Controlled Use of a Robot Colony Power Supply

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Abstract - *The controlled use of a continuous power supply for robots of a colony is presented. This work builds on previous work where capacitors were used as an onboard power supply, and where robots with metallic probes were charged at a power station. An onboard controller was implemented to direct the hexapod colony robot behavior according to its power supply status. A PIC chip, implemented as an Analog-to-Digital voltage converter, was used as the robot's voltage sensor. A BASIC Stamp II was used in conjunction with photocells as the robot's light sensors while a light source was placed at the power station. Tests were performed and revealed the plausibility of implementing a voltage sensor and light sensor/source for colony robots powered with capacitors.*

Keywords: hexapod, power supply, capacitors, colony, robots, Analog-to-Digital converter, voltage sensor, photocell, light sensor.

1 Introduction

A robot colony allows the study of member interaction such as cooperation, competition, communication, and predator-prey issues. The task of supplying power to the colony robot is difficult because the robots must be powered in such a way that they can function autonomously. A continuous power supply for colony robots provides the benefit of reduced human intervention. Previous work has been done concerning an optimal implementation of a continuous power supply.

RedZone Robotics, Inc. and Carnegie Mellon University's Field Robotics Center built a robot, Rosie, specifically created to operate in nuclear environments. A tethered wire, over which power, control, and video signals were sent, was attached to the robot on one end and a consol on the other end [1]. Such a system provides support for extended work periods, but decreases maneuverability due to having to drag the line and because space is needed for sensors. For our research we chose an on-board power supply.

Another system involved a continuous power grid. In specific, a research group at Brandeis University built an electrified floor in order to provide power to colony robots [2]. This was a plausible solution for our robot colony, but due to adverse technical effects related to issues with resistance we concluded that the use of power onboard in the form of capacitors along with a power station would be a better solution [3].

In general, there are two issues with an onboard power supply: power storage and recharging. Two forms of power storage are batteries and capacitors. Batteries are more reliable, but take a long time to charge, while capacitors recharge and release power more quickly. Two forms of charging are solar panels and a continuous power station. Brooks used a robot, Attila, which had batteries and recharged with solar panels [4]. This system required long charging times, which we hoped to avoid. Other researchers have used the Khepera robot, which can carry batteries that recharge at power stations [5]. This solution was not plausible for our robot because unlike small wheeled robots, our ServoBots need more power to drive the 12 servomotors.

Our colony robots have been configured with both batteries and capacitors. A 9V battery is used to power the controller, which has a very low power draw. The battery can supply sufficient reliable power for the experiments we intend to run. The capacitors supply power to the 12 servomotors, which require significantly more power. 50F capacitors at 2.3V were used in two-capacitor, parallel groups in series producing a charge time minimized at 30 seconds and the run time maximized at 3 minutes [3]. The robot had two metal piano wires attached to it as probes so that when they came in contact with the metal plates of the power station the robot's capacitors would recharge.

In this paper, we use the results of these previous tests to develop a control system where the robot senses when it is low on power, finds and moves to the power station, recharges its capacitors, backs away from the power station, and resumes its normal activities.

2 Colony Environment

An 8*8 foot walled area was established in the Connecticut College Robotics Lab for colony robotics research and will be populated with hexapod robots. A power station was placed in the middle of an inner wall of the area. The power station consists of two metal plates that have a 6V power supply wired to them. In addition, a light source was placed directly above the power station (Figure 1). The light source is a bright light that projects a wide beam of light that reaches the general area; it is positioned approximately one foot above the ground. The light source acts as a marker for the power station.

The ServoBot (Figure 1), the type of robot used in this research, is a hexapod robot with two degrees of freedom per leg including horizontal thrust and vertical movement. The robot was configured with an onboard power supply, in the form of 50F capacitors at 2.3 V in two-capacitor, parallel groups in series [3]. It is controlled by a BASIC Stamp II microcontroller, which has separate pins dedicated for the movement of each servo, a PC serial port connection, a system ground, a 5-volt DC input/output, general I/O, and unregulated power in. The power in can accept 5.5 to 12 DC volts, which was supplied by a 9V battery. The BASIC Stamp stores and executes a sequence of servo control pulses in its program, which command all servos to move to their next specified location every 25 msec. The capacitors provide sufficient power to run the 12 servos while they are operating simultaneously.

