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Solar Powered Robotic Vehicle for Optimal Battery Charging Using PIC Microcontroller

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***Abstract*—This paper focuses on the design and construction of an optimization charging system for Li–Po batteries by means of tracked solar panels. Thus, the implementation of a complete energy management system applied to a robotic exploration vehicle is put forward. The proposed system was tested on the VANTER robotic platform—an autonomous unmanned exploration vehicle specialized in recognition. The interest of this robotic system lies in the design concept, based on a smart host microcontroller. On this basis, our proposal makes a twofold significant contribution. On the one hand, it presents the construction of a solar tracking mechanism aimed at increasing the rover's power regardless of its mobility. On the other hand, it proposes an alternative design of power system performance based on a pack of two batteries. The aim is completing the process of charging a battery independently while the other battery provides all the energy consumed by the robotic vehicle.**

***Index Terms*—Li–Po battery, mechatronic system, photovoltaic (PV), robotic vehicle, solar tracker.**

I. INTRODUCTION

SOLAR power systems in autonomous robotic vehicles have been often used for some years. A real example is the So- journer rover, in which most of the supplied energy is generated by a reduced-size photovoltaic (PV) panel [1]. However, in case of scarce to no solar light, the rover should minimize consumption, since its batteries in line could not be recharged when depleted [2]. The use of rechargeable batteries in a space mission was used for the first time in the Mars Exploration Rovers. Nevertheless, the need for greater operation autonomy by Spirit and Opportunity was solved by means of larger deploy solar panels [3]. This solution works as the basis for the design of solar panels for the future ExoMars mission. This rover, thanks to its high-efficiency ultrathin-film silicon cells constructed on carbon-fiber reinforced plastic, is capable of providing higher power [4], [5]. NASA designs inspired different generations of exploration vehicles [6]. This is the example of K9, a rover for remote science exploration and autonomous operation [7]; field integrated design and operations, an advanced-technology prototype by Jet Propulsion Laboratory for long-range mobile planetary science [8]; and Micro5, a series of robotic vehicles devised for lunar exploration [9]. As its main design advantage, this rover series has a dual solar panel system coupled to an assisted suspension mechanism. This prevents the manipulator arm mounted on the middle of the rover from having to minimize solar panel-generated power and allows it to dust solar panel surface. Other robotic exploration vehicles have also been developed in academic spheres. T On the other hand, the Carnegie Mellon University developed Hyperion, a rover in which the major technological milestone was the implementation of solar-synchronous techniques to increase the amount of energy generated by solar panels [12]; and

Zoe¨, a rover capable of long-distance traverses under extreme environmental conditions devoted to science investigation at the Atacama desert [13]. With an educational approach, Carnegie Mellon University also developed a personal exploration vehicle called PER [14].

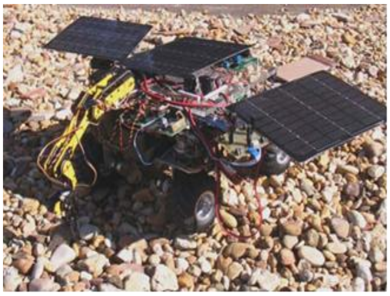

Fig. 1. VANTER: a solar-powered robotic vehicle.

The platform—known as Cool Robot—uses a control algorithm of maximum power point (MPP) aimed at maximizing system-supplied power for five PV modules designed as a cube. Finally, there are some noteworthy projects which main achievement is the optimal selection of solar energy and different power sources according to the operation conditions of a robot.

The VANTER robotic exploration vehicle aims to improve various aspects of the aforementioned rovers with scientific and academic purposes. Subsequently, this paper is organized as follows. The next section presents the mobile robotic system. Its main features are described and its hardware and software architecture are presented. Section III introduces the concept of smart host microcontroller (SHM) for intelligent power management applied to an exploration vehicle.

The following sections present the control of the battery-charging system by means of tracked solar panels, which is the main aim of this paper; the design of its mechanical structure, its electronic devices and the graphical user interface (GUI) are presented. Section IV aims at providing the necessary parameters for the batteries sizing, charging, and discharging algorithm, and the PV system sizing. Therefore, Section V puts into practice the developed methodology by testing the rover power systems. Finally, the results and findings from the developed work are presented.

II. MOBILE ROBOTIC PLATFORM

VANTER—Spanish acronym for autonomous unmanned ex- ploration vehicle specialized in recognition—is a robotic exploration vehicle developed at the University of Huelva, Huelva, Spain [20]. The rover was developed to be guided and has a set of four wheels coupled to a plane chassis that can rotate independently. The four-wheel-drive (4WD) and the individual control of each wheel allow different types of movement; in- cluding Ackerman configuration, the crabbing maneuver or the rotation with inner inertial center. The four wheels in VANTER are sustained by means of independent passive suspension of double aluminum fork to absorb terrain vibrations. Each wheel consists of two motors, one for rotation and another for driving. On the one hand, forward movement is produced by means of dc motors (12 V and 60 mA) that provides 120 r/min with a torque of 8.87 kg/cm. On the other hand, the rotation motor provides a speed of 152 r/min Among others instruments aboard VANTER disposes of a 5-DOF robotic arm, an OmniVision MC203 wire- less microcamera, and an analog video receiver with a Pinnacle Dazzle DVC100 video capture card [20]. Its reduced weight, small dimensions, and versatility make VANTER suitable as a robotic exploration vehicle (see Table I).

