CONTINUOUS POWER SUPPLY FOR A ROBOT COLONY

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ABSTRACT

A continuous power supply for the robots of a colony is presented. Capacitors are used to replace the previously employed batteries, allowing more freedom of movement and providing the required continuous power. Tests were performed to determine the most effective configuration of capacitors that would allow the hexapod robot to walk for 3 minutes without recharging. Recharging of the capacitors was done through the connection of the robot's metallic probes to the metal plates of a power station.

KEYWORDS: hexapod, power supply, capacitors, colony, robots

1. INTRODUCTION

A robot colony allows for the study of the interaction between its members (cooperation, competition, communication, and predator-prey issues). A continuous power supply offers the benefit of reducing possible human intervention in the life of the colony. There are three primary ways of supplying continuous power to the robot that have been considered: a tether, a continuous power grid, and storing power onboard with some means of recharging.

A tethered system has its power constantly supplied through a line from the power supply that is connected to the robot. The advantage of this way of providing power to the robot is that the power supplied is continuous, constant, and uninterrupted. The disadvantages are: maneuverability is reduced (the robot has to drag the line everywhere it goes) and a long line adds additional weight that the robot has to pull. RedZone Robotics, Inc. and Carnegie Mellon University's Field Robotics Center built a robot, Rosie, specifically designed to meet the challenges of performing decontamination and dismantlement operations in nuclear environments. A tether was used to transmit all power, control, and video signals to and from the robot. All signals from the console were combined with the power and routed into the tether [1]. While a tethered system such as Rosie guarantees communications and power for extended work durations, our research chose to use an on-board power supply. This configuration leaves more room on the robot for peripheral devices and eliminates the need to drag the tether, thereby decreasing the torque requirements on the drive-train. In addition, on-board power does not require a management system that would make sure the robot does not get caught in or damages the tether.

A continuous power grid is a system that uses an electrified floor and/or ceiling to provide continuous power to a robot that has a connector. One possible option would be a system similar to a bumper car. The advantage of this way of providing power to the robot is that the power supplied is continuous and uninterrupted. The disadvantages are: the power supplied is not constant, maintenance of grid and robot connector is needed, the overhead grid obscures observance, and a specific floor is required. A research group at Brandeis University built an electrified floor in order to provide power to the robots of the population that they created. [2] This was a viable solution; however, there is a potential problem with using an electrified floor in order to power a robot colony. If a metallic grill is used and if resistance is not taken into account, power will be lost as it runs through the wires. As a consequence, the power will be concentrated at the edges and will fade in the center of the grill. Our research attempts to resolve this issue by having the robots charge at a power station, store the energy in capacitors, use the stored energy for walking, and then navigate back to the power station for recharging.

Storing the power onboard involves some form of power storage and some means of recharging. There are two possible storage devices: batteries and capacitors. Batteries are usually more consistent and last longer, but take longer to charge. The new super capacitors hold enough power to last and can be quickly charged. Charging can take place using solar power or a charging station. Solar power is good because it does not require a specific spot for charging, but it does require a large surface area for the solar panels. Charging stations provide sufficient power in concentration to effect timely recharging. In his research [3], Brooks used a robot, Attila, which had batteries that powered it for about 30 minutes while actively walking. Afterwards, the robot had to recharge from solar panels for about 4.5 hours in sunlight. Solar panels alone do not have enough power to supply continuous power to a robot and the charging time is a serious constraint. The Khepera robot can carry batteries that are recharged at charging stations [4]. Although this works well for these small wheeled robots, the ServoBots need more power to drive the 12 servomotors.

Our research deals with storing power onboard. A combination of batteries and capacitors is used for power storage. A 9V battery supplies the power to the controller, capacitors supply power to the 12 servomotors. Initially the robots were equipped with solar panels for recharging, but due to extended charging times the solar panels were replaced by a charging station. Tests were done to find the correct combination of capacitors that could supply sufficient power, charge quickly, and not over burden the robot with excessive weight.

