USING SOLAR ENERGY IN ROBOTICS AND SMALL-SCALE ELECTRONIC APPLICATIONS

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Abstract

Now, more than ever before, the use of renewable energy is critical to the well-being of our planet. Solar energy, in particular, is one of the main sources of renewable energy and the subject of research worldwide. While most renewable energy projects using solar energy target large-scale applications, renewable energy technologies are also suited for small-scale applications. This is evident in hand-held calculators, recreational electronics and, more recently, traffic signals. One of the main issues encountered in the renewable energy industry, particularly the solar energy arena, is the storage of the harvested energy. The authors of this study developed a novel approach to the storage of solar energy for applications where weight may be a constraint. Particularly, the use of super capacitors is exploited as an alternative storage method for robotics and small-scale electronics. To this end, a solar-powered robot was designed and tests were conducted indoors using high-power light sources.

Introduction

The continuous discovery of novel materials used to fabricate the harvesting cells sustains the ambition of increased efficiency and the possibility of arriving at a global energy solution based on solar energy. However, solar energy is far from replacing conventional forms of energy used to supply the growing public and commercial demands. The highest market efficiency is about 24.2% and made available at a very high cost to the consumer. Incentives offered by states and the federal government encouraging residents to use alternative sources of renewable energy are having a negative effect on the solar industry by increasing demand and thus increasing the price to obtain the technology, especially in the private sector [1].

Exploring alternate sources of energy has become a priority amongst the scientific community. Recent oil spills, mine disasters and global warming have been the driving forces behind this ever-growing interest in alternative sources of energy throughout the world. Solar energy, in many ways, seems to be the obvious solution to the soon-to-be global energy crisis. The conversion of solar radiation into usable energy is still very expensive and inefficient. One of the problems is the power efficiency of materials used for fabrication of photovoltaic cells (PV) [2]. Storage of the harvested energy from the sun can also present an issue, due to losses and further processing such as conversion from DC to AC. For some applications, the energy is transferred directly to a grid system. In others, batteries are used to hold the converted energy. In very-small-scale applications, a capacitor connected to a solar engine maintains the voltage at a nearly constant level. For applications requiring higher energy and relatively light weight, this technique will not hold and the need for alternatives must be investigated.

This paper presents the results of a capstone project in Electronic Engineering Technology aimed at investigating an alternative way of storing solar energy for robotics and small-scale, lightweight applications. The background information necessary to understand the technology used for the design is presented, followed by a detailed design description of a solar robot used to investigate the feasibility of the project.

Design Description

The project is based on the IEEE southeast conference hardware requirements for the 2010 robotic competition. The robot had to be powered exclusively by solar energy, there could be no battery of any kind, and the robot had to maneuver on a course for a certain amount of time. The size of the robot was restricted to a maximum height and width in order to conquer height and width obstacles. The team had two minutes to harvest the energy from high-power lights and then three minutes to complete a course by traversing through and over certain obstacles varying in height and width.

Robot Design

The first prototypes of the robot were constructed by taking apart other robots, mainly Parallax Boebots, and using their components in lightly constructed frames. But it was concluded early on that using servos was not the best way to go as they are slow and consume quite a bit of energy along with the BS2 board used by the Boebot platform. In order to be successful, the design had to meet three basic interdependent constraints: structure size, navigation and power management.

After several prototypes, it was decided that with the amount of power stored during the initial stage, the number of obstacles to conquer would be compromised. The aim was to overcome the width and height obstacles and bypass the ramp obstacle. Even eliminating one obstacle, the design of the body was challenging.

The width and height had a great impact on the power, so tradeoffs had to be made. The panels produced more power when closer to the light source, but getting too high compromised the height obstacle. Having a heavy robot consumed power, but having it too light compromised traction and, thus, accuracy in navigation. Another parameter that dictated the shape of the body was the number of panels needed. Light wood was chosen for the frame and a “butterfly” look when placing the panels, as seen in Figure 1 (W=8”, H=16”, and L=25”).

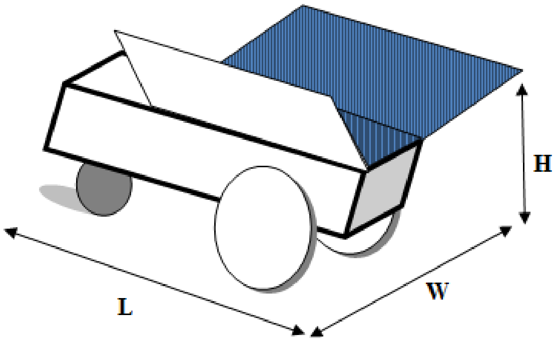

Figure 1. Block Diagram of Coolerbot Functionality

Navigation

In order to maintain the robot’s trajectory, sensors had to be used. Again, dealing with such power restrictions, there was only so much one could do before the power would fall below levels required for motion. Most electronic sensors, such as ultrasonic and IR sensors, require some self-supporting power and normally consume compromising amounts of energy. So, in an attempt to conserve energy, mechanical sensors were implemented. There were whisker-like extensions from the frame with mechanical switches at the ends. In later stages of the design, IR sensors were implemented on both sides and on the front of the design. However, most of the navigation was accomplished through code-controlled subroutines.

