University of Florida
Department of Electrical and Computer Engineering
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SENSOR REPORT

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Introduction

One of the primary objectives of my robot, ELSI, is to survive and operate indefinitely by being completely self-sufficient and replenishing its own power supply. A solar cell matched with a lightweight, high capacity battery cell is ideal for this purpose. With this setup, the robot can be provided with power indefinitely and is limited only by the life of the power cell and other components. The solar charging circuit must allow for monitoring of battery voltage and shutdown of high power components during charging for optimum performance. A special purpose battery-charging chip can be used to charge the battery, but this chip can be eliminated from the design by properly matching the solar cell and battery cell so that they work together without the need for complex control circuitry.

Solar Charging System Components

Solar Cell

To provide solar power, I selected a Power Film 15V solar panel from. The cell is rated at 15V and 100mA in full sunlight and is extremely thin and light.

Lithium-Polymer Power Cell

Lithium-polymer cells are ideal for this application because they have a very high capacity-to-weight ratio. They are also very efficient and relatively easy to charge. For this application, I selected a 730mAh Thunder Power 2-cell lithium-polymer pack. The pack is very compact, measuring only 34mm x 50mm x 9.5mm. It weighs only 31 grams and can support over 8 amps of continuous discharge.

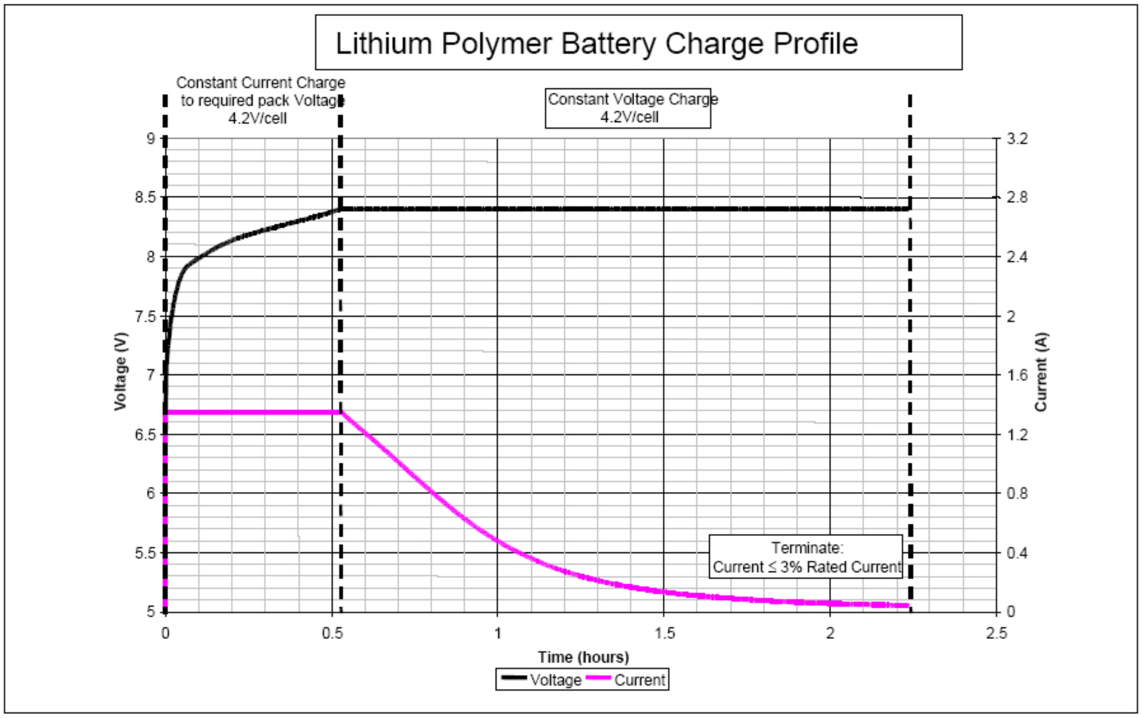
Shutdown-Capable Switching Regulators

To complete the solar power circuit and provide maximum efficiency, switching regulators with a shutdown feature are used. A shutdown feature is necessary because it allows the microcontroller to disconnect power to the servos and sensors while charging. When operating, the sensors and servos require more current than the solar cell can provide and therefore must be shutdown to allow the battery to be charged effectively. Two regulators must be used: one to power the microcontroller and another to the power servos and sensors. Since the microcontroller does not require a lot of current, the 500mA, 5V LM2574N-5.0 from National Semiconductor will be used. To power the servos and sensors, National Semiconductor's LM2599T-5.0, which provides up to 3A, will be used. Both of these switching regulators offer high efficiency and have a shutdown feature.

Theory of Operation

