Self-Sustaining Solar Powered Robot

Design Proposal

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Problem background

Most robots today can be categorized by their energy source. These can be broken down into three categories: AC powered, battery powered, and solar powered. Each one of these categories has limitations that can make it unattractive in certain situations.

An AC powered robot is, in a sense, self-sustaining. It can operate for long periods of time unassisted. These types of robots have one very limiting factor. It must always be close to an outlet and must have a cord attached to it at all times. For this reason, AC powered robots are usually immobile. This prohibits the robot from performing any useful functions outside a certain range. An AC powered robot provides the functionality for most needs in today's society but lacks the flexibility of performing actions across distances.

On the other hand, battery powered robots are usually mobile. They can travel away from a stationary energy source, because they carry their energy with them in batteries. The downfall of using a battery is that it eventually is going to have to be replaced. This limits the time that a battery powered robot can operate without assistance. An outside source of assistance will have to be available to enable the robot to continue its task. This also limits the range a battery powered robot can travel because it cannot travel out of the range of its assistance.

An alternative to battery power is solar power. A solar power robot can operate without assistance for very long periods of time if the conditions are perfect. The robot must constantly be in a strong light source so that the solar panels can generate enough energy to drive the electronics. This puts a limit on the robot's operating environments.

All these robots have one thing in common. They are not self-sustaining. They need outside assistance, whether it is a power cord connected to an outlet, or a person changing its batteries, or a constant light source that never fades. The energy source of a robot is one of its most limiting factors. If robots had an apparently infinite energy source, while still maintaining mobility, they could separate themselves from outside assistance to become self-sustaining entities.

A self-sustaining robot would be useful in many situations. It could be used in extreme environments that would not allow for easy maintenance to be performed. For example, a battery powered robot that enters into an environment not fit for humans can only use half its energy inside before it must return to the "safe" environment. Then, human interaction must be done to replenish its power supply. This severely limits the usefulness of the robot. A self-sustaining robot would be able to use all of its power supply and also be able to replenish it unassisted. This will allow the robot to completely separate itself from necessary assistance giving it the opportunity to perform its task in places not possible with the other types of robots.

Problem Statement

Robots are restricted by their energy source. Some robots are required to be plugged into an outlet at all times. Others use batteries, but they must be replaced or recharged periodically. Some are solar powered but they must be in direct light at all times. All these types of robots require too much outside monitoring and assistance to operate for long periods of time.

Problem Objective

The purpose of our project is to design a mobile self-sustaining robot. The robot should be able to operate unassisted for long periods of time. To do this, the robot should be able to perform a task while monitoring its battery level. Once the robot senses that its battery has dropped below a specified level, it will stop its current task to seek a strong light source. The robot should be able to navigate to the light and stop at it to charge the battery. Once the battery is charged, the robot will leave the light source and continue to perform the task assigned to it.

Design Constraints

There are many design constraints that are going to be taken into consideration. These constraints are the major aspects that we are going to be considering throughout the design process.

- Self-sustaining – The robot should be able to operate without any assistance from the outside world.
- Monitor energy – The robot should be able to monitor the battery's energy level at all times. It should know when it needs to seek more energy and it should also know when the battery is done charging.
- Mobile – The robot should be able to navigate on a flat surface without obstacles.
- Light-seeking – The robot should be able to locate the strongest light source in the area and navigate toward it.
- Solar-Rechargeable – Once in a strong light source, the robot should enter a charging mode where it consumes very little power and stores the energy into rechargeable batteries.
- Light weight – The robot will have to light enough that the motors can move it.

Design Assumptions

Some assumptions are going to have to be made to make this project feasible.

- No obstacles blocking the robot from the light source.
- Strong contrast between bright light source and surrounding ambient light.
- Strong light source will always be available. (If time allows we plan to design a feature that makes the robot enter a low power "sleep" mode when a light source is not available. The robot will evaluate the environment at a set interval until it senses a light source, then it will "wakeup" and perform as usual.)

