Solar Energy Powered Bicycle for Wireless Supervisory Control and Remote Power Management Applications

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Abstract – In this paper, a solar energy powered bicycle linked to a wireless sensor network (WSN) which monitors the transfer of solar energy to an electrical energy storage unit and an analysis of its effectiveness is proposed. In order to achieve this goal, a solar-powered bicycle with an attached ZigBee and a far-end wireless network supervisory system is setup. Experimental results prove that our prototype, solar energy powered bicycle, can achieve enough solar energy for charging a two lead-acid battery pack. As a result, the user, through use of a wireless network in the parking period can be kept aware of the data on the amount of immediate solar radiation, the degree of illumination, the ambient temperature, and electrical energy storage capacity information of the bicycle through an internet interface.

Keywords: Solar energy, Remote power management, Electric bicycle

1. Introduction

With the increasingly wide range of applications for renewable energy and wireless network technology, the conventional supervisory control and data acquisition (SCADA) system that employs power cable deployment for remote terminal units and the data line network between the monitoring end point and the SCADA host center can be replaced. Taking advantage of renewable energy resources in a given mode of transportation's environment offers a power source limited by the mode of transportation's physical survival rather than an adjunct energy source. This study examines "Solar Energy Powered Bicycle for Wireless Supervisory Control and Remote Power Management Applications". The integration of renewable photovoltaic energy and wireless network technology enables a remote terminal units located in an open outdoor area to conduct on-site monitoring with photovoltaic power through a ZigBee wireless module, transmitting data back to the SCADA host center without physical wiring. Considering the unreliability of photovoltaic power systems, this study also provides an in-depth understanding of the availability of photovoltaic energy. Moreover, the unreliability of photovoltaic energy also makes user understanding of residual electrical energy crucial.

The ZigBee network element is one kind of wireless network agreement which is mainly made by the ZigBee Alliance [1]. Its first cross-system platform is both the media access levels and the entity level through the use of the IEEE 802.15.4 standard. By using the Global System for Mobile Communications (GSM), a handset mobile phone can receive information from electric bicycle about the stored electrical energy, feed the information into the remote monitoring center and momentarily accept the monitoring center's instructions. Valente et al. [2] first made wireless data transmission through the use of ZigBee under media access control (MAC) construction. Pegatoquet et al. [3] used a system-on-a-chip (SOC) chip, the digital signal processor (DSP), the micro control unit (MCU), the GSM, Bluetooth, and the global positioning system (GPS) which are needed to apply the audio applications of this system.

This study integrates renewable solar energy sources, the WSN and three units of wireless internet, and abbreviates the use of power lines and battery chargers. Using lays aside on the solar-powered bicycle's sensor element launcher, the user can know the data of the solar energy's immediate degree of illumination, the solar generated electrical power rate, the ambient temperature, the storage electrical energy and so on.

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2. System Structure

This structure is carried on the solar energy powered bicycle as shown in Fig. 1 by the WSN far-end network monitoring solar energy to transfer the electrical energy storage and the effectiveness analysis. In order to achieve this goal, a ZigBee is attached to a solar-powered bicycle, and the far-end wireless network supervisory system is setup. As a result, the user of the wireless network in the parking period can be aware of the data on the amount of immediate solar degree of illumination, the ambient temperature, and electrical energy storage capacity information through the internet interface. Further experiment results will be shown to verify a remote power management strategy for the solar energy powered bicycle with the proposed WSN far-end network monitoring solar energy system.

3. WSN in Campus Applications

Fig. 1. Prototype of the proposed solar energy powered bicycle

There are several outdoor applications that seem very feasible for WSNs. However, to eliminate their dependence on batteries and use of solar cells as an exclusive energy source would require the outdoor lights to be on continuously in the daytime. A simplified block diagram of a wireless router node operating on solar energy is shown with series and parallel connection in Fig. 2 and Fig. 3, respectively. Typically, a router node consists of an eight bit microprocessor with adequate resources to operate its kernel [7]. The microcontroller manages power to the sensors and data acquisition elements, as well as responding to commands from the base station. A ZigBee ready radio frequency transceiver [1] integrated with an eight bit microcontroller and the system communicates in the 2.4 GHZ frequency band. In this section, the results of research are explained and at the same time are given comprehensive discussion. The present result and Patent [9] can be presented in figures, graphs, tables and other formats that allow the reader to easily understand it.