To understand how the solar charging circuit will work, we must understand how lithium-polymer cells are charged. Lithium-polymer cells are relatively easy to charge and have a clean and simple charging curve. Each lithium-polymer cell outputs 4.2V when fully charged, and about 3.0-3.6V when discharged, depending on the manufacturer. The Thunder Power cells are discharged when at about 3.5V. The cells should be charged using a constant current/constant voltage method. To charge the cell, any amount of current up to a maximum of 1C (where C is the battery's capacity) should be supplied until the battery voltage reaches 4.2V. At this point, the cell is about 70% charged, and should be charged further by supplying a constant 4.2V to the cell. When the current through the battery begins to drop below 3% of the rated current, as shown in Figure 1, the cell is fully charged. Lithium-polymer cells cannot be discharged past their minimum charge or they may become damaged. 3V is a safe value for most cells. If the cell's voltage drops below 3V, the cell must be charged with very low current to reverse the damage and bring it back to full capacity. The cell must also never be charged above 4.3V, or it can become permanently damaged. Most lithium-polymer battery packs, including the Thunder Power pack that is being used to power ELSI, have a built-in protection circuit that prevents overcharge or over-discharge.

Figure 1: Charge Profile of Lithium Polymer Battery Pack



In order for the microcontroller to determine when to start and stop charging the battery, it must be able to monitor the battery's voltage. Since there are 2 cells in the pack, a voltage divider consisting of two resistors is used to divide the voltage in half. The microcontroller can then monitor the battery voltage through one of its ADC channels. When the battery pack voltage nears 7V, the robot will start searching for sunlight to charge itself with and turn off its servos and sensors. If the voltage drops below the critical point of about 6V, the robot will shutdown completely to prevent damaging the battery cell.

The solar panel must be connected to the battery cell through a diode. This prevents the battery from discharging itself through the solar cell in low light. The diode drops the solar panel's voltage rating by about 0.7V, bringing the maximum voltage on the battery pack to approximately 8.4V, or 4.2V per cell. This will allow the battery pack to be charged to at least 70% of its capacity. The battery pack will never run the risk of being overcharged. The solar panel will not provide constant current or voltage to the battery cell, because these values depend on the amount of sunlight available. However, since these values will be within acceptable levels and will not vary enough to damage the cells. Figure 2 is a block diagram of the complete solar-charging circuit. The microcontroller is powered by a separate switching regulator than the servos and sensors. This allows the microcontroller to switch off all unnecessary devices while the battery is being charged. Since the battery pack uses two lithium-polymer cells, a voltage divider consisting of two resisters can be used to divide the battery voltage in half. The resulting voltage, V_MONITOR, is used to monitor the charge level of the battery. This allows the robot to determine when the batteries need charging and when to conduct an emergency shutdown procedure to save the batteries.