Research

Existing Solutions

The desire to harness solar energy has existed for generations, but the technology to fulfill this desire has been relatively slow in maturing. The specific task of creating self-sustained devices has been of great interest, especially to space-related research and exploration. The creation of Sojourner portrays such interests. Sojourner was placed on the surface of Mars in 1997 for exploration purposes. The robot made use of solar power cells to provide it with its energy needs. Unfortunately, the robot was rendered useless after only 78 days of exploration due to dust and debris that accumulated on its solar cells; this prevented recharging vital to Sojourner's continued life.

Another notable attempt to use solar energy to power a robot was documented in mid 2001 with the work done on Hyperion. Hyperion is a solar powered exploration robot developed by researchers at Carnegie Mellon University's Robotics Institute. With support from NASA, the goal of this project was to ultimately create a robot that could track the sun while simultaneously exploring unfamiliar terrain. Hyperion is a relatively light robot, at 350 pounds, that creates up to 200 watts from a sail looking sheet of solar panels. It uses approximately 80 watts of power to run its on-board computer components and the remaining is used in motor function. A very important characteristic of Hyperion, in contrast to the average uses of solar energy on earth, is its ability to make decisions about survival and means for reaching its destination. The robot is built with logic that responds to sensors in order to navigate its environment without losing track of its ever important source of energy and final target. A testing process that became publicized in June and put into operation during the month of July provided successful results from tests on the robot. Among the testing conditions were harsh terrain, complex routes, and even goals that conflicted with the position of the sun. The end result was a solar power robot that was able to complete exploration of difficult terrains and both began and ended the journey with a fully charged battery.

Solutions existing for robots seeking solar energy range in scope, from the hopes of NASA to reach the greater depths of space to the smaller visions that follow. The exciting field of solar powered robotics has also been the focus of many hobbyists world-wide. In fact, solar powered robots are a subset of an entire concept of robot “genetics” labeled BEAM, which stands for biology, electronics, aesthetics, and mechanics. This idea takes evolution and applies it to robots, trying to create a newer, better robot rooted in the previous ones and improving for particular needs. In the specific arena of solar powered robots, an interesting amount of technology exists to mimic real world items, such as vehicles or insects. Of particular interest are two small robots called the Sunseeker Light Tracker and the Scoutwalker II. The Sunseeker by itself is a light seeking robot that pivots on a stand and locks onto a light source. The Scoutwalker II is a walking robot with a semi-flexible range of mobility features. The combination of the two robots, Scoutwalker II/Sunseeker combination, can be interfaced with each other to track light.

There are a number of existing solutions that shine a light on the path to creating a self-sustaining robot in the specifications of this project, but none reach all goals or face the same limitations. Two major issues that prevented prior solutions from completing our task are those of power consumption and interesting behavior. A great number of robots were considered when choosing the one most suited for self-sustaining abilities. Some, like the previous example of Scoutwalker II/Sunseeker, required more energy consumption than could be handled by practical solar cells. Most robots were specifically targeted toward immediate utilization of solar energy and did nothing in the way of storing energy or providing a means by which such expandability was possible. A lack of interesting behavior was crucial in the elimination of numerous robots created to simply track light without an interface for controlling the robot’s actions. The space related experiments were ideal for our particular needs except in financial limitations. With a budget ranging from $500 to $1000, it became impractical to replicate or follow the design of a research experiment supported by the financial backing of NASA. So the problem still exists, to design a mobile self-sustaining robot with survival and behavioral characteristics without exhausting limited funding.

Battery, Meter, and Charging

Power considerations do not stop at the solar panel and extend into every decision made when designing the robot. It would only be appropriate, therefore, to mention the thought process of choosing an efficient power storage unit and the concepts behind maintaining it. The main units of power storage include the choice of battery, the means of measuring charge, and the method or interface of charging. Each unit requires its own thought process and interfacing with the other units.

