., & Hart, P. (1999). VADE: a Virtual Assembly Design Environment. *Computer Graphics and Applications*, IEEE, 19(6), 44-50.
[24] Adams, R. J., Klowden, D., & Hannaford, B. (2001). Virtual Training for a Manual Assembly Task. *Haptics-e*, 2(2).
[25] Hegarty, M., & Just, M. A. (1989). Understanding Machines from Text and Diagrams. In H. Mandl and J. Levin (Eds.), *Knowledge Acquisition from Text and Picture*. Amsterdam, North Holland: Elsevier Science Publishers.

Biographies

YI-HSIANG CHANG is an Assistant Professor of Technology at University of North Dakota. He received a B.S degree in Mechanical Engineering from Tatung University in Taiwan, a M.S. degree in Mechanical Engineering from Carnegie Mellon University, a M.S. degree in Industrial Engineering and a Ph.D. degree in Technology from Purdue University. Dr. Chang's research interests are in User-centered Product Design, Spatial and Cognitive Learning, and Product Lifecycle Management. Dr. Chang may be reached at yihsiang.chang@und.edu

THOMAS R. KLIPPENSTEIN is an R&D engineer at Andros Engineering in Paso Robles, California. He received a B.S. degree in Industrial Technology from California Polytechnic State University in San Luis Obispo. Prior to attending Cal Poly, Mr. Klippenstein worked for US Air Force over a decade, specialized in technical maintenance of aircraft.

INSTRUCTIONS FOR AUTHORS: MANUSCRIPT REQUIREMENTS

The INTERNATIONAL JOURNAL OF ENGINEERING RESEARCH AND INNOVATION is an online/print publication, designed for engineering, engineering technology and industrial technology professionals. All submissions to this journal, including manuscripts, peer-reviews of submitted documents, requests for editing changes, as well as notification of acceptance or rejection, will be handled electronically. The only exception would be CDs containing high-resolution pictures and/or images to be used during journal production.

All manuscript submissions must be prepared in Microsoft Word (.doc or .docx) and contain all figures, images and/or pictures embedded where you want them and appropriately captioned. Also, each figure, image or picture that was imported into your Word document must be saved individually as a 300-dpi or higher JPEG (.jpg) file; that means one additional file for each figure in your manuscript. If, for example, a table or graph is created directly in Word, you do not have to submit it again in a separate file. Use the respective figure number (where it goes in your manuscript) as the file name. You can send all of these files separately via email, or zip them all into one file to be sent via email or snail mail on a CD. Send all submissions to the manuscript editor: philipw@bgsu.edu

The editorial staff of the International Journal of Engineering Research and Innovation reserves the right to format and edit any submitted document in order to meet publication standards of the journal. Included here is a summary of the formatting instructions. You should, however, review the sample Word document included on our website (www.ijeri.org/submissions) for a detailed analysis of how to correctly format your manuscript.

The references included in the References section of your manuscript must follow APA-formatting guidelines. In order to help you, the sample document also includes numerous examples of how to format a variety of scenarios. If you have a reference source for which you are not able to find the correct APA format, contact me for help anytime (philipw@bgsu.edu). Keep in mind that an incorrectly formatted manuscript will be returned to you, a delay that may cause it to be moved to a subsequent issue of the journal.

1. Word document page setup: Top = 1", Bottom = 1", Left = 1.25", Right = 1.25". This is the default setting for Microsoft Word.

2. Page Breaks: No page breaks are to be inserted in your document.

3. Paper Title: Centered at the top of the first page with a 22-point Times New Roman (Bold), Small-Caps font.

4. Body Fonts: Use 10-point Times New Roman (TNR) for body text throughout (1/8” paragraph indention); 9-point TNR for author names/affiliations under the paper title; 16-point TNR for major section titles; 14-point TNR for minor section titles; 9-point TNR BOLD for caption titles; other font sizes may be noted in the sample document.

5. Images: All images should be included in the body of the document. As noted earlier, all objects/images that have to be embedded into Word (i.e., an image not created in Word) must also be saved as a 300-dpi or higher image, saved as a separate file and submitted along with the original manuscript.

6. In-text referencing: List and number each reference when referring to them in the text (e.g.. [1]). The first entry must be [1] followed by [2], [3], etc., continuing in numerical order through your references. Again, see the sample document for specifics. Do not use the End-Page Reference utility in Microsoft Word. You must manually place references in the body of the text.

7. Tables and Figures: Center all tables and figures. Captions for tables must be above the table, while captions for figures are below; all captions are left-justified.

8. Page Limit: Manuscripts should not be more than 15 pages (single-spaced, 2-column format).

9. Page Numbering: Do not use page numbers.

The International Journal of Engineering Research & Innovation (IJERI) is the second official journal of the International Association of Journals and Conferences (IAJC). IJERI is a highly-selective, peer-reviewed print journal which publishes top-level work from all areas of engineering research, innovation and entrepreneurship.

IJERI Contact Information

General questions or inquiry about sponsorship of the journal should be directed to:

Mark Rajai, Ph.D.

Founding and Associate Editor-In-Chief

Office: (818) 677-5003

Email: editor@ijeri.org

Department of Manufacturing Systems Engineering & Management

California State University-Northridge

18111 Nordhoff St.

Room: JD3317

Northridge, CA 91330