The robot was controlled by the Pololu Orangutan LV-168 Microcontroller depicted in Figure 2a. It is a full-featured controller for low-voltage robots that can be powered with two or three 1.2-1.5V batteries while maintaining 5V operations for its Atmel mega168 AVR microcontroller and sensors. It is mounted on a small (2.15" x 1.9") module and includes two bidirectional motor ports, each capable of providing 2A (continuous).

The design made use of Micro Metal Gear Motors with a 150:1 ratio (see Figure 2b). These are very-low-power motors and can deliver a very high torque while maintaining a high speed. They have a long (0.365" or 9.27mm), D-shaped metal output shaft, and the brass faceplate has two mounting holes threaded for M1.6 screws (1.6mm diameter, 0.35mm thread pitch).

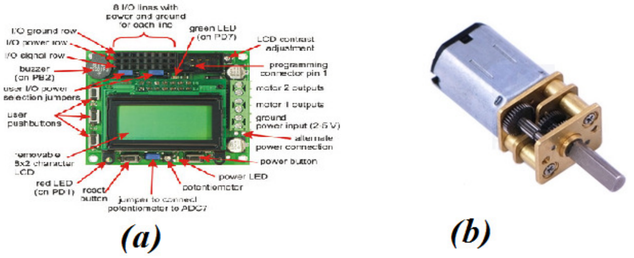

Figure 2. (a) Orangutan LV-168 Microcontroller, (b) Micro Metal Gear Motors

Power Management

An important piece of this design was power management. Many factors determined the type of power scheme used. The solar panels had to be efficient yet affordable; the capacitors had to be configured in a certain way for maximum performance; and, circuitry had to be introduced to manage or regulate the power.

Different types of panels were considered for the design. The first panel investigated was the rigid encapsulated solar panel rated at 0.9V 400mA, as shown in Figure 3a. It measures 2.5" X 3.75" X .25" and can be connected in series or parallel using small screws mounted on the embedded frame. Although the current was not bad, this panel had two problems: low voltage and a small surface area which called for more combinations. The second type of solar cell used was a thin-film module, specifically the 4.8V 100mA Flexible Solar Panel MPT4.8-150, shown in Figure 3b. Again, the power was not sufficient and the panels were cumbersome to connect due to a copper strip provided for the connections.

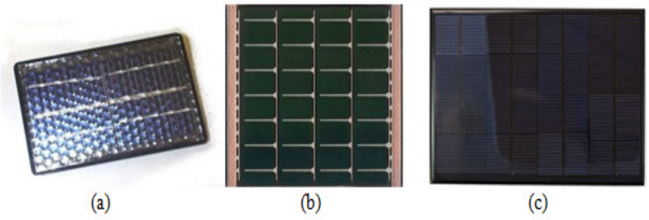

Figure 3. Solar Panels: (a) Rigid, (b) Flexible Thin-film and (c) High-Quality/High-Output

Finally, by a series of experiments involving height, capacitor combination and initial charge conditions, a more rigid and larger panel was chosen which could sustain the entire run shown in Figure 6c. The cell is a high-quality solar cell custom made for SparkFun Electronics, a site usually used by hobbyists. It is rated for 8V open voltage and 650mA short circuit, but has reached 9.55V open voltage and 850mA short circuit. The high output power was what the design needed, but some compromises had to be made such as the ones evident on topology. Termination is a 5.5mm x 2.1mm barrel plug, center positive on a 2m cable. It is a monocrystalline high-efficiency cell with a clear epoxy coating with hard-board backing.

One of the requirements for this project was that there should be no on/off switch. As a result, the microcontroller was altered to bypass the start button. This caused a problem because there is a point during charging where the microcontroller wakes up and starts pulling high current from the capacitor bank, which in turn slows charging and the robot cannot move. There is an initial potential barrier to overcome at start up requiring more charging capacity. At the same time, the initial charging time must be minimized in order to increase run time. The solution was to add two additional panels to the original two-panel configuration, all connected in parallel. This increased the charging capability of the system.

In order to get a speedy charge initially and still have enough power to run the field, several capacitor configurations were tested, of which one proved more efficient than the others. The capacitors used were 10-Farad super capacitors. Their small internal resistor allows for a fast charging time [3]. Combining them in a hybrid format (series and parallel) increased the charging time and slowed the discharge phase (when the robot is active).

Using Multisim 11.0 and Ultiboard 11.0, software packages from National Instrument, the circuit was simulated and laid out for in-house fabrication. Figure 4 shows the circuit diagram obtained from Multisim 11.0. As can be seen from the circuit diagram, there are two series banks. Bank1 is formed by C_1 in series with C_2, in parallel with the series combination of C_3 and C_4. Bank2 is formed in a similar manner. The final configuration is bank1 in series with bank2.