In order for this to be an effective charging system, the robot needs a way to tell when it is time to charge, when it is charging, and when charging is complete. A voltage sensor was needed on the robot so that it could tell these things and react with the appropriate changes in behavior. Additionally, the robot needed to be able to autonomously find and travel to the power station to recharge on its own. A light sensor and source were needed for this purpose. Lastly, these two sensors needed to be coordinated in a system where their readings would be intelligently interpreted by onboard controllers in order to best guide the robot. Our task was to select specific types of voltage and light sensors to be used, and to select microcontrollers that would be best in intelligently making use of the sensor's input data. Then we sought to develop a method that would guide the robot's controller programs.

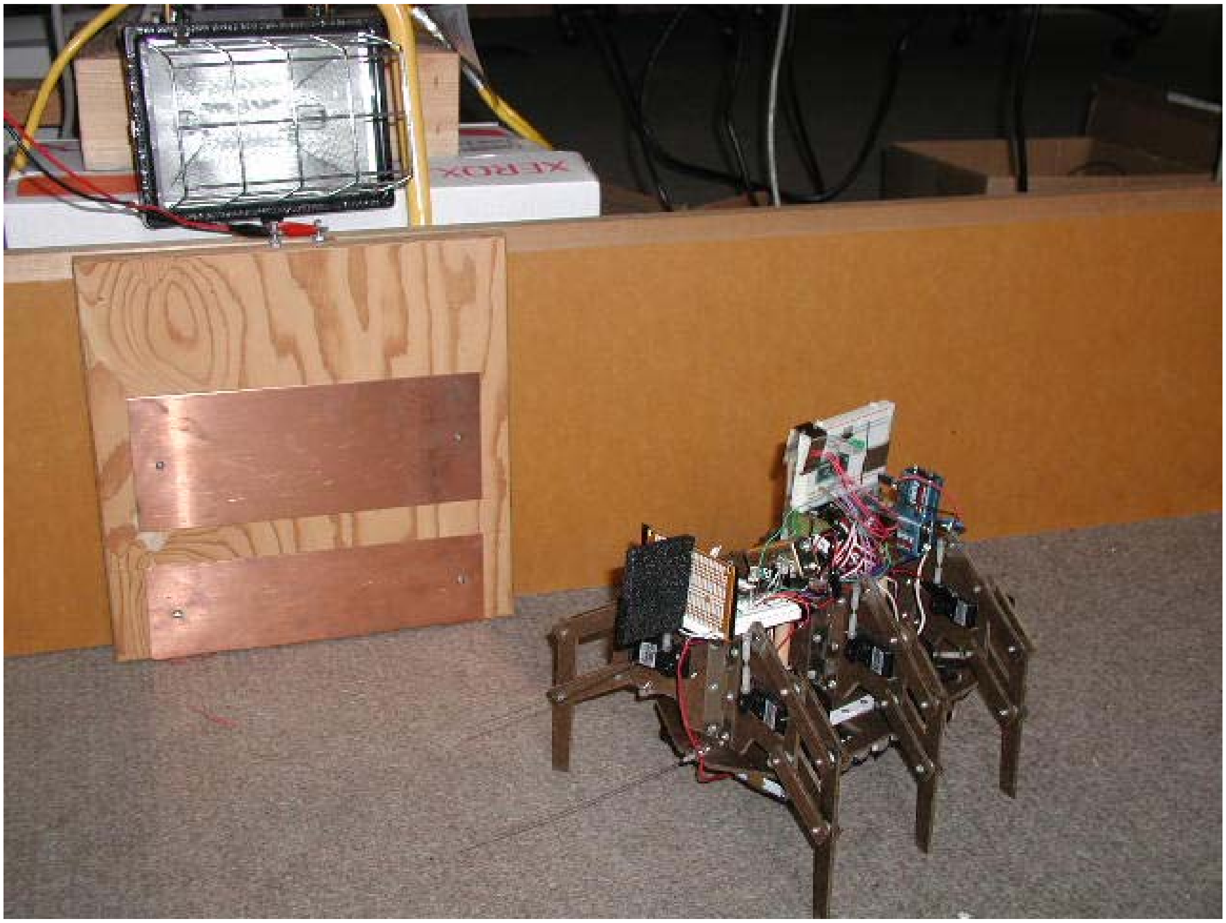

Figure 1. The robot, power station with its metal plates, and light source.