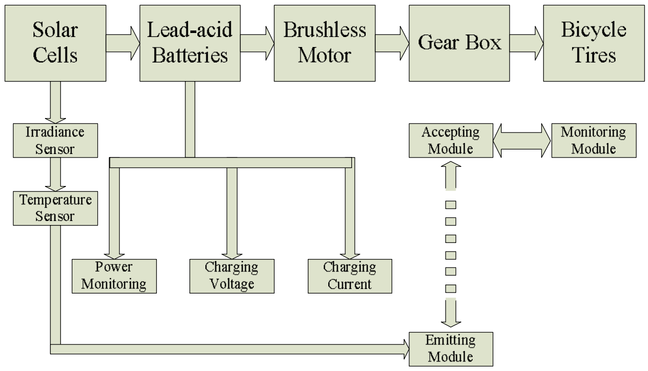


Fig. 2. The series connected monitoring block diagram

Fig. 4 shows one such wireless supervisory monitoring concept of a solar energy powered bicycle that can be used to monitor the degree of immediate solar of illumination, the ambient temperature, and the electrical energy storage capacity information. It is clear that solar energy is the most efficient natural energy source available for outdoor applications [6]. Exploiting solar energy resources in the outdoor environment offers a power source limited by the device's physical survival rather than an adjunct energy source likes electrical sockets or a battery charging station. However, the design of an efficient energy harvesting module involves complex tradeoffs due to the interaction of several factors such as the characteristics of the energy sources and environment. It is therefore essential to thoroughly understand and judiciously exploit these factors in order to maximize the energy efficiency of the solar cells module.

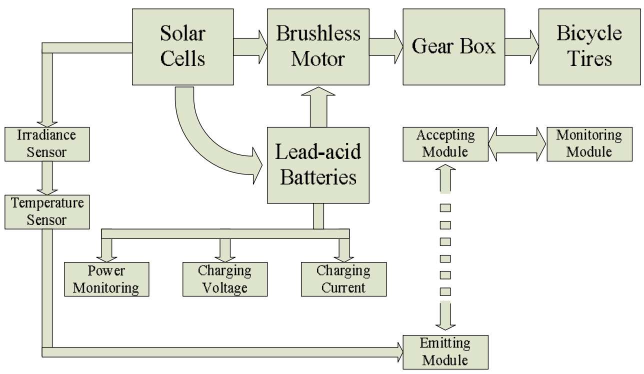


Fig. 3. The parallel connected monitoring block diagram

Due to the unstable characteristics of solar energy, it is more convenient to allow electric bicycles to run on stable sources of energy such as batteries. The maximum range of data transmission for the ZigBee is approximately one hundred meters [3]. Thus, additional nodes may be required to pass the data back to the central monitoring location. There might be several such router nodes distributed in these WSNs; the number would depend on the campus size and coverage requirements. Typically, each router node in the network has a fixed location and its only function involves establishing itself in the network and enabling prompt data transfer to the nearest router node or base station. These router nodes obviously need to be continuously turned on so that data may be promptly transferred. Since the unstable solar power outdoors is harvested in the daytime, it is advantageous to get continuous data for scavenging solar energy. This would result in a cost saving overtime and eliminate the need to charge batteries.

Referring to Fig. 2 again, the base station in such networks consists of a router that receives data and is connected to a server. The data received by the base station is displayed to allow continuous monitoring and can be routed to the battery's characteristics for easy access in real time. Similarly, ZigBee sensors in the solar powered bicycle with the solar cells can scavenge energy through overhead sunlight rather than using a battery charger. In fact, in such systems, ZigBee sensors might be mobile and therefore, it might be possible and advantageous to monitor the electric power in the batteries through photovoltaic solar cells [5]-[8].

There are two key issues that were addressed before embarking upon the design of this solar powered bicycle for wireless supervisory monitoring applications. First, solar energy has to be harvested by an efficient energy scavenging system. Secondly, there has to be an efficient means of storing this harvested energy. The system must also effectively deliver the stored energy data to the remote user so that he or she is made aware of the distance he or she can use to run the solar powered bicycle. This means there has to be an intelligent power management strategy in place. Obviously, this strategy must be aware of how much of the stored energy can be used and where the batteries can be recharged. These details along with design considerations that impact efficiency and the associated tradeoffs are explained in the next few sections.

3.1 Solar Cells Characteristic

Solar cells have vastly differing characteristics from batteries. As listed in Table 1, an 835×540×35mm 50W single crystalline solar panel from GE was chosen for the system due to its ease of availability and low cost. Each panel was rated at 3.522A short circuit (Isc) and 22.38V open circuit voltage (Voc) under the sun's irradiance (1000W/m^2) conditions. In order to determine the number of panels required per solar powered bicycle, a simple load test was conducted. A single solar panel was connected across a varying load to determine its V-I profile. Fig. 4 shows the V-I profile wherein it can be observed that at around 18VDC the panel sourced out approximately 3A. Therefore, a 50W solar panel was enough to recharge the lead acid batteries. Although the size of the panels was not a concern, a modularized approach was taken in order to reduce the panel size and weight further. It was assumed to use the solar power with 1/3 duty cycle in the daytime that the system is always turned on to charge the batteries. In addition, two lead acid batteries 12VDC 36Ah were used in parallel with the solar panels to store the solar energy and to reduce the solar panel power rating requirement even further. These details are explained in the next few sections.

