

# VIRTUAL PROTOTYPING AND MECHATRONICS FOR 21<sup>ST</sup> CENTURY ENGINEERING

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## Abstract

The modern era of machine design has put new pressures on designers. The requirement to design devices with more functionality has driven engineers to combine multiple disciplines to create smarter electromechanical machines. This has become known as mechatronics. Another requirement is to get designs to market in a considerably shorter time. Virtual Prototyping, through the combination of SolidWorks and LabVIEW, will enable engineers to meet these requirements and maintain a profitable business.

## Introduction

The 21<sup>st</sup> century has ushered in a new era of machines and methods for design. The demand for more cost-effective, better, and more functional machines, coupled with an unstable economy and intense global competition, has put considerable pressure on engineers. They are expected to produce more complex systems at a better product value, lower cost and faster rate. This necessitates an entirely new paradigm for design.

Mechatronics is defined as the synergy of mechanical systems featured with its precision in electronic control and intelligence in the design of products and manufacturing processes [1-6]. Further, these disciplines can be rendered down to the functional structure of Mechatronics, reflecting the product's six aspects: microcontroller, power supply, mechanical body, sensing apparatus, precision mechanical actuators and communication systems. These methods contrast the old paradigm of electromechanical design.

In traditional designs, designers of electromechanical systems would use a sequential method. That is, the mechanical engineers would first establish the basic design. It would then be passed on to the electrical engineers, and finally to the control and software engineers. Figure 1 below illustrates this point. In modern designs, the traditional approach promotes neither communication nor synergy, while mechatronics design methodologies and systems do promote these values. Concurrent engineering in mechatronic design is the new paradigm. Mechanical, electrical, control and software engineers participate in a given design simultaneously. This is illustrated in Figure 2, which shows the

design engineering departments in parallel [7].

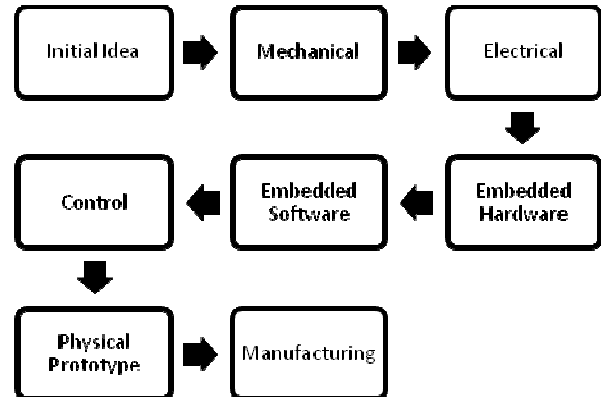


Figure 1. Traditional Design Method

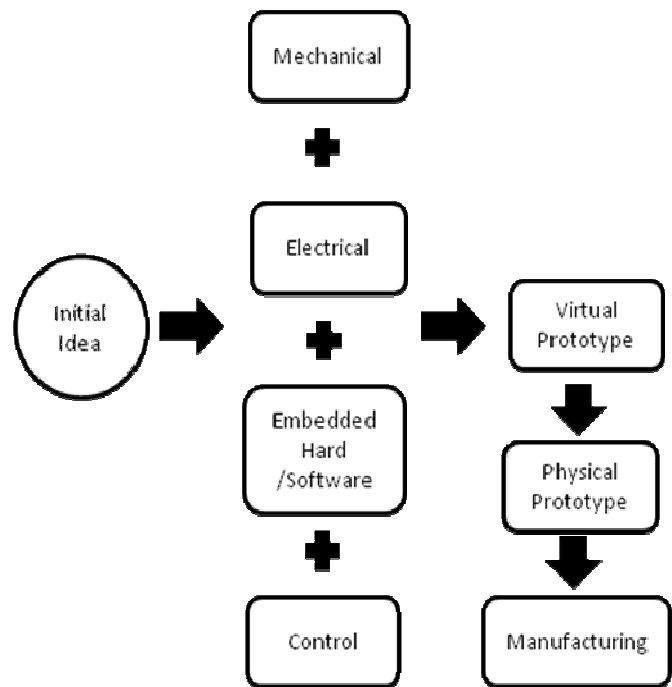


Figure 2. Modern Design Approach with Parallel Engineering Teams

For virtual prototyping (VP), concurrent engineering and successful synergy was difficult when the means to effectively communicate technical data and information was underdeveloped.[8-10]. This is a thing of the past because vir-