3 Configuration of Capacitors

The production of super-capacitors capable of high levels of storage made their use plausible for robot actuator power. The capacitors used in this research are Panasonic Electric Double Layer Radial Lead Capacitors (Gold Cap). They are rated for a maximum potential difference across the leads of 2.3V and have a 50F capacitance. Twelve capacitors were connected in parallel groups of two capacitors connected in series. In order to provide approximately 5V of power to the servos, two capacitors connected in series were required. Six pairs of these capacitors were connected in parallel to obtain a suitable level of power storage [3].

Two capacitors of capacitance C connected in series have a total capacitance that can be computed using Equation (1).

$$C_{series} = \frac{C^2}{2C} \tag{1}$$

The total capacitance of capacitors connected in parallel is the sum of their capacitances. With six pairs of 50F capacitors, the total capacitance of the system is 150F (Equation (2)).

$$C_{total} = 6 \times \frac{50F \times 50F}{50F + 50F} = 150F \tag{2}$$

The capacitors were placed underneath the robot since this design provides more stability to the robot, is more compact, and leaves the top of the robot available for other items such as sensors. Figure 2 shows a photograph of the underside of the robot were that capacitors were mounted.

In order to decrease the charge time, the capacitors were charged at a higher voltage than their maximum accepted voltage and the process was stopped when the maximum accepted voltage was reached. It was possible to significantly decrease the charge time in this way since the graph of Voltage vs. Time for charging a capacitor is an exponential graph.

Tests were done to determine the run time and charge time for our specific capacitor configuration when the capacitors were charged at 4.6V. It was determined that for the task of walking the ServoBot had a charge time of 2min 20sec and had a run time of 2min 50sec [3].