The battery is at the heart of the issues dealing with power storage and three major constraints must be taken into account when deciding which battery is most appropriate for the needs of this project. The first necessary characteristic is to fulfill the power requirements needed to work a solar power robot. Most robots that run motors or servos, a microcontroller, and other minor logic elements need energy at a potential of about six volts. This initial requirement narrowed the possibilities for batteries but still left a large range in the running. Size and weight requirements were another major factor when limiting the battery choices. In order to make sure that a battery could be mounted on a robot and to prevent a tremendous drain during movement (to allow movement for that matter) battery dimension and weight were important in providing restrictions to fit the constraints of this project. Lastly, financial limitations were an important concern. The materials used to make a battery tend to directly affect its cost, so finding a rechargeable battery made from relatively inexpensive material was a must. With these considerations in place, a 500mAh 6.0V NiMh battery with approximate dimensions of 2”x1”x0.5” became the optimal choice.

Measuring the charge of a battery is crucial to recognizing when it needs to be recharged or when a robot can resume some other functional activity. The most important decision to be made on a means of measuring battery levels was that of cost. For our purposes, the ideal meter to measure battery as well as provide convenient outputs, FM500 Series created by Fox Meter, Inc., priced at slightly over $150. This was well out of our range for a device that would only serve to provide a battery reading, not to mention the waste of additional power needed to supply the meter. After reading the inner workings of a battery and the idea behind battery testers included in many consumer battery packages today, an alternative method to determine charge level became the better choice. By placing a high resistance parallel to the terminals of a battery, a reading can be taken that tells the status of the battery. The options from this point can be two, a threshold method or A/D converter. The threshold method waits until reading levels fall below a specified point to consider it as invalid. This can be interfaced with ports directly on a microcontroller to trigger the appropriate reaction. The A/D converter, which seems the best option, would provide a means to take more specific readings and use these values as a trigger as well as for detailed status updates.

Charging is the third major aspect of power storage. Charging, for the most part, is quite straight forward and requires little, if any at all, interface between solar panels and the actual batteries. The device of most significance in the charging setup would be the solar charge controller. This is a device that is used to provide safe and efficient charging without overcharging. Complex charge controllers even manipulate waveforms to produce a more efficient charge of the battery. Though the need for a complex controller is not required, a charger to control flow to the battery would help prevent damage to the battery as well as promote charge consistency. With the factors of battery characteristics, battery measurement methods, and possibility of a solar charge controller taken into consideration, an optimal solution for the listed constraints are obtained. In this particular case, a small rechargeable battery with simple measurement logic and an A/D converter alongside a solar charge controller would provide a complete and efficient power storage solution.

Photo Sensors

In order for our robot to be able to detect and move toward light sources we need a way to sense light. The cheapest and simplest way to achieve this is to use photo resistors. The most common photo resistor a discrete analog component made of Cadmium Sulfide. The resistance of the photo sensor changes depending on the amount of light that reaches the surface of the device. One way to interface a photo resistor to a microcontroller is to create a voltage divider circuit with a pull-up resistor and measure the voltage with an analog to digital converter. Photo resistors are sensitive to the visible spectrum of light and can distinguish fairly accurately between different brightness levels (e.g. robots using simple photo resistors have been able to trace the outline of a shadow)

Photoresistor Specifications

Resistance (Ohms)					Peak Spectral Response nm	V_{MAX}	Response Time @ 1 fc (ms, typ.)	
10 Lux 2850K			Dark					
Min	Typ.	Max.	Min.	Sec.			Rise (1-1/e)	Fall (1/e)
20K	29.0K	38K	1M	10	550	100	35	5

Solar Panels

Solar panels (also known as photo voltaic cells) convert light into electric current. They are made of semiconductors with silicon being the most widely used. When a photon strikes the cell it is absorbed within the semiconductor; the energy knocks electrons loose allowing them to flow freely. Photovoltaic cells also all have one or more electric fields that act to force electrons freed by photon absorption to flow in a certain direction. We are going to use solar panels in order to charge the batteries of our robot.