tual prototyping and the associated software can facilitate these needs. Design engineering is on the cusp of change; mechatronics and virtual prototyping are positioned to enable that change. Prototypes are early models of equipment developed at full scale to be used for evaluating performance. Traditionally, these are physical prototypes built to identify problems in the initial design. They often lead to design changes and multiple iterations of the prototype as a means of optimizing the design. Creating multiple physical prototypes is extremely costly. Each new design demands more time, money and materials to realize the next iteration.

A virtual prototype is meant to serve the same function without the need for a physical model, thus reducing cost. When engineers discover the need for a change, and ways to optimize their design, they can simply alter the virtual prototype itself. This eliminates time- and money-consuming physical prototypes. Additionally, and perhaps more importantly, the initial design and virtual prototype can be created with simultaneous input from every engineer involved in the project. New software developments are enabling engineers to achieve optimized designs with fewer physical prototypes.

The essential techniques of virtual prototyping are reflected in the union of LabVIEW and SolidWorks [10-18]. National Instruments (NI), in combination with Dassault Systems, has developed a module that allows for a seamless union between NI's LabVIEW and Dassault's SolidWorks, known as the SoftMotion Module. This software allows the different design engineers to work simultaneously with CAD models, embedded software and control logic to simulate and analyze the dynamic behavior of a system.

Virtual prototyping with SolidWorks, LabVIEW and SoftMotion gives the mechanical and control engineering team a way to assess the function of the virtual mechatronic system in which the realistic machine operations are visualized, the cycle time throughput is simulated, and the product's performance and important information about the dynamic behavior of the design are demonstrated. In the past, these properties were explored mainly through the creation and testing of a physical prototype.

This study focused on virtual prototyping via 3D modeling and graphical programming, which is the trend in intelligent product design, and which is more intuitive for students not majoring in computer engineering and technology.

## The 21<sup>st</sup>-Century Engineering

Industrial products in the 21<sup>st</sup> century will be mechatronic products, or smart machines. As stated before, mechatronics

is meant to be a synergistic combination of multiple engineering disciplines. Mechatronic devices make use of microprocessors, data acquisition sensors and actuators, all within a mechanical body. What separates mechatronics from traditional electromechanical systems is the system's intelligence, logic and internal communication. Figure 3 illustrates this point.