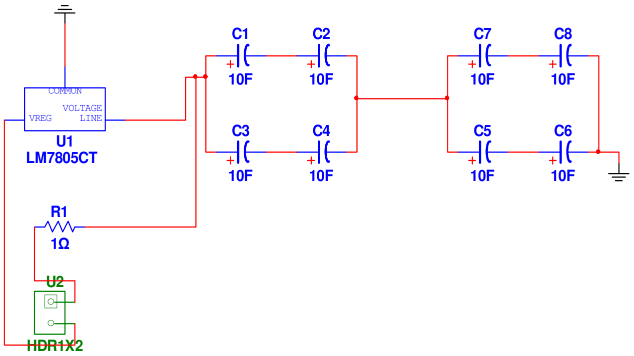

Figure 4. Multisim 11.0 Circuit Diagram

The circuit contains an additional voltage regulator and charging resistor. The regulator has an adjustable output and can regulate from 3.0V to an output between 5V and 12V DC. This regulator ensures that the microcontroller input voltage is maintained at the required 5 volts. A 1Ω resistor is used for charging-time minimizations [4]. Figure 5 shows the 2-D and 3-D circuit layout diagrams used in printed circuit board (PCB) fabrication. The final circuit and robot after fabrication of the PCB circuit are shown in Figure 6(a-c). The circuitry is housed under the panels.

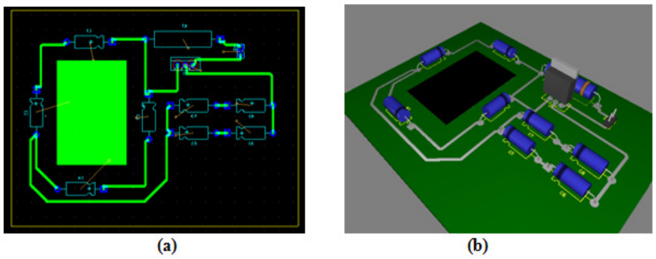

Figure 5. Ultiboard Circuit Schematic with Capacitor Combinations – (a) 2-D View and (b) 3-D View

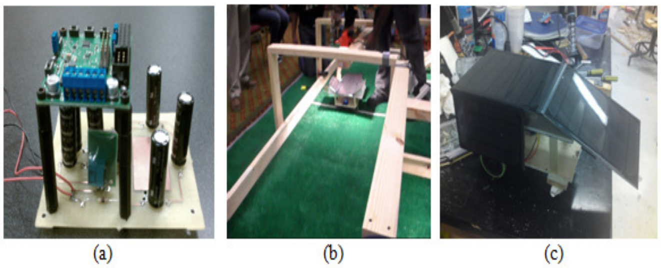

Figure 6. Final Design: (a) Circuit after Fabrication, (b) Robot Charging under a High-Power Light Source, and (c) Robot on a Lab Bench

Discussion and Conclusion

The final robot was able to charge up to 8.5 volts under the light source in about 1 minute. The charge stored in the capacitor bank was sufficient for the robot to reach the midfield point of a predesigned indoor field, where another light source was available for recharging. Navigation, however, proved to be a challenge once the design was moved from field to field. The dependency on code routines to navigate the robot through the field proved to be an issue. As the field texture changed, the robot deviated from the course because it required more power due to higher surface friction. The solution to this problem was the implementation of additional sensors to aid in navigation.

Tests were also conducted using natural sun as the source of energy by placing the robot outdoors. In the sunlight, the panels produced a large amount of energy and the addition of sensors was no longer an issue. The robot could run continuously as long as there was some sunlight available.

This capstone project made use of an unconventional method of energy storage that can be utilized in small, lightweight applications such as for robotics design applications. It shows that by combining super capacitors in hybrid formation and using additional circuitry it is possible to manage the solar energy stored in capacitors. The stiff constraints imposed by the design requirement used in this project clearly demonstrate that a combination of solar panels and super capacitors can be used to power small-scale electronics both indoors and outdoors. The configuration described here can supply small-scale devices that fall within the power ratings specified. However, for devices such as laptops, analysis shows that additional changes to the capacitor bank and circuitry are necessary. With advances in the photovoltaic industry, it is only a matter of time until laptops are self-charging by placing solar cells on the casing and using the same design approach discussed in this study.

References

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Biographies

ANTONIO SOARES received a Bachelor of Science degree in Electrical Engineering from Florida Agricultural and Mechanical University in Tallahassee (FAMU), Florida in December 1998. He continued his education by obtaining a Master of Science degree in Electrical Engineering from FAMU in December of 2000 with focus on semiconductor devices, semiconductor physics, Optoelectronics and Integrated Circuit Design. He then worked for Medtronic as a full-time Integrated Circuit Designer until November 2003. Antonio started his pursuit of the Doctor of Philosophy degree at the FAMU in January 2004 under the supervision of Dr. Reginald Perry. Upon completion of his PhD, Dr. Soares was immediately hired as an assistant professor (Tenure Track) in the Electronic Engineering Technology department at Florida A&M University. He may be reached at antonio.soares@famu.edu

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