In order to interface solar panels to our batteries we also need a charge controller. Charge controllers, as stated before, monitor the battery's state-of-charge and insure that battery isn't over-charged. Connecting a solar panel to a battery without a regulator risks damaging the battery and potentially causes a safety concern.

Robot

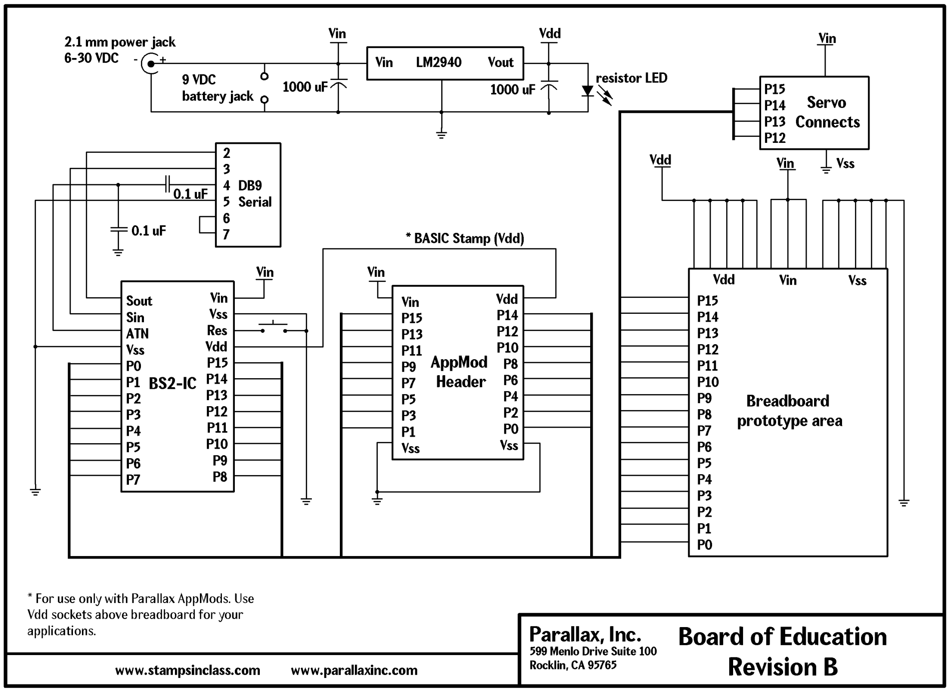
After considering alternatives, we chose the Boe-Bot to use as the starting block of our design. The Boe-Bot is a simple robot with three wheels. Two wheels for drive and one wheel for support. The chassis is made of aluminum that will allow us to easily attach a light weight frame to hold the additional parts such as solar panels and rechargeable batteries. The Boe-Bot full kit comes with everything needed to build and program a functioning robot. The kit includes software and a serial cable for program loading. Most importantly are the electronics, a circuit board and microprocessor, which are included with the kit.

Electronics

The Boe-Bot comes with parallax's Board of Education which includes a Basic Stamp 2-IC microprocessor. This package was designed to be used in classroom settings to help instructors teach integrated electronics and microprocessor programming. The Board of Education will be work adequately for our project and keep costs down.

Circuit Board

The Board of Education (BOE) contains most of the components that are going to be needed to successfully complete our project. The BOE includes a DB9 connector for serial interfacing used for both programming and serial communication during run-time. A 2" x 1 3/8" breadboard is included directly on the BOE to allow for small circuitry to be added. The breadboard can easily be connected to the 16 input/output pins of the microprocessor by a female adapter that is directly connected directly to the microprocessor socket. This adapter also allows for easy connections to additional add-on circuitry. This solder-free design of the BOE permits easy building, testing, and redesigning without the trouble of reprinting a circuit board or re-soldering connections. The BOE specifications state that a 9 Volt battery input or a 6-30 Volt AC adapter can be used to power the board. The following figure is a wiring schematic for the circuit board.



