RoBM^2: Measurement of Battery Capacity in Mobile Robot Systems

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Abstract. With battery driven robot systems performing very sophisticated tasks, increasing demands on the power supply play a critical role. Operation breakdowns are unpredictable unless the state of the battery is known, and the overall performance should be adjusted according to reliable remaining capacity estimations.
This paper addresses many of the issues related to the management and monitoring of battery packs for mobile robots, whereas an implementation for a particular system is presented.

1 Introduction

Modern robots increase in complexity as new applications, e.g. cameras or navigation modules, are added to the system. These enhancements pose demanding operation conditions on the battery, emphasizing the importance of this component. Usually batteries represent an unpredictable source of power, whereas little or no knowledge about their characteristics or state is available. Methodologies to perform estimates of the remaining capacity may not be implemented. Equipment powered by the battery cannot determine if the battery, in its given state, is capable of supplying adequate power for an additional load. Even worse, the batteries may not be used correctly, e.g. due to wrong charging procedures or inadequate storage conditions at too high temperatures, what may result in damage or reduced performance. Under these suboptimal conditions it is often not possible to ensure the proper operation of the robot, this being unacceptable for security-critical applications.

An intelligent interface between the battery pack and the supplied mobile robot is introduced here. Previous work on battery management and monitoring solutions for portable communication devices [1] helps to develop hardware and algorithms able to cope with the challenges of high-power consumption robots. A Robertino robot [2] is upgraded with a dedicated Robot Battery Management and Monitoring module (RoBM^2), and serves as a flexible framework to test and develop new routines that provide the robot with reliable remaining capacity estimates and extend battery life.

2 The Smart Battery System (SBS) Reference Model

The Smart Battery System (SBS) [3] contains multiple specifications detailing a complete power system for portable devices. Guidelines are provided for developing compliant products, that share a common interface (the SMBus) and a set of commands as defined by the Smart Battery Data (SBData) specification. The System Management bus [4], a specific implementation of a Phillips I^2C-bus, is a two-wire bus used to transport data between low-speed devices. It describes protocols, device addresses and additional electrical requirements for the SBS.

The following components should always be present:

- Smart Battery: A battery equipped with specialised hardware that provides present state, calculated and predicted information to the SMBus Host.
- Smart Battery Charger: A battery charger that periodically communicates with the Smart Battery and adjusts the charging profile in response to the actual requirements (charging current and charging voltage).
- SMBus Host: A device powered by a Smart Battery. It receives information about the battery's present state and capabilities. The SMBus Host will also receive alarms from the Smart Battery when it detects a problem.

2.1 Limitations and Alternatives

An intelligent power supply as specified by the SBS has many advantages, since reliable energy and accurate information are available. The major difficulty in implementing the SBS reference model relies on the fact, that Smart Batteries are rarely available and the given robot system has to deal with standard battery packs that offer no information about their status. A Smart Battery System architecture as proposed in Fig. 1(a) is not feasible in this case.

Fortunately, this drawback does not discard this reference model as an option for standard batteries. The SBS specification itself gives a hint to overcome this obstacle: *"The electronics need not be inside the Smart Battery if the battery is not removable from the device"*. This statement enables the adoption of the architecture shown in Fig. 1(b). The Smart Battery can be replaced by a standard battery, if reliable environment measurements (sensors), battery models (stored in a nonvolatile memory) and intelligence (software running on a microcontroller) are added to the power supply system. These subblocks should be attached to the SMBus to perform a transparent replacement of the Smart Battery.

SMBus Hosts are not always available. The microcontroller shown in Fig. 1(b) implements the intelligence of the proposed battery management and monitoring system, and can also communicate with the host over a serial interface (in this case a RS232), building a bridge between the robot-processor and the SMBus. With this latter step, the SBS specifications are feasible for any battery pack.

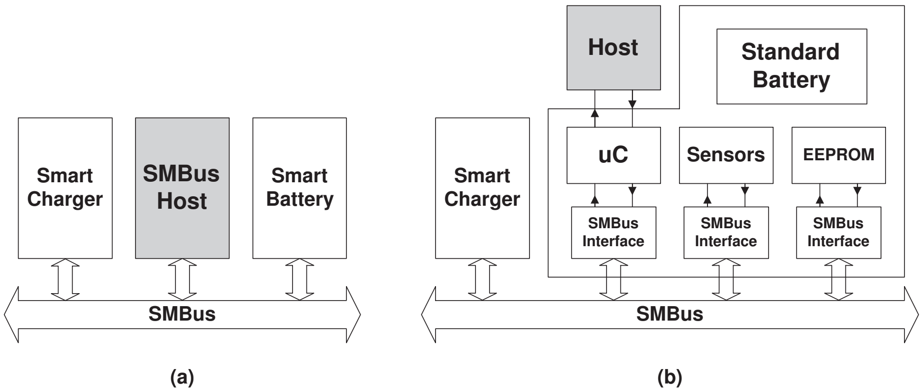

Fig. 1. (a) Smart Battery System specification. (b) Alternative architecture supporting standard batteries.