2. PROBLEM DESCRIPTION

An 8*8 foot walled area has been constructed in the Robotics Lab for colony robotics research. This colony will be populated by hexapod robots. The ServoBot, one of the robots used in this research, is a hexapod robot (constructed out of particle board) with two degrees of freedom per leg. Each leg has two servos, which provide forward thrust and vertical movement. The ServoBot was constructed to be capable of carrying its own power supply, in the form of one 9V battery and 4 AA batteries [5]. The ServoBot is controlled using a BASIC Stamp 2. The BASIC Stamp has pins dedicated to the servos, the PC serial port connection, a system ground, and an unregulated power in, which can accept 5.5 to 12 DC volts supplied by the 9V battery. The control program is written in a BASIC Stamp editor on a PC and then downloaded onto the controller via the serial port connection. The BASIC Stamp stores and executes a sequence of servo control pulses in the control program. The pulses sent out by the control program command all 12 servos to move to their next specified location. The servos require 5V to operate and 12 servos running at the same time can be powered by 4 fully charged AA batteries. The MiniBot is an additional hexapod used in this research. It shares the design of the ServoBot, but differ in size; it is 3/4 the size of the ServoBot. The MiniBot has the same controller as the ServoBot but smaller servos.

Supplying the power to the colony should not involve batteries since they only supply power for a limited period of time. A means of power storage needed to be used that could replace the 4 AA batteries. The 9V battery did not need to be replaced because it lasts long enough to run reasonable experiments. It was decided that the robot would use capacitors to store the energy and that some method of charging that would not hamper the robot’s maneuverability would be developed. A problem that needed to be solved was to decide on the number of the capacitors to be used that would allow the robot to run for approximately three minutes. Other aspects that needed to be addressed were how and where to mount the capacitors and the metallic probes on the robot and how to connect the capacitors so that the most powerful circuit would be created while being constrained by the maximum voltage allowed by the capacitors and by the weight to be added to the robot.

3. SUPPLYING POWER TO THE ROBOT

In order to power the robot several configurations were designed, tested, and compared. The power storage issue was solved by using a combination of batteries and capacitors while the power source issue was solved by choosing to use a power station instead of solar panels. A design was developed that equipped each robot with an upper and lower metal probe that could connect in parallel to charging plates of a power station. The supplied energy would be stored in capacitors and consumed during the time that the robot was in operation. When the power was low, the robot would go back to the charging station to recharge itself and the process would be repeated. The design was such that the robots should be able to charge themselves either from the power station or from another robot, by connecting in parallel to its back metallic probes. This way, complexity was added to the life of the colony, as cooperation or predator-prey behavior could develop.

3.1 Power Source

Initially, it was intended that light energy would be used to power the robots. The light would have been spread over a specific area and when the robots, equipped with solar panels, walked into this area they would have been able to acquire the necessary amount of energy. This energy would be stored in the capacitors each robot carried and when consumed, the robot would go back into the area where the light energy was available. It was discovered, however, that the solar panels were not large enough to provide the needed energy in a relatively short amount of time; the panels needed around 5 hours to charge and deliver their energy to the capacitors, thus the design was considered to be ineffective. Solar panels large enough to provide the needed power would be too cumbersome for the robot to carry, so another approach had to be devised. Therefore, a power station was built to replace the solar panels. The power station consists of two metallic plates mounted on a wood piece and connected by alligator clips to the 5V and ground outputs of a DC power supply. During the recharging process, the robot is connected in parallel to the power station, its metallic probes touching the metallic plates of the power station (Figure 2a).

3.2 Capacitors

Capacitors are primarily used for storing and releasing electrical charge (and energy) in controllable ways. The capacitors used in this research are Panasonic Electric Double Layer Radial Lead Capacitors (Gold Cap). The capacitors have "polarity", so the negative pole of the power station needs to be connected to the negative lead on the capacitor which is marked on the capacitor casing; the same needs to be done for the positive pole.

The first configuration used to power the robot consisted of two 50F[1] capacitors connected in series, four 10F capacitors connected in series, twenty 1F capacitors and six 1.5F capacitors (all these groups being connected in parallel). This mix of capacitors was used so that experimentation with different total capacitances was possible. The goal was to find the optimum capacitance for the system, i.e. to maximize the effectiveness of the configuration while minimizing the number of capacitors.