The robotic system programming is divided into three main code levels and its hardware was designed with a hierarchical control structure based on modular microcontrollers (see Fig. 2). The top level program, carried out in LabVIEW language, is exe- cuted in a remote PC and offers a GUI to monitor and control the whole robotic vehicle. The second code level, programmed in C language, runs autonomously on a master PIC16F876A microcontroller aboard VANTER. Communication with the re- mote PC is performed by using a UHF modem for the centralized control of rover functions. The third code level consists of several slave microcontrollers distributed in an I^2 C network aimed at the distributed control of the VANTER driving functions (4 × PIC16F88), remote manipulation, and power management.

III. MECHATRONIC SYSTEM DESIGN

A typical power management design consists of smart batter- ies integrating both communication devices and electronics able to control the charge. However, when an economical system is required, the concept of intelligence should be applied to soft- ware design for simple batteries. One of the main objectives of this paper is the implementation of the SHM concept to develop a low-cost power management system aboard a robotic vehicle. The system consists of an electrical circuit interconnecting a PV system, a charger device, a selector system, a batteries monitor system, and a battery system.

The SHM is based on a PIC16F886 microcontroller, which monitors VANTER consumption and decisions in a completely autonomous way [22]. The SHM has two main functions: 1) detecting environmental light level and controlling the solar tracking system to obtain the highest power; and 2) interpret- ing operation data from batteries and solar panels to control the working mode of the charger accordingly. The cost of this system—regardless of the navigation instruments and VANTER.

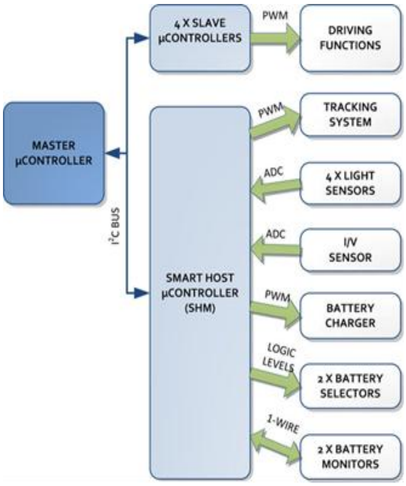

Fig. 2. Mobile robotic Platform Block Diagram

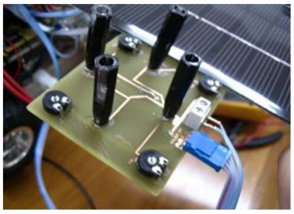

Fig. 3. Picshot hardware architecture for VANTER

A. *Photovoltaic System with Solar Tracking Mechanism*

When selecting the solar panels, VANTER physiognomy and consumption dictated its construction and electric requirements (see Section IV-C). The panel weight is a factor that limited its mechanical design; light-weight panels provide lower power consumption and require optimizing the robot's overall perfor- mance. The proposed PV system consists of three monocrys- talline solar panels with laminated PET, whose dimensions are 200 mm × 250 mm × 3.2 mm and its weight is 0.7 kg per panel.

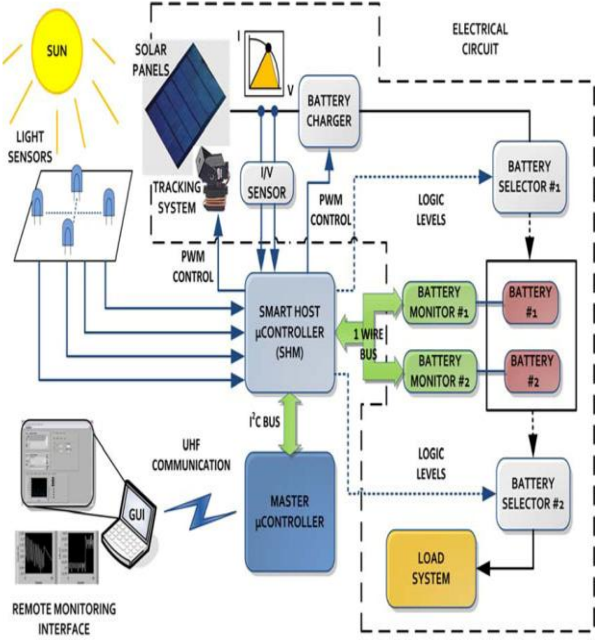

Fig. 4. Overall scheme of the power management system of VANTER

The PV system provides power, keeping in mind that voltages and currents generated must adapt to the maximum and minimum values of the hardware. However, since the environmental natural features cannot be predicted at each instant, the quantitative energy from solar radiation cannot be predicted either. Thus, one of the main proposals of this paper is the implementation of a solar tracking mechanism aimed at increasing power levels in the PV panels. Unlike other rovers that use navigation techniques to guide their panels toward the Sun [12], VANTER’s mobility does not represent a disadvantage, since the proposed tracker system looks for the most powerful light source. Solar tracker prototypes built in mobile robots have proven that orientation of PV systems leads to increased energy efficiency relative to systems with fixed solar panels (20–50% per collector). This gain depends on several construction strategies of the solar tracker such as the type of axis movement (either single or dual), type of sensors on which is based(photoresistors or photoconductive cells), and the accuracy rendered by the number of sensor pairs [24]–[26]. On the contrary, parasitic load consumption associated to the proposed configuration (a mobile solar panel, two batteries, and electronics) compared to a simple system (a fixed panel, a battery, and electronics) is increased between 1.14% and 21.42%. The consumption increment varies mainly due to the operation of the solar tracking system, which is based on servos; thus, standard dc motors is proposed to reduce the consumption up to 8.57%.