3 RoBM^2 Board

It is common to find robots that adopt lead-acid batteries as their power supply. Despite the low power-density of these cells, they are appreciated due to their price and robustness. Charging electronics are usually simplified for this chemistry, whereas system complexity is reduced to a minimum at the cost of battery life and reliability. The work introduced here has improved this scenario with the implementation of battery management and monitoring resources in compliance with the SBS guidelines, relying on a Smart Battery Charger and an ATmega16 microcontroller [5].

The RoBM^2 board is a flexible platform for the implementation of battery-tailored supervision policies, even in the absence of smart power supplies. It has been conceived to handle batteries (max. 2 packs in series) that match the requirements of the Robertino platform, ranging from lead-acid, Ni-based to Li-based chemistries.

All the tasks undertaken by this board can be separated into two major categories that are explained in more detail in the following subsections.

3.1 Battery Management

A Smart Battery Charger and the battery management software running on the microcontroller are responsible for an intelligent battery charging procedure.

The Level 2 Smart Battery Charger is a charging circuit that provides the battery with charging current and charging voltage to match the battery requirements in the presence of an external power supply. This charger must understand the characteristics of the battery it is charging. The battery management software reads battery charging models from the system EEPROM and programs the proper charging profile, as a function of the battery chemistry and the full capacity of the battery pack [6]. End-of-charge is determined by various methods depending on the specific chemistry and environmental conditions.

The RoBM^2 is even able to perform pulse-charging besides the more common galvanostatic charging. The pulse-charge method can reduce long-term damages of the battery as gas and heat generation are minimised.

3.2 Battery Monitoring

Battery monitoring deals with remaining capacity estimations and the communication with the host over the RS232 interface.

The battery State-of-Charge (SOC) [7] is calculated basically taking into account the difference between the charging and discharging currents (Coulomb-Counter method). Measurements of voltage, temperature, charging and discharging currents (see Table 1) are made in a continuous loop by a multi-channel Analog-to-Digital Converter (ADC). The battery monitoring software collects data from the ADC and battery models from the EEPROM.

Voltage measurements are a good parameter to determine the SOC when no load is applied, since Open-Circuit-Voltage (OCV) and SOC are correlated [8] and manufacturer independent, but this is unfortunately not true under load. The impedance of the battery distorts the voltage measurements during power consumption and this is why SOC calculations should not rely on those only. Nevertheless, voltage can be an indicator to know if we are close to the cut-off point, and the OCV should be employed in combination with Coulomb-Counter methods to perform accurate remaining capacity estimations.

There are other pieces of information that are as important as the SOC. Alarms are generated in case critical situations are detected, e.g. damaged batteries, external supply is available or SOC is below a predefined threshold. These are sent to the host using the serial interface.

Table 1. Measured parameters used by the battery management and monitoring software at the RoBM^2 board.

Measurement	Purpose
Battery Voltage	Battery Management
Pack1 Voltage	Battery Monitoring
Pack2 Voltage	Battery Monitoring
Open Circuit Voltage	Battery Monitoring
Temperature	Battery Monitoring
Discharge Current	Battery Monitoring
Charge Current	Batt. Man. and Mon.

4 Integration in the Robertino platform

The Robertino platform is the result of a collaboration project, between the Fraunhofer AIS in Sankt Augustin and the Chair of Computer Science No. VI at the Technical University of Munich. Briefly, the Robertino platform consists of a standard industrial PC (PC104) with a Debian GNU/Linux operating system and an internal communication CAN-Bus.

Figure 2 depicts the PC104 stack, where the main functions are implemented. In this work the so-called Connector board was replaced with the new smart RoBM^2 board. The original board is only responsible for connecting the battery packs to the main board and possesses an interruptor for main on/off switching purposes.

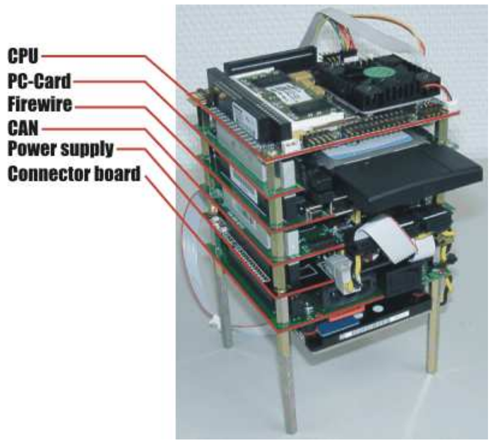

Fig. 2. The RoBM^2 board replaces the Connector Board [2] in the PC104 stack.

The new smart RoBM^2 has been designed to match the PC104 card size. Nevertheless it has been necessary to expand the board in one direction to accommodate two new connectors for uploading software updates and debugging purposes, as well as the additional RS232 connector for the serial interface. Thus has been achieved a compact design, which makes it possible to replace the board in a smart and quickly manner.

5 Conclusions and Future Work

In this paper we have introduced an architecture for battery management and monitoring systems relying on the Smart Battery System specifications. The RoBM^2 board is a practical implementation of this open standard, and serves as a universal platform to develop supervision algorithms for any battery chemistry. This board has been conceived to be part of a Robertino robot, providing the host periodically with accurate information about the state of the power supply. Future work will focus on the development of optimised algorithms for battery management and monitoring on base of the Robertino platform.

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