Microprocessor

The microprocessor that will be used is Parallax's Basic Stamp II-IC. The Stamp contains all the memory and programming capabilities that are going to be needed for the project. The program, written in PBASIC, is stored in 2048 bytes of EEPROM which is included on the Stamp. The stamp can operate on 6-15 Volts DC because it includes an on-board voltage regulator to convert the voltage to the required 5 Volts. It consumes 8mA of current in running mode and 100μA in sleep mode. The Stamp can hold approximately 500-600 lines of code and execute about 4000 instructions per second.

Simple Power Analysis

Power Consumption

Basic Stamp Microcontroller (BS2-IC): ~50mA

Two parallax pre-modified servos for 360 degree rotation: ~200mA at full speed

National Semiconductor LM2940 5-volt voltage regulator: ~30mA

Photo sensors: (negligible)

Average Estimated Power Consumption for entire Boe-Bot: ~300mA

BS2-IC
24-pin DIP
1.2" x 0.6" x 0.4"
0º - 70º C* (32º - 158º F) **
Microchip PIC16C57c
20 MHz
~4,000 instructions/sec.
32 Bytes (6 I/O, 26 Variable)
N/A
2K Bytes, ~500 instructions
16 + 2 Dedicated Serial
5 - 15 vdc
8 mA Run / 100 µA Sleep
20 mA / 25 mA
40 mA / 50 mA per 8 I/O pins
36
Serial Port (9600 baud)
STAMP2.EXE
Stampw.exe (v1.04 and up)

Dimensions:		40.5 x 37.9 x 19.7 mm
Weight:		45.0 g
Output torque:		3.4 kg-cm
Operating Speed at 4.8V		0.23 sec/60 degrees
Power Consumption:		6.0 V / 12 mA at idle

Batteries

Nickel Metal Hydride 6V approximately 500 mA-hours

Solar Panels

Approx. 70 square inches can generate 2.8 watts (7V @ 400mA)

Assuming our solar panels can generate their optimal output (noon sunlight conditions) they will be recharging the battery at about 80% of its capacity. Empirical evidence suggests that this supply should be able to charge the batteries to full capacity in about two or three hours. We are hoping to be able to run our robot on a much shorter cycle (e.g. charge for 8 minutes, operate for 5)

Design Process

Sub-Units

The following sub units are logical sections that represent specific tasks of our design process.

- Order parts – order the individual parts from the specific companies and wait for them to arrive.
- Assemble Boe-Bot kit and Test – build the basic robot and test the mobility and circuitry.
- Modify robot for lower power consumption – Adjust the servo settings and reprogram microprocessor to consume less power to navigate robot.
- Modify robot to accept 6V NiMh power cells – connect the battery pack to robot and create voltage regulator circuit if necessary.
- Test robot with modified power source – Verify that all robot functions work properly with new battery.
- Interface photo sensors to microcontroller via A/D converter – use an A/D converter to input digital data directly to the microprocessor via the breadboard.
- Program robot to find and travel to light source – create an algorithm to sense the strongest light and navigate the robot toward it.
- Interfacing battery power meter with microcontroller – implement the interface that will read battery level and connect it to microcontroller.
- Assemble solar array – assemble the solar array independent of robot. This includes soldering the individual solar panels together.
- Interface solar array, charge controller, and 6V cells – connect all parts together to independent of the robot.
- Collect charge time data – Test the length of time to charge 6V batteries with respect to different light sources.
- Collect power usage data – test the amount of power the robot will consume will performing a specified task
- Interface complete solar assembly to Boe-Bot – attach the completed add-ons to the robot.
- Program Boe-Bot to do something interesting – Develop and program an interesting behavior for the robot to perform to consume energy.
- Test robot in demonstration environment