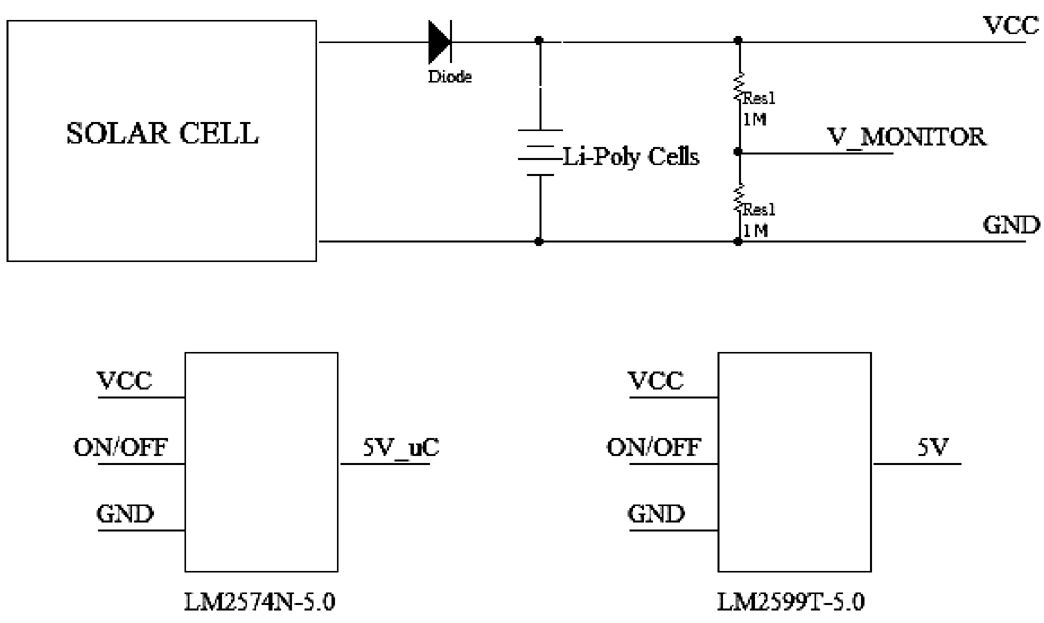


Figure 2 – Solar Charging Circuit

Other Sensors

Ultrasonic Ranger

A Daventech SRF04 ranger is used to basic obstacle avoidance and detection. These sensors operate with one input pin and one output pin. A trigger input pulse of 10uS is written to the input pin of the ranger to initiate a measurement. The ranger then responds with a pulse on the output pin. The time between the falling edge of the trigger pulse and the response is then measured and related to the distance of the object.

Infrared Sensors

Two Fairchild Semiconductor short range infrared detectors are used for edge detection. These sensors are mounted on the two front legs of the robot. For this application, the sensor only needs to tell the difference between an object in close proximity and no object or an object that is very far away.

CDS Cells

Four CDS cells are used to detect light. CDS cells act as light-sensitive resistors that change resistance with light intensity. One cell will be used to detect ambient light and determine if there is enough light present to charge the battery. The other three will be used to detect the direction of light. These three cells will be located inside black plastic tubes at the front of the robot so that they each detect light from only one direction. One cell will be directed forward while the other two will point left and right at 45-degree angles. I got this idea from a robot designed by one of the first students to participate in

IMDL. The three cells will be connected together in series so that only two voltage measurements need to be made in order to determine the voltage across each cell, as shown in Figure 3 below.

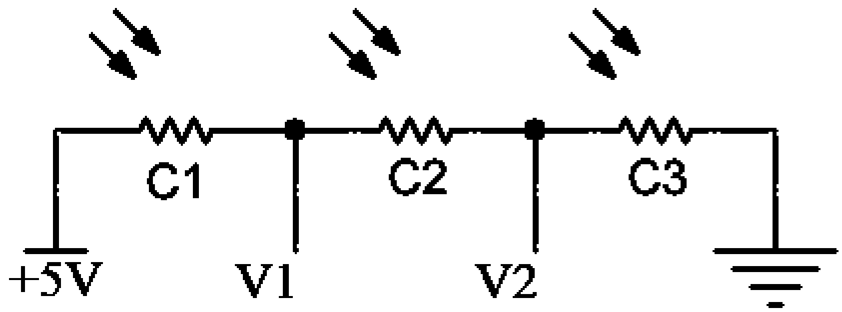


Figure 3 –Circuit diagram for light-direction-sensing with 3 CDS cells

Table 1 shows how the voltage drop across each cell is calculated from voltage measurements V1 and V2. Since the resistance across a CDS cell decreases as light intensity increases, the cell with the smallest voltage drop is seeing the most light and the cell with the largest voltage drop is seeing the least amount of light.