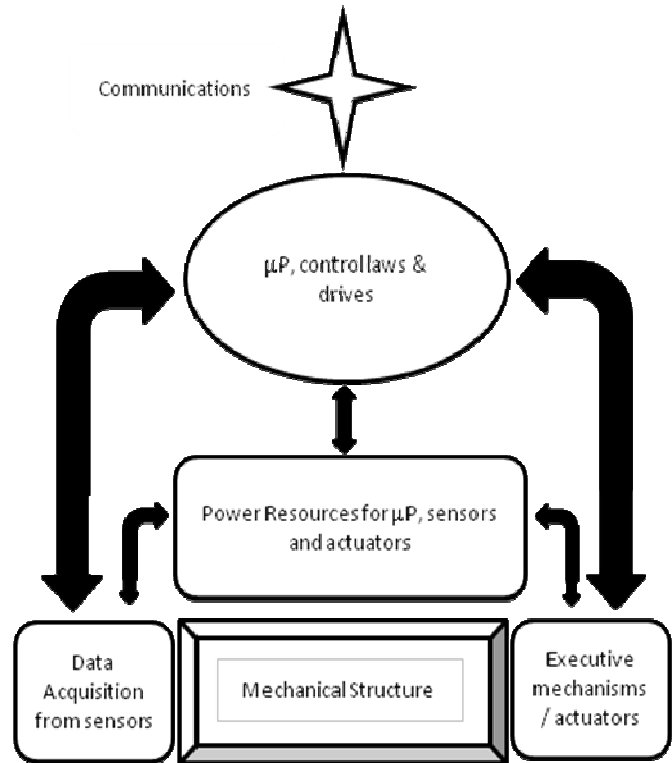


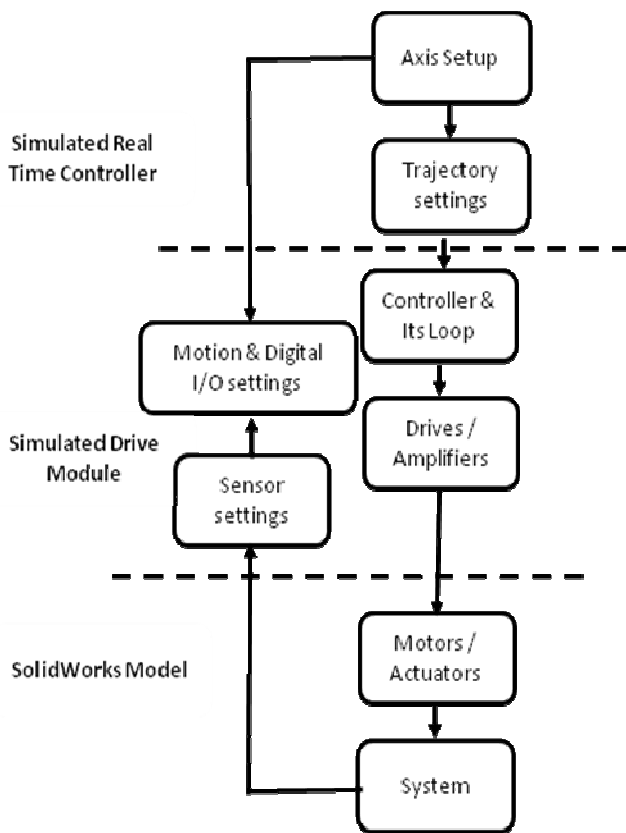
Figure 3. Synergy and Communication in Mechatronics

This is a very powerful combination of tools. If these systems are combined properly, the result is a machine that can be set to complete a task with minimal input from the user. The microprocessors and control logic allow mechatronic devices to react to inputs and make decisions based on these inputs. Therefore, nearly any process that requires mechanical actuation can be automated through the use of a synergistic mechatronics design. However, for engineers to successfully create a synergistic system, they need to work in a synergistic manner themselves. The traditional, "over the wall" technique does not allow them to do so. Virtual prototyping of mechatronics does.

Virtual prototyping is the integration of computer-aided design, embedded software programming and simulation software to visualize an intelligent mechatronics device in a computer environment. This environment allows design engineers to manipulate their models without the need for building a physical version. It has been commonplace in

industry for decades to use CAD packages to develop solid models of mechanical designs. Programming and embedded logic have been widely used as well. The fact that these parts of the design were never developed in unison is what created a disconnect, especially in mechatronics design. Virtual prototyping with NI and Dassault software has changed that forever by bridging the gap.

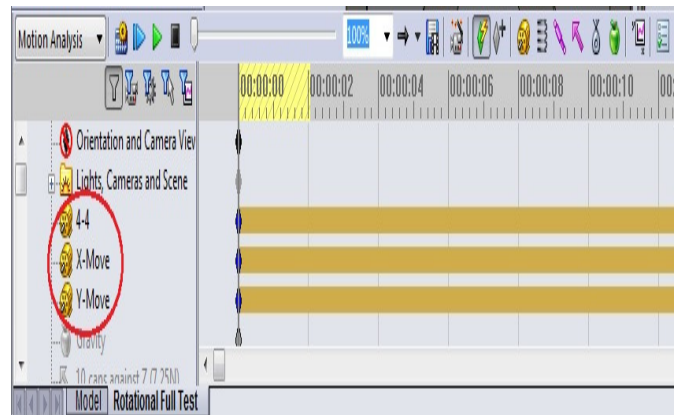
National Instruments has developed an extremely useful tool known as the NI SoftMotion Module. This tool enables the combination of a SolidWorks 3D CAD model with a LabVIEW project tree. By doing so, all motors, sensors, gear trains, etc., defined within the CAD model can be connected with the LabVIEW algorithms developed to govern the model. The actuators are connected using the SoftMotion Axis tool. If using multiple axes together, the designer can create a coordinate space in which the axes will operate simultaneously. A model of the SoftMotion Module is demonstrated in Figure 4, which presents this process in a very easy-to-understand, graphical way.