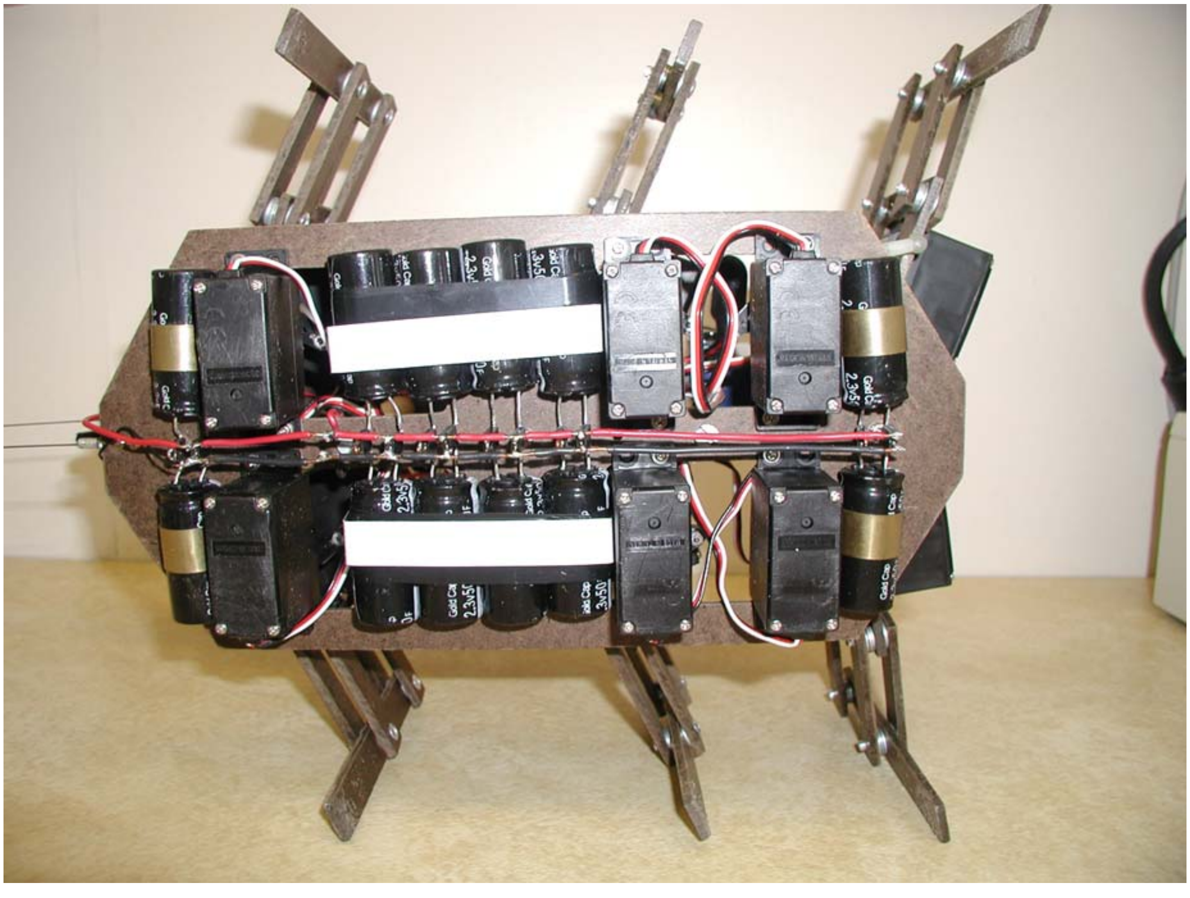

Figure 2: Six pairs of capacitors to power the ServoBot.

4 Sensors and Microcontrollers

We used a microcontroller functioning as an Analog-to-Digital voltage converter (ADC) to sense the voltage level of the capacitors. The chosen microcontroller was the PIC 12F675 [6] microcontroller due to its ADC capabilities, its low cost of $1.26, and its small size of 8 pins. The programming environment MPLAB IDE was used with the C programming language which takes less memory than other high level languages such as BASIC. The compiler PICCLITE was used to compile the C code into a .hex file which was then downloaded onto the PIC chip with the PICKit programmer.

We used two CdS (cadmium sulfide) photocells as light sensors, and a BASIC Stamp II to read and interpret the light sensor input. The choice of light sensor was made through references to similar experiments in PIC books that used Photocells and a microcontroller to intelligently guide a robot towards a light source [7, 8]. The choice of microcontroller was chosen because of the need to debug sensor input when configuring the system, and because the lab had the hardware and software to debug BASIC Stamps.

4.1 Configuring an ADC on the PIC Chip

The analog voltage value on the Voltage Reference (VREF) pin provides the upper bound in voltage readings and defines the range increments of the 10-bit resolution. The voltage input pin is specified in order to identify the pin to expect the analog voltage level to be read. If the voltage on the voltage input pin is equal to the voltage on the VREF pin, a result of all ones occurs. Otherwise, a result of somewhere between 1024 and zero would be represented.

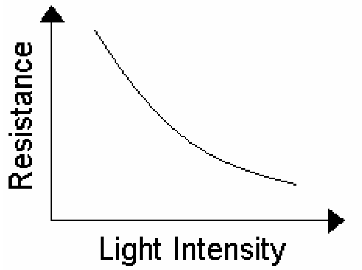

Figure 3. Graph representing inverse relationship between resistance and light intensity.

The ADC worked by connecting a wire to an already existing circuit of the robots capacitors to the voltage input pin of the PIC chip. The four different states identified by the ADC on the PIC were identified with two bits. The first was if the robot had between 3.3 and 4.7 volts; the second was if the robot had less than 3.3 volts; for the third, if the metal probes on the robot contacted the metal plates of the power station, the robot would detect a slight jump in voltage and would stay in “charge” mode; and for the fourth, once the voltage of the robot rose above 4.7 volts the robot would transfer out of “charge” mode, use up a little energy, and then return to the first state.

4.2 Configuring Photocells with a BASIC Stamp II

The CdS (cadmium sulfide) photocells are light-sensitive resistors. Their resistance varies in proportion to the light intensity sensed on its surface. The brighter the light source, the lower the resistance, and vice-versa (see Figure 3).