Design Validation

To validate or design will place the robot in an environment that meets and tests all of the design objectives. The testing environment will be a flat, smooth surface without any obstacles. There will be two lamps in the room placed near the floor with all other ambient light turned off. The robot will be placed in the middle of the room and will start to consume energy. When “hungry” the robot should seek one of the lamps and move toward to charge. It will remain under the lamp until full charge threshold is met, then continue to middle of the room to consume power. While the robot is doing that, the lamp that the robot chose the first time will be turned off, leaving the other lamp the only light in the room. Again, when the robot is “hungry” it should now seek out the other lamp. We can continue this by moving lamps and alternating turning them on and off.

If the robot performs well in this experiment, and is able to stay “alive” unassisted, we will have met our design objectives.

Societal, environmental, safety analysis

All projects would mean little without specifying its affects or influences on society and the environment. The advances made on a project such as this and related projects would prove enormous in countless ways. A self-sustaining solar power robot would provide a means to perform tasks difficult for humans and maybe even create a new industry from the possibilities. Such a future would, of course, require a given amount of imagination. Envision a world where humans would no longer need to peril in toiling heat to complete road or house construction, or any sweat inducing work for that matter. Or even more, imagine robots that could perform resource mining or industry on other planets to preserve our valuable Earth. Robots that could find their own energy, especially from the sun, can do things that could far beyond the current boundaries of human limitations. These ideas may seem far reaching, but the implications of a successful, self-sustained robot could very well be a society utilizing such robots for vital functions to maintain mankind without an overwhelming draw on limited resources. This solar powered robot technology may not too far precede a more convenient and sustainable society for humans as well.

Analyzing the affects that solar powered robots would have on the environment prove even more interesting. Efficiently powered robots would save on precious non renewable resources that are currently used for robot experiments and explorations. Advanced research into such areas may in turn provide valuable information on how to better use solar energy. As far as the specifics of this particular robot, the only resources required to maintain the robot would be rarely replaced parts due to deterioration. Those damaged pieces would have to be recycled if not disposed of properly. In general, the resources consumed and the waste created would be far less that alternative choices.

With all things considered, safety must constantly be in mind in design and implementation. The design process can include precautions to keep batteries from over-charging and providing a consistent source of controlled energy to the entire robot. This prevents hazardous situations from occurring and potentially dangerous materials from harming people or surroundings. Safety during implementation of design is important when looking at procedures to assemble and program the robot. Being cautious when performing tasks, such as soldering, as well as keeping safety in mind when programming robot behavior will help to avoid possibly harmful situations. Safety measures during testing are equally important so as to keep people from getting hurt when seeing if the self-sustaining robot functions properly. This may include something as simple as keeping the robot from hitting others or something more complicated requiring robot modifications to ensure its safe behavior. Basically, safety concerns should be present during each and every step and measures taken to prevent any and all risks.

Management

Economic Analysis

The following chart details the current estimated budget.

Budget			
Item	Quantity	Price	Subtotal
Boe-Bot Full Kit	1	$ 229.00	$ 229.00
6V 500mah NiMh Flat ANTPack	1	$ 13.50	$ 13.50
Sundance Solar Super Solar Cells .5 V 125mA 4-pack	12	$ 10.95	$ 131.40
Photo-sensors	8	$ 2.00	$ 16.00
A/D converter	2	$ 10.00	$ 20.00
Charge controller circuitry	1	$ 30.00	$ 30.00
	Estimated Shipping		$ 50.00
	Grand Total		$ 439.9[illegible]

Time Scheduling

The sub-tasks specified in the design process are used to aid in scheduling time efficiently. The time for each task was estimated and a Gantt chart was created. The

Gantt chart included on the following page contains sub-unit dependencies therefore representing the task relationships that would be found in a pert chart.