Fig. 4 shows the mechanical solar tracking system. This comprises (a) a fixed solar panel mounted horizontally on VANTER and (b) two panels with symmetrical movements. The mechanical structure is mounted on (c) an aluminum chassis on which the electronics were mounted. On top of this platform (d) a methacrylate panel with (e) two side supports has been assembled. The solar panels are mounted on (f) pan and tilt units formed by two DYS0213MGs metal gear servos. Each pair of digital servomotors allow soft rotations with an amplitude of 180° in (g) azimuth and (h) elevation, so that the solar panels can be oriented toward any part of the space.

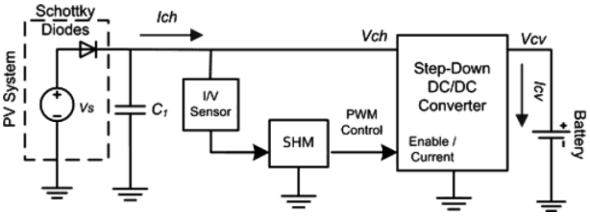

Fig. 5. Connection diagram of the charger system

B. Batteries Monitoring System

The aim of the monitoring system is maximizing the life and energy storage of Li–Po cells. Therefore, the main function of this system is monitoring the state of charge (SoC) of the batteries and accurate control of the charging–discharging cycles. The use of a dual battery monitor system was required for control and parameter measurement. This module consists of two. Each of these is connected to the batteries in parallel—so that the charge/discharge current passes through its measuring resistor—and by means of a 1-Wire bus multidrop type, both to the load system and the charger through the SHM. The main advantage of the dual monitoring system is that it allows continuous measurement of both the capacity of the battery in charge as well as of the one being discharged.

Among other essential monitored parameters such as voltage, current, and temperature—which prevent batteries from working near their warming limits—the monitor displays some other important parameters such as the batteries’ SoC, relative capacity (%), absolute capacity (mAh), state of health (SoH), and internal resistor (R_{int}).

IV. EXPERIMENTAL RESULTS

This mathematical expression responds to an SHM- programmed algorithm where y stands for servo displacement, *x* is the difference of illumination between each couple of photosensors, and constants are values experimentally obtained in ground testing (see Fig. 6). The advantage of this strategy relative to other types of equations (i.e., linear or logarithmic) is the servos performing large displacements when the lighting values between each pair of photosensors evince high discrep- ancies on its axis. Similarly, shorter and accurate shifts are obtained when lighting values are approaching the most power- ful light source. In this way, the pan and tilt units try to place mobile solar panels perpendicularly to the most intense light source available. Higher energy collection is therefore possible.

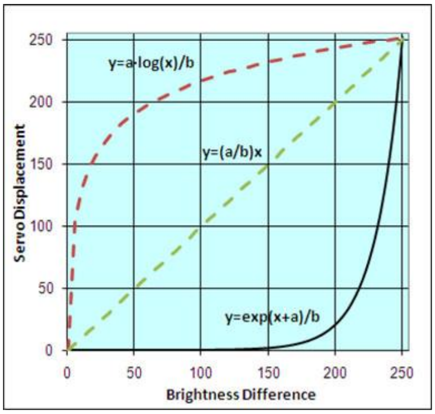

Fig. 6. Simulation Result of Displacement Response

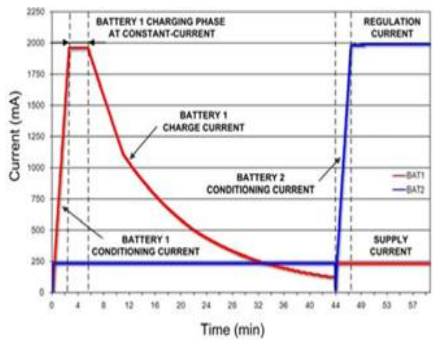

Fig. 7. Graph Showing Time vs Current

V. CONCLUSION

Delivering the systems' energy requirements while recharg- ing the backup battery was made possible by implementing a dual system of selectors, monitors, and batteries. This strategy implies small solar panels to power a single battery at a time. A relatively good compromise between total weight, capacity available, and source-required power is reached. This solution does not attempt to achieve high charging times or great operat- ing times but to prove a sustainable and commercially feasible solution applied to a robotic vehicle. In this sense, an SHM was designed for optimal charge regulation by means of an MPP- tracking scheme based on the DPPM.

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