Efficient powering of a robot swarm

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Swarm robotics design follows the behavior of insects operating in a group, such as ants and bees. Autonomous robots need to be aware of their power system, especially regarding battery life. Power distribution in these types of robots is very important, powering a myriad of on-board sensors, actuators, and communication modules (Figure 1).

Figure 1: Hardware architecture design showing all of the devices that will be powered by the on-board battery power system of the typical swarm robot. (Image courtesy of Reference 1)

The battery

In this paper, a rechargeable Nickel Metal Hydride (NiMH) was chosen as well as a Lithium Polymer battery as a source of power for the robots in the swarm. This class of batteries are characterized by small size, light weight, and are easy to install into the robot chassis.
Power distribution and management

Designers need to calculate the total power consumption by taking into account the current consumed by sensors, actuators, microcontrollers, cameras, and any other electronic components used on the robots for their desired tasks.

The working environment, terrain composition, elevation, and actions such as how many times a gripper closes and pulls an object must also be carefully considered in an efficient power system.

Designers will have to determine and measure the time that sensors and actuators will be active and multiply this time by their operating current. So, for example, if the ultrasonic sensor uses 20mA when powered on, and will be on 80% of the time, the calculated current used will be 0.8 x 20mA = 16mA. Let’s look at an example from Reference 1. See Table 1.

**Table 1**: The total power consumption for one of the types of robots in the swarm. Each robot in the swarm can have different combinations of sensor sets. (Image courtesy of Reference 1)
In this case a 2000mAh Lithium-Polymer battery was supplying the power, and the total power consumed by this particular robot rover is 650.5 mA. The battery life is calculated as follows:

\[
\text{Battery Life} = \frac{\text{Battery Capacity}}{\text{Total power consumed for this robot}} = \frac{2000\text{mAh}}{650.5\text{mA}} = 3.07 \text{ Hours of operation}.
\]

**Table 2:** The total power consumption for another of the robots in the swarm (Image courtesy of Reference 1)

<table>
<thead>
<tr>
<th>Component</th>
<th>Rating (mA)</th>
<th>Operating Time (%)</th>
<th>Current Consumption * No of Components</th>
<th>Total (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultrasonic Sensors (SRF02)</td>
<td>4</td>
<td>70%</td>
<td>2.8 mA * 2</td>
<td>5.6 mA</td>
</tr>
<tr>
<td>Ultrasonic Sensors (URM V2)</td>
<td>20</td>
<td>100%</td>
<td>20 mA * 1</td>
<td>20 mA</td>
</tr>
<tr>
<td>IR Sensors (Sharp)</td>
<td>33</td>
<td>50%</td>
<td>16.5 mA * 1</td>
<td>16.5 mA</td>
</tr>
<tr>
<td>Temp and Humidity sensor</td>
<td>4</td>
<td>10%</td>
<td>0.4 mA * 1</td>
<td>0.4 mA</td>
</tr>
<tr>
<td>Servos (HS 422)</td>
<td>120</td>
<td>50%</td>
<td>60 mA * 4</td>
<td>240 mA</td>
</tr>
<tr>
<td>Wheel Drive Motors</td>
<td>160</td>
<td>100%</td>
<td>160 mA * 1</td>
<td>160 mA</td>
</tr>
<tr>
<td>Microcontroller (PIC)</td>
<td>90</td>
<td>100%</td>
<td>90 mA * 1</td>
<td>90 mA</td>
</tr>
<tr>
<td>Encoders</td>
<td>4</td>
<td>100%</td>
<td>4 mA * 2</td>
<td>8 mA</td>
</tr>
<tr>
<td>Motor Controller</td>
<td>10</td>
<td>100%</td>
<td>10 mA * 1</td>
<td>10 mA</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>100</td>
<td>100%</td>
<td>100 mA * 1</td>
<td>100 mA</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>650.5 mA</strong></td>
</tr>
</tbody>
</table>

In this case a 2000mAh Lithium-Polymer battery was supplying the power, and the total power consumed by this particular robot rover is 650.5 mA. The battery life is calculated as follows:

**Battery Life = Battery Capacity / Total power consumed for this robot = 2000mAh/650.5mA = 3.07 Hours of operation.**
In this second case, a 2200mAh Lithium-Polymer battery is used to supply the power, and the total power consumed by robot = 815.1 mA. The battery life is calculated as follows:

Battery Life = Battery Capacity/Total power consumed another for robot =
2200mAh/815.1mA = 2.69 Hrs.