Cell	Voltage Drop
C1	5V – V1
C2	V1 – V2
C3	V2

Table 1 – Calculation of Voltage drop across each CDS cell

Passive Infrared Sensor

A passive infrared (PIR) or pyroelectric sensor is used to detect the presence of people and animals. The main purpose of this sensor will be to “wake up” the robot. When not stimulated, the robot will go into a sleep mode in order to save power and recharge its batteries. In this sleep mode, the only sensors that will receive power are the CDS cells and the PIR sensor. If the robot detects a person moving in front of it while in sleep mode, it will wake up and power up its actuators and sensors so that it can interact with the person. If the battery levels are very low, however, the robot will remain in sleep mode until the batteries are charged sufficiently.

The PIR sensor was removed from a Regent MS35 Motion Activated Security Floodlight, which I purchased from Lowe's for $8. This is cheap method of sourcing a PIR sensor since these sensors usually sell on robotics sites for $60 or more. Most manufacturers recommend a resistor in the range of 47KOhms to 3MOhms to restrict the current to the sensor. With a 1MOhm resistor, the output voltage from the sensor is around 1.9V. The output voltage changes depending on the direction of movement. Motion in one direction causes the output voltage to rise, while motion in the opposite direction causes it to fall. This property can be used to allow the robot to determine whether the person is moving left or right.

Testing and Experimentation

To verify that the solar panel will charge the battery, I conducted a simple experiment. I placed the solar panel under a powerful desk lamp, and made the measurements summarized below in Table 2 below.

Property Measured	Value
Battery Voltage	7.56V
Solar Panel Voltage	8.25V
Short-Circuit Current	70mA
Current Through Battery	10mA

Table 2 – 2-Cell Lithium-Polymer Battery with Edmund Scientifics 8.5V Panel

For comparison, I conducted the same experiment with a 1.2V AA Nickel-Metal Hydride battery. The measurements made are displayed in Table 3.

Property Measured	Value
Battery Voltage	1.11V
Solar Panel Voltage	8.25V
Short-Circuit Current	70mA
Current Through Battery	70mA

Table 3 – Single Cell AA Nickel-Metal Hydride Battery with Edmund Scientifics 8.5V Panel

Another experiment involved simply leaving the solar panel in the sun to charge the battery. The experiment was conducted in full sunlight, from roughly 12:00pm to 4:30pm. The measurements made are summarized below.

Property Measured	Value
Initial Battery Voltage	7.71V
Solar Panel Voltage	8.08-8.30V
Short-Circuit Current	90mA
Current Through Battery	10mA
End Battery Voltage	7.72V

Table 4 – 4.5 Hours of Full Sunlight with Edmund Scientifics 8.5V Panel

These results show that the internal resistance of the battery is much higher than originally thought. A charge current of only 10mA is much too small – the battery would take 70 hours to charge instead of 7. The internal resistance appears to be around 50 ohms instead of in the milliohm range. The only way to get around this problem is to use a larger, higher voltage solar panel. A 15V solar panel, manufactured by Power Film, was purchased and produced the results in Table 5.

Property Measured	Value
Initial Battery Voltage	7.57V
Solar Panel Voltage	19V
Short-Circuit Current	120mA
Current Through Battery	120mA
End Battery Voltage	7.63V

Table 5 – 2 Hours of Full Sunlight with Power Film 15V Panel

The test results with the 15V solar panel were very encouraging. The panel provided even higher voltage and current than it is rated, and the battery received a full 120mA charge current through it. Two hours in the sun already showed an increase in battery voltage.

Conclusions

In conclusion, a solar powered, self-charging robot is clearly very viable. However, a high voltage solar panel must be used to overcome the internal resistance of lithium-polymer cells, which increase as the cells reach full capacity.