The varying resistances of the photocells can be used to produce different sensor input data. In particular, the varying resistances are utilized in a resistor-capacitor circuit specified by the BASIC Stamp programming manual [9], which suggested using 0.1 uF capacitors and 220 Ohm resistors which we used (see Figure 4).

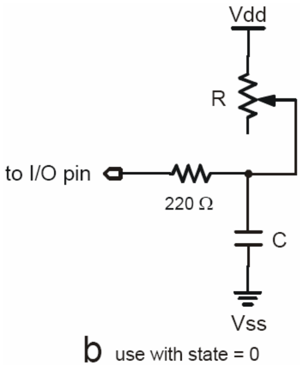

Figure 4. Resistor-capacitor circuit used. Diagram from the BASIC Stamp Programming Manual [9].

The command that utilizes this circuit is RCTIME, which measures the charge/discharge time of the resistor-capacitor circuit, which here is dependant on the varying resistance [9]. When RCTIME executes, it starts a counter and stops this counter as soon as the specified I/O pin on the BASIC Stamp II is no longer in state specified (i.e. either 0 or 1). The process starts by setting the I/O pin to be used in RCTIME to the state to be specified in RCTIME. Then there is a PAUSE command, which we set to 3 milliseconds, after which RCTIME is executed. Since we used state 0, the voltage seen by the pin would start at 0V and rise to 1.5V before RCTIME stops (because the BASIC Stamp II's logic threshold is approximately 1.5 volts). The time measurement is stored in a variable specified by the RCTIME command.

This time variable would be near zero when there was much light falling on its surface, and around 180 when sensing ambient room light. The reading of input data with

RCTIME was continuously executed by the BASIC Stamp II in a loop. The implementation of these light sensors was intended to direct the robot to a light source, and is shown in Figure 5.

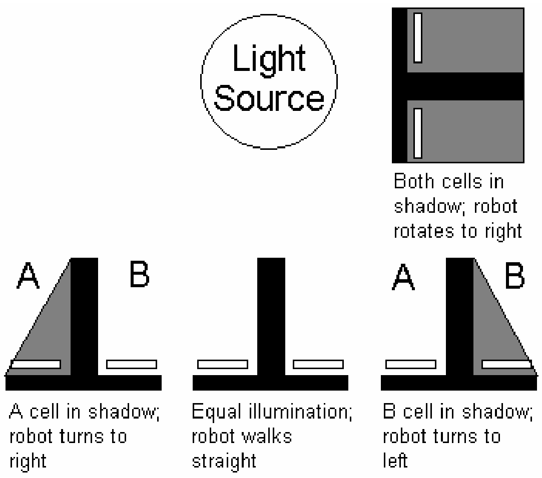

Figure 5. The four possible states of the light sensor.

This scheme is a modified version of one used in PIC books [7, 8]. It can be used to identify four states, which were represented by two bits. First, it can tell if both cells are in a shadow when both of their data values are above a certain threshold; it can tell that both cells have bright and equal illumination if they both had values below a very low threshold; and it can tell if only one cell is in a shadow if at least one cell is below a certain threshold and the difference between the two cells' data is larger than another threshold.

5 The Controller

The sensors were part of a control system that used three BASIC Stamp IIs, along with three 9V batteries (to increase the battery life of the controllers). A diagram of the system is shown in Figure 6. The ADC reads in the voltage input to sense the voltage level of the capacitors. The light sensors are the photocells.

The light sensor controller and ADC each send two bits of information (indicating one of four states) to the main controller. Based on these four bits of information, three bits were sent to the walking controller, which initiated one of seven gaits (straight, turn left, turn right, rotate left, rotate right, stop, backwards). In specific, if the ADC detected a voltage level between 3.3V and 4.7V, the robot would turn right and walk in a circle. This was to give the robot a task that would make it expend its energy, simulating a robot out performing its primary function. If the ADC detected a voltage level below 3.3V, the main controller would start "listening" to the light sensor controller, which allowed it to send the needed signal for the robot to walk to the power station. When the robot reached the power station and the metal probes contacted the metal plates, the ADC would detect this third state. Its signal to the main controller would cause it to discontinue "listening" to the light sensor controller and instruct the robot to stop movement so that it would stay in place to charge. When the robot's voltage level rose above 4.7V, the ADC would sense this fourth state, and the signal sent would result in the main controller calling the robot to walk backwards for three cycles. Then the robot would return to the first state. The robot with its sensor hardware, the power station, and the light source are shown in Figure 1.