**Figure 4. Motion Control System with SolidWorks**

Once these steps have been completed, motion profiles can be created. The functions within the NI SoftMotion Module are used to move the profiles in a variety of ways.

The movements can be as simple as a single-axis, straight-line movement or a complex, contoured motion. If properly programmed, complex, coordinated motion can be achieved. These tools allow the designer to manipulate the profiles as a means of optimizing the design. Figure 5 demonstrates a motion study of the enabled motors and their analysis using the SoftMotion Module.



**Figure 5. Motion Analysis and Motors Enabled**

If the models are properly programmed and the appropriate connections are made in the software, a 3D CAD model in SolidWorks can now be brought to life for simulation and analysis. One of the few drawbacks for this method is the inability to perform real-time visualization. SolidWorks performs intense calculations to create the simulation, thus moving at a pace slower than real-time. The time, however, is accurate relative to the programmed timing. The results of a simulation can serve the purpose of visualizing machine operation, cycle-time estimation, accurate force and torque requirements, collision detection, validation of motion control programming, design optimization and identification of issues on the mechanical/electrical boundary. By means of collaboration between SolidWorks and LabVIEW, the mechanical dynamics, including mass and friction effects, cycle times and individual component performance, can be simulated without any physical parts. These dynamic effects will be especially precise when material mass properties are accurately programmed into the SolidWorks model. Making use of these analysis results is a very powerful way of optimizing a design and far less costly than doing so with a physical prototype. The benefits of virtual prototyping are numerous.

The purpose of every business is to generate profit. Engineering firms generate profit by producing products at a cost lower than what they are able to sell them for. Therefore, if virtual prototyping can reduce production costs, these firms can increase their profit margins. In addition, they will produce better and more efficient products that will increase

sales and revenue. How do virtual prototypes reduce production costs? The most observable way is through the reduction of iterations of a physical prototype.

Physical prototypes are extremely costly. They require a large amount of input from the engineers as well as materials used to actually build it. Developing a prototype in a virtual environment will save huge amounts of money by reducing not only the input time required of the engineers, but also the materials used to bring it to life. Additionally, when a physical prototype must be redesigned, much of the material used to create it will go to waste. Virtual prototyping will reduce this waste as well. Risk is also reduced through the use of virtual prototyping. Every decision a business makes runs the risk of inducing an undesired outcome. VP can make engineers more confident in their designs, thus reducing the potential for undesired outcomes. Profits are increased by more than just the reduction of cost. Can virtual prototyping increase profits in other ways? The answer is yes.

Throughput is a somewhat elusive term used by businesses. With respect to design engineering, it can be thought of as the amount of information successfully transmitted from one place to another. By increasing the amount of throughput via virtual prototyping, firms can achieve more. The growing complexity of 21<sup>st</sup>-century mechatronics devices demands that engineers increase their throughput. Virtual prototyping does this by allowing the various engineering departments to communicate far more efficiently and work in parallel. Their ability to achieve more throughput has a threefold effect: increased functionality, optimization/customization opportunity, and marketplace dexterity.