The second configuration used identical capacitors. The capacitors chosen are rated for a maximum potential difference across the leads of 2.3V and have a 50F capacitance. It was determined that overcharging the capacitors would be a better option than using several smaller capacitors to make up for the difference to 2.5V and 5V capacitors with 50F were not available. Twelve capacitors were connected in parallel groups of two capacitors connected in series thus obtaining a total capacitance of 150F. The calculations below show how this capacitance was

[1] 1F = 1 Farad = $1\frac{C}{V}$ (unit of electric capacitance)

computed. For two capacitors of capacitances C_1 and C_2 connected in series, the total capacitance is shown in Eq. (1).

$$C_{series} = \frac{C_1 \times C_2}{C_1 + C_2} \quad (1)$$

The total capacitance of capacitors connected in parallel is the sum of their capacitances. In the second configuration there are six identical capacitors groups connected in parallel, each group consisting of two capacitors connected in series. Since all the 12 capacitors are 50F capacitors, the total capacitance of the system is 150F (Eq. (2)).

$$C_{total} = 6 \times \frac{50F \times 50F}{50F + 50F} = 150F \quad (2)$$

The parallel group had to consist of two capacitors connected in series in order to provide 5V of power to the robot. The aim was to obtain a maximum accepted voltage close to 5V (two 2.3V capacitors connected in series work with a maximum voltage of 2.3V*2=4.6V). Figure 1 shows a drawing and circuit representation of one of the six groups connected in parallel.

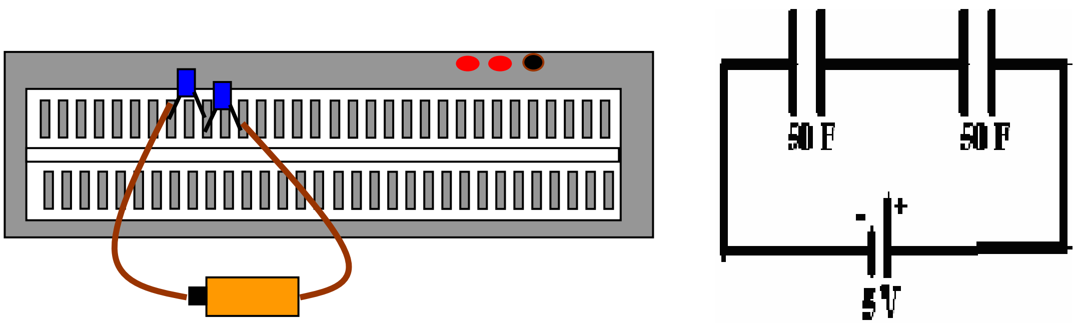

Figure 1. One of the six capacitor groups connected in parallel (i.e. two capacitors connected in series). The left figure shows a drawing of it mounted on a breadboard and connected to voltage. The right figure shows a schematic representation of the circuit.

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.

The capacitors were soldered on a breadboard, which was sustained by metal hinges and mounted on the robot above the breadboard supporting the Basic Stamp 2 (Figure 2a). In subsequent models, 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 2b). The capacitors were initially mounted on the ServoBot since it is harder to work with the MiniBot as it has very little available space. The design was then adjusted for the MiniBot.

3.3 Power Probe Placement

The probes were mounted vertically (one under the other) to avoid any issues of mixing positive and negative charges. This was an issue in both robot to robot charging and robot to power station charging. Metallic blades were used first in the design since they would provide a large area of contact (Figure 2a). They were found to be difficult to work with since they were not elastic enough to maintain their shape. It was discovered that piano wire provided enough contact area and was easier to use. In subsequent models, vertically mounted piano wire probes were used (seen on the extreme right of the robot in Figure 2b). Figure 2a shows the initial ServoBot equipped with the capacitors and the metallic probes while charging from the power station. Figure 2b shows a side view of the MiniBot equipped with 8 capacitors connected in parallel groups of 2 capacitors in series. A bottom view of the MiniBot can be seen in Figure 3b.

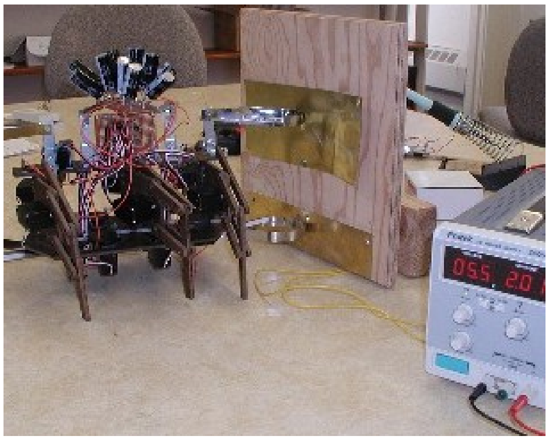

Figure 2a. The ServoBot equipped with capacitors and probes during charging.