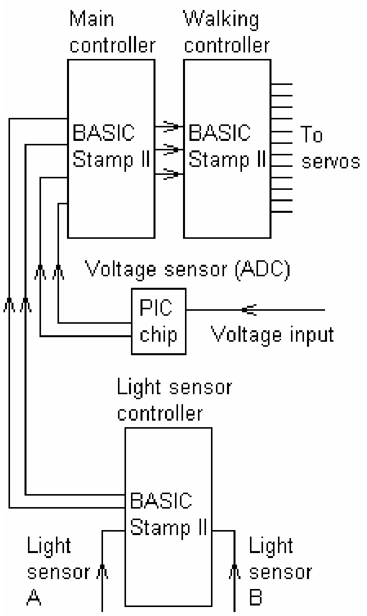

Figure 6. Wiring scheme with voltage sensor (ADC), light sensor controller, main controller, and walking controller.

6 Tests

Four sets of five identical tests were conducted to test the effectiveness of our system. In the first set, the robot was set in "charge" mode and was placed to charge at the power station. The robot was then left to itself. When fully charged, it would walk backwards for the distance of one foot and start to circle. In all five tests, the robot successfully returned to the power station after discharging and autonomously began to recharge.

The three remaining sets of tests were designed to see if the robot could find and track toward the power station from different locations in the colony area. In each test the robot was set in a specific location where it would circle. The test was to observe whether it would track toward the power station once it became low on power. The specific locations for each of these sets of tests were 3ft. out in front of the power station, 1ft. out and 2ft. to the right, and 1ft. out and 2 feet to the left. The results of all three sets of tests, 15 in all, were positive; once the robot expended sufficient power to reach the low power threshold, it would turn directly toward the power source and track toward it.

7 Discussion

There is a balance that needs to be considered when configuring the lower threshold. The lower threshold determines the distance that the robot can work from the recharging station since the remaining energy determines the distance the robot can travel. The lower threshold also determines the time at the worksite since the robot leaves once the threshold is met. This threshold needs to be set such that the robot can safely return to the charging station, yet have sufficient time at the worksite. In cases where the worksite is too far from the charging station and/or the on site time is too great, there is no setting that will allow the robot to complete the task.

The upper threshold is determined by the capabilities of the capacitors and their configuration. Unfortunately, high capacitance capacitors were only available at 2.3V when the test robot was constructed. With a maximum of 4.6V with two in series, the available voltage is 0.4V less than the 5.0V needed by the servo motors when the capacitors are fully charged. We now have 2.5V super capacitors available, which will increase the upper threshold and result in more options for the lower threshold setting, thus expanding the possible tasks. Super capacitors with a 5.0V maximum charge would significantly increase the system's capabilities (see Equation 2).

8 Conclusions

These results show the plausibility of our method for incorporating a voltage and light sensor into the controller of the robot, which helped to establish the effectiveness of our system of providing a continuous power supply for a robot operating in a colony environment. The use of capacitors as an onboard power supply has been shown to be a valid method of powering our robots to engage in colony tasks. The robots can perform tasks in the space and recharge themselves autonomously.

The configuration developed can be easily replicated on additional robots allowing for the creation of a robot colony. The prototype robot used was a hexapod but the design of the power supply is flexible and would work with other types of robots.

Future work will deal with using improved capacitors and their arrangement in order to supply power so that our robots can operate longer before needing to recharge. Issues with multiple robots trying to charge at the same time also need to be addressed. Multiple robots charging would require more complex behavior, such as a second robot in need of power waiting for the first to finish or charging from the back of a robot at the charging station. Other possible future research could be in developing independent power stations that are equipped with capacitors charged by wind or solar power.

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