Deploying a robot swarm with a control algorithm that determines particular robots with a specified task in which only the necessary sensors and actuators for the specified assigned task are energized, while all the others are in sleep mode, will optimize operating time and task performance (Reference 1).
Charging via automatic docking

A battery chemistry of Lithium Polymer (LiPoly) should be used for small robots because of its high energy density and output current capabilities (Reference 2). Other advantages are capability of assuming a low profile, the size of a credit card in some cases, in a flexible form factor not bound by cell formats, a lightweight advantage (use of gelled electrolyte can eliminate a metal enclosure need), and safety because of resistance to overcharging and less chance of electrolyte leakage. However, the LiPoly battery should still be protected against over/under voltage as well as over current conditions.

In order to deploy a large robot swarm, manually re-charging the robots is not very practical. Automatic docking with a charging station or stations should be considered. The robot can be designed to find and engage with a docking station, but this is a higher level task for the robot than its usual tasks, so a smart power module should be designed (Reference 2). The power module, however, should be designed with the mating contacts for the charging station using a feasible mechanical design to enable easy contact engagement. It would be advisable for safe/optimum charging to allow another set of contacts on the robot for bi-directional high-speed communication with the charger host computer for proper/safe charging.

Swarmrobot.org also outlines some advantages and disadvantages of locating the charge management on or off the robot and also includes some charging circuitry examples and ICs (Figure 3).
Figure 3: A possible power management design using a Linear Technology (Soon to be merged with ADI) LTC4054ES5-4.2 IC (Image courtesy of Reference 2)

Power management in robot vision

An important aspect of robot swarms is robotic vision (Reference 3). Without vision, the robots in the swarm would have more difficulty in performing their tasks without collisions. Of course, LIDAR and or RADAR can be used as well, but there are advantages in using embedded vision, and especially bio-inspired vision akin to locust swarms detecting objects (other locusts and obstructions) that are approaching at relatively high speeds. Locusts use a wide-field visual neuron known as lobula giant movement detector (LGMD) with which they appropriately respond to imminent collisions.

In this article I will only discuss the power management design needed for such a vision system. The Colias swarm robotic platform which provides motion, short-range proximity sensors and power management, and the vision processing module from Reference 3 are used in the robot design and shown in Figure 4.
Figure 4: This image shows the Colias robot platform (That’s tiny!) (a) and its block diagram (b). The lower board shown is marked within a red rectangle in the block diagram, and was used in the Reference 3 study. (Image courtesy of Reference 3)

The lower board in Figure 4a (and outlined in red in Figure 4b) manages power consumption and re-charging for the power section.

The robot, under normal conditions, in a walled-arena, with short-range, low-power IR emitter communications, consumes around 2 Watts. Using a 3.7V, 600 mAh lithium-polymer battery as the main power source, allows a typical 2 hour running time of operation.

The motion motors for the robot are two micro DC motors and are individually controlled by a pulse-width modulation (PWM) technique and each motor is driven by an H-bridge DC motor driver that will draw 120 mW and 550 mW depending upon the load. Pretty efficient.

Using a low voltage CMOS image sensor in a tiny package, allows its power supply at 3.3V at 60 mW to be low power as well. See Figure 5 for the vision module shown attached to the Colias robot platform and Figure 6 for the hardware architecture of the system. Finally, Table 3 summarizes the power consumption of the robotic system.
Figure 5: The micro-robot is shown here with the vision module in green on top of the red Colias board. (Image courtesy of Reference 3)

Figure 6: The block diagram of the complete robotic hardware architecture system (Image courtesy of Reference 3)

Table 3: Power consumption characteristics of the robotic system
Due to the small size and low power of the vision system shown here, it is possible to integrate two vision modules into the robot, which will enable a binocular vision system. Higher power FPGAs have been used effectively in robotic vision systems as well, but their high power eliminates this option in a small swarm robot.

So in robot swarm applications, much emphasis must be placed on function with an eye on low power consumption. This is certainly a challenge and a balancing act that circuit designers need to make regarding decisions of functionality vs. running time for the robots.

I will have more articles like this one, and the EDN Astrobotics article for space exploration, coming soon.

References

2. **Power Management Board**, swarmrobot.org