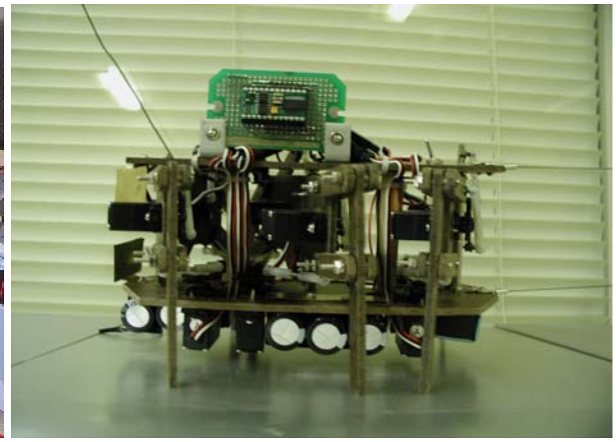

Figure 2b. The MiniBot with the capacitors and piano wire probes (side view).

4. TESTS OF CAPACITOR CONFIGURATIONS

Although the basic design of the power supply system had been completed, it was still left to determine the number of capacitors required to provide the power needed. It was desired to have 3 minutes of continual robot operation with minimal charge time. A major limiting factor was the number of capacitors each robot was capable of carrying, so it was desirable to keep this number as low as possible. All the results discussed in this section are the average of at least 5 runs of each test so that they give a good approximation of the real values for the charge time and the run time. The initial tests were performed with the robot placed on a box (its legs did not touch the ground) so that friction was minimized.

For the initial design, in which there were capacitors of dissimilar capacitance used, the charging time was determined to be 50 sec, the MiniBot could run for 3 min 30 sec and the ServoBot could run for almost 30 sec. By switching to a cleaner design, the performance was improved. For the case of charging the capacitors at 5V and stopping the process at 4.6V; the results are presented in Table 1. Afterwards, tests were performed with the capacitors charging at 6V while being connected in parallel groups, each group consisting of 3 capacitors connected in series. The results are displayed in Table 2. It can be observed that this setup is less efficient since the run times are shorter than their counterparts obtained with the previous setup.

# Capacitors	Charge Time	Run Time (MiniBot)	Run Time (ServoBot)
2	30sec	50sec	30sec
4	1min	1min 25sec	1min
6	1min 30sec	2min	1min 55sec
8	2min	3min 10sec	2min
10	2min 15sec	3min 30sec	2min 15sec
12	2min 20sec	5min 30sec	2min 50sec

Table 1: Charge time and run time on box by charging the capacitors connected in parallel groups of two capacitors connected in series at 4.6V.

# Capacitors	Charge Time	Run Time (MiniBot)	Run Time (ServoBot)
6	1min 30sec	1min 25sec	1min
12	2min 30sec	4min 30sec	1min 50sec

Table 2: Charge time and run time on box by charging the capacitors connected in parallel groups of three capacitors connected in series at 4.6V.

All the testing up to this point was done with the robots sitting on a box, so that the legs did not touch the ground. In the next step, the robots walked on the carpet; due to the inherent friction, the running times were expected to decrease compared to the previous cases. In order to help counter this change and to speed up the charging times, the capacitors were charged at 5.5V and the charging process was stopped at 5V. The results are displayed in Table 3. Figure 3a graphs the results of Table 3.

# Capacitors	Charge Time	Run Time (MiniBot)	Run Time (ServoBot)
2	20sec	1min 5sec	25sec
4	45sec	2min 40sec	1min
6	1min 15sec	3min 50sec	1min 25sec
8	1min 40sec	5min 10sec	2min
10	2min	6min 15sec	2min 15sec
12	2min 20sec	8min	2min 50sec

Table 3: Charge time and run time on ground by charging the capacitors connected in parallel groups of two capacitors connected in series at 5V.