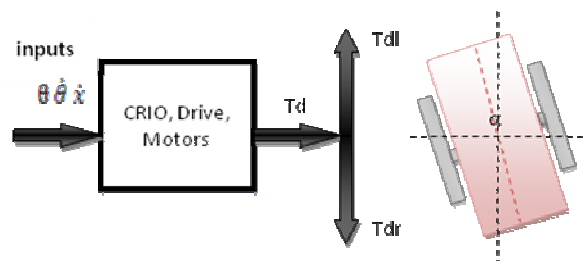
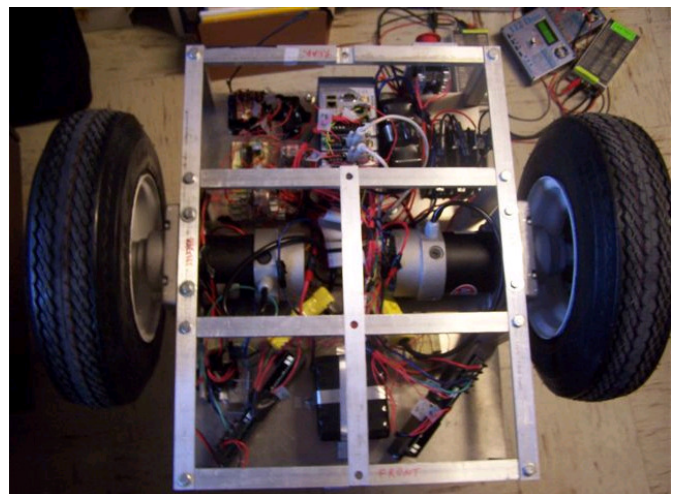
It has been previously stated that functionality is the backbone of a 21<sup>st</sup>-century mechatronics design. This means that the machines themselves must be more functional. It also means that the models must be the same. When making a bid for a contract, who is more likely to win it? The company with basic CAD designs and a text-based description, or the company with a fully animated, dynamic, ready-to-optimize-and-customize, virtual simulation? The choice is clear.

Being able to stay flexible and react to a changing market is also very important. Customer needs change and businesses must be able to meet those changing needs if they intend to keep their clients. The use of VP allows firms to make changes and reach final designs more quickly. This enables them to meet customer needs faster. Furthermore, given the appropriate situation, customers and suppliers could work side by side (much like the aforementioned parallel engineering concept) to achieve a mutually beneficial

design concept. Considering the current state of the economy, these are all extremely useful benefits of using virtual prototyping.

## Examples and Applications

There are many mechatronic systems in use today. Hybrid gas-electric vehicles and wind turbines, for example, are some of the most complex mechatronic devices and they are becoming more and more prevalent. Purdue's Mechanical Engineering Technology Department has built a physical prototype a mechatronic device: a two-wheeled, self-balancing scooter, as shown in Figure 6. This physical prototype was developed without the use of a virtual counterpart. The final cost was greater than \$5,000. This could have been significantly reduced if certain design considerations could have been made prior to the physical prototype being built. The methodology for doing so is quite simple.



**Figure 6. MET Two-wheeled, Self-Balancing Scooter**

Virtual prototyping has been clearly defined, the software needed, identified and its benefits outlined. But what steps should be taken within each software package in order to reach the optimal design? The flowchart shown in Figure 7 illustrates a simple algorithm for use as a guide in the crea-

tion of a virtual prototype. The numbers shown in rectangles are reference points for the solutions of Table 1, and which are used for the Analyze section of the algorithm.

Table 1 is meant for use with Figure 7 in the following way. The designer follows Figure 7 to produce the VP. When analyzing the VP, the questions under “Analysis” in Table 1 should be asked. If the answer to the question is no, the designer should refer back to Figure 7 and the step that is associated with the number in the “Solutions” column. However, if Table 1 refers you back to solution number 2 or 3, the following section details further the appropriate steps to correct the analysis problem. Certainly there are more questions that could be asked and further analysis that could be done, but the scope of this study did not allow for everyone to be detailed.