It can be seen that in order to have the robots running for 3 minutes, 6 capacitors are powerful enough for the MiniBot but for the ServoBot more than 12 capacitors are required. A natural concern was that when the capacitors are mounted on the robot, their weight would have a negative effect. Thus, it was decided to have the ServoBot carry 12 capacitors, which allow for 2 minutes and 50 seconds of run time as it can be seen in Table 3. This performance was considered to be reasonably close to the initial goal of 3 minutes run time. The MiniBot could comfortably carry 8 capacitors (Figure 3b), which resulted in over 5 minutes of run time after less than 2 minutes of charging.

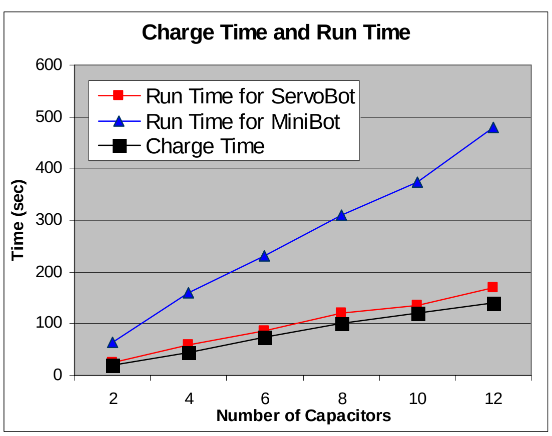

Figure 3a: Charge Time and Run Time for the two robots when charged at 5V with the capacitors connected in parallel groups, each of two capacitors connected in series.

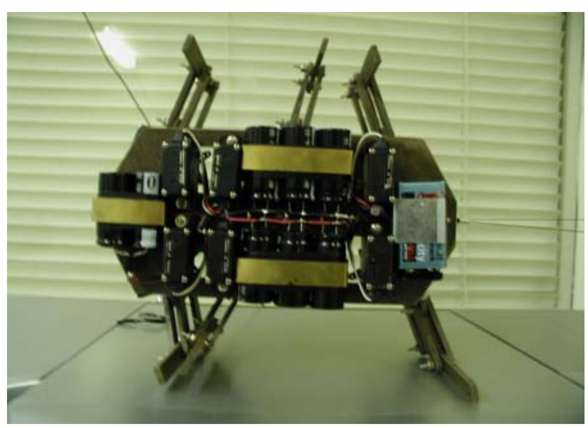

Figure 3b: The mini hexapod with eight capacitors (view from underneath).

The power supply was designed to have the robot walk to the power station and charge itself by touching the metal part of the power station with its metallic probes. The charge time was tested and found to be the same both when the capacitors were connected to the alligator clips coming from the power station and when they barely touched the charging plates. Therefore, the contact surface for charging did not need any modifications because it served its purpose well; when the metallic probes of the robot barely touched the power station the robot started charging its capacitors. In addition, when the probes of one robot touched the probes of another robot the former was able to start charging itself from the latter, as desired.

The design required that a robot be allowed to steal energy from another robot only when connected to the back of the prey and not when connected to its front. This will be achieved by using a diode that controls the current flow, allowing the current to go only in one direction. The diodes to be used are 1.5A diodes but the current flowing through the circuit when charging the capacitors reaches 5A so the diodes will need to be connected three in parallel before they can be used.

Tests were done to determine how fast a robot could charge itself from another robot. When the first robot had 2 empty 50F capacitors and the second robot had 8 charged 50F capacitors, it would take 25 seconds to equalize the capacitors on the two robots to the same voltage. When the first robot had 4 empty 50F capacitors and the second robot had 8 charged 50F capacitors, it would take 35 seconds for all of the capacitors on the two robots to have the same voltage.

5. CONCLUSIONS

Our research demonstrated that the designed power supply is an effective one. Both the ServoBot and the MiniBot were able to run for approximately the target run time of 3 minutes. They were able to successfully charge themselves from the power station in a relatively short amount of time and they were also able to recharge by connecting in parallel to another member of the colony. The recharging times of these two different approaches to powering the robot proved to be almost identical. The results were particularly promising for the MiniBot configured with 8 capacitors, a comfortable load for this robot. After less than 2 minutes of charging, the MiniBot can actively operate for over 5 minutes.

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.

6. REFERENCES

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