The analysis solution number 2 suggests returning to the “create motion profile” phase within LabVIEW. By doing so, one can change the path of motion to avoid collisions or optimize the cycle time. Figure 8, Adjusting Motion Profile with LabVIEW, details the steps to accomplishing this task. Solution number 3 sends the user back to SolidWorks to adjust the details of the material. This step can solve problems related to strength, friction, weight, etc. The flowchart of Figure 9 details specifically what must be done in order to make changes to the material properties of the solid model.

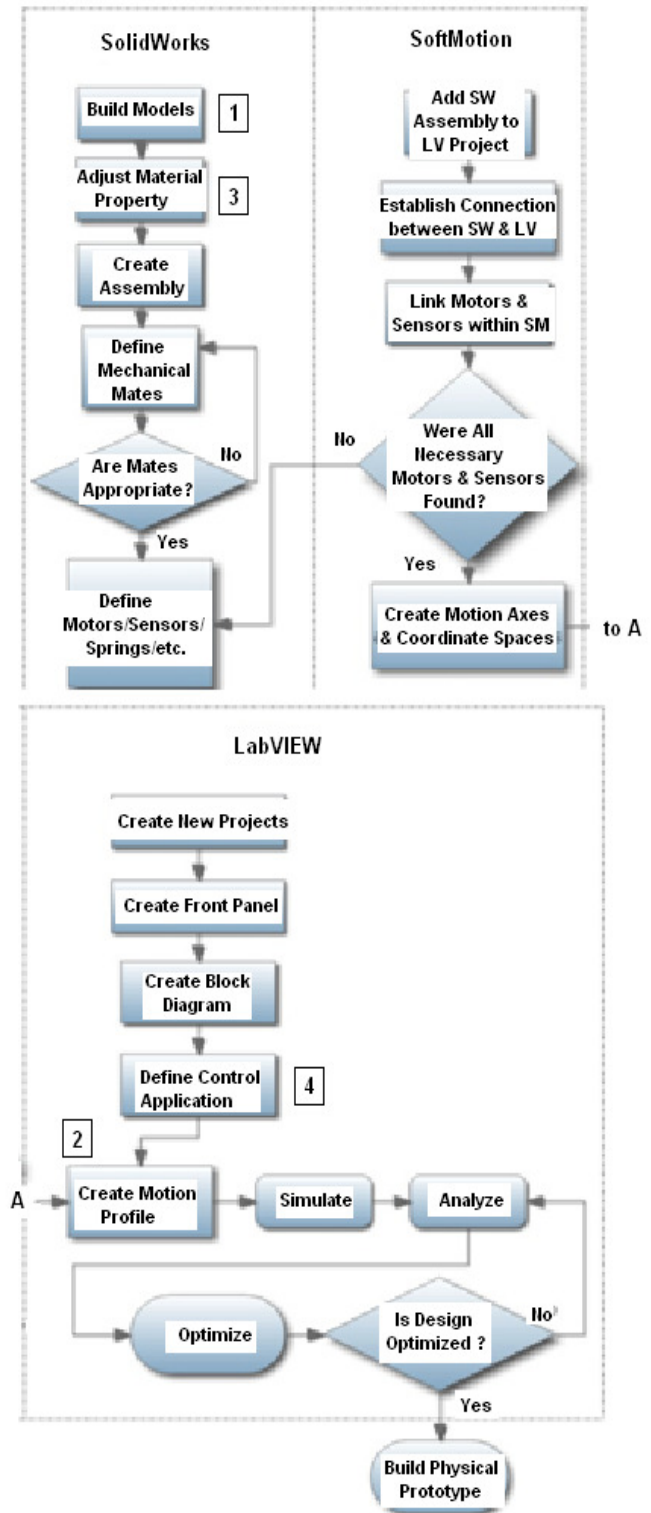
**Table 1. Analysis Table for Optimization of VP in Figure 7**

| Analysis                                  | Solutions |
|---|-----------|
| Were there any collisions?                | 1 2       |
| Is there a better material option?        | 3         |
| Is there excessive friction?              | 1 3       |
| Is there excessive torsional load?        | 1 3       |
| Are limit switches appropriately placed?  | 1         |
| Was the cycle time optimal?               | 1 2 4     |
| Is the mechanical device strong enough?   | 1 3       |
| Did the machine accurately perform tasks? | 4         |

## Conclusions

Mechatronic devices will dominate the 21<sup>st</sup> century. The requirement that engineers continue to increase functionality will drive the industry and virtual prototyping will become an ever more valuable tool as a means to that end. Fortunately, National Instruments and Dassault Systems have joined forces to make virtual prototyping a reality. As companies are required to be more efficient, virtual prototyping will become more popular. The design process will never be the same, and it would appear that this process is

moving in the right direction.



**Figure 7. VP Flowchart with SW, LV and SoftMotion Module**

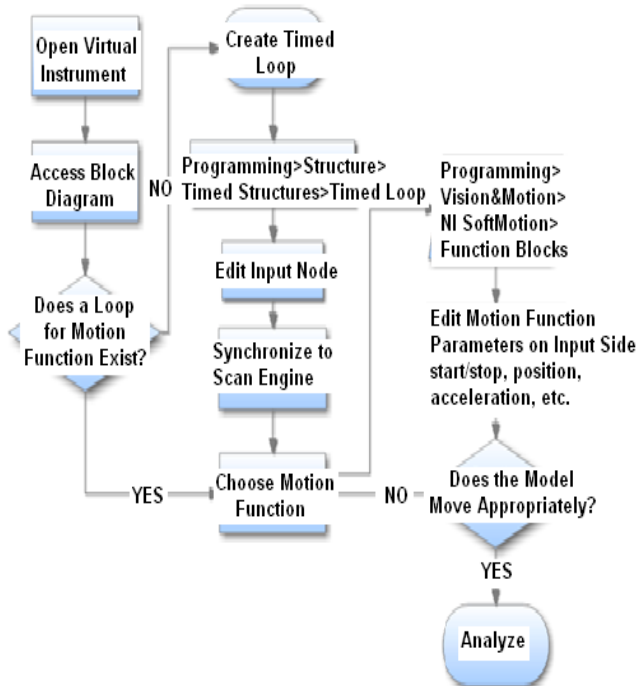


Figure 8. Adjusting Motion Profile with LabVIEW

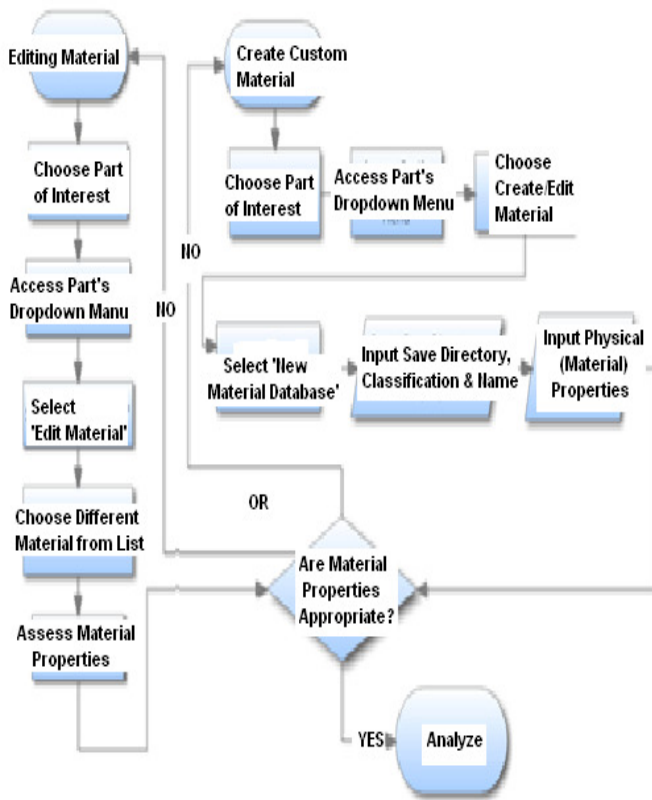


Figure 9. Adjusting Material Properties with SolidWorks

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## Biographies

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