Table 1. The specification of the solar powered bicycle

Solar cells	
Type	GE 50W 12V
Test conditions	
Irradiance	1000W/m2
Module temperature	25℃
Module size	835x540x35 mm
Module weight	6.5kg
Maximum power	50W
Maximum power voltage	18V
Maximum power current	2.7778A
Open circuit voltage Voc	22.38V
Short circuit current Isc	3.522A
Module efficiency η	$\eta > 16\%$
Electric bicycle	
Weight	32kg
Tire	20inch
Maximum speed	30km/h
Rated loading	<75kg
Lead acid batteries 2x	36Ah x2 (12V)
Noise	62dB
Rated Voltage	24V
Over-current protection	14A±1A
Motor type	Brushless motor
Dimension	1580x565x1075 mm

3.2 Remote Power Management Strategy

An energy harvesting scheme was used for the solar energy powered bicycle. It consisted of an adequate number of solar cells to charge the energy storage devices which in turn outputted regulated power to recharge a lead acid battery and another lead acid battery for discharge. This strategy probably works well for an electric bicycle where adequate solar energy in the daytime is available to charge the energy storage devices. However, in many outdoor applications, solar energy scavenging from a 50W solar panel is fairly practical. This strategy was utilized to obtain power for the bicycle's driving or stopping period in the daytime. The core of the energy harvesting module is the power management circuit which draws power from the solar panels and manages energy storage and power routing to the electric motor. The most important considerations in the design of scavenging energy are to maximize energy efficiency, enhance device reliability, and lengthen the range of the electric bicycle. The power management circuit designed for this system provides regulated power in lead acid batteries.

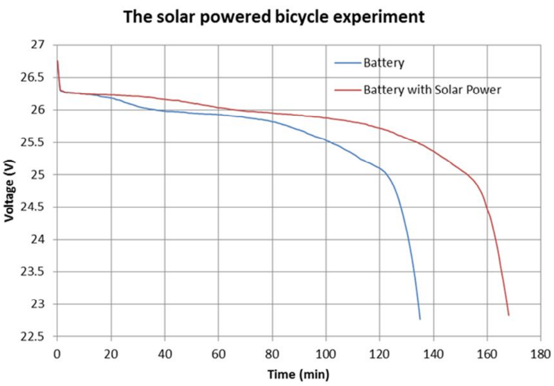


Fig. 4. The monitoring voltage output of solar powered bicycle in the winter

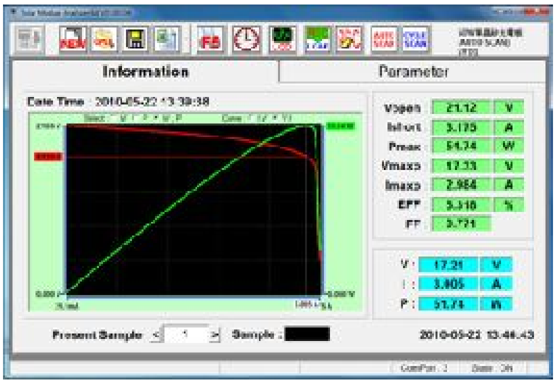


Fig. 5. V-I characteristics of a GE 50W solar panel

Fig. 6. ZigBee sensors mote with blue PC module

3.3 Experimental Results

In order to determine the right number of solar cells for powering each electric bicycle a simple load experimental test was first conducted. The electric bicycle with two sets of 36Ah lead-acid batteries and the 50W solar cell in the back seat, which was tested upon during sunny summer weather, when only depending on the built-in batteries to run has a range of about 66.5kilometers; conversely if the solar cell is used, the range increases to 94.4km. In the winter, the experimental results respectively were 64.4km and 85.9km as shown in Fig. 4. For reference, the ZigBee based wireless sensor node for real time monitoring, the operation of the ZigBee sensors mote, ZigBee router based mote (red PC module) and the solar powered bicycle monitoring screen are shown in Fig. 6, Fig. 7 and Fig. 8, respectively. It is showed that the proposed electric bicycle charging source is solar cells, it may lengthen the travel distance and reduce the time of manual charge. By using the ZigBee and GSM network which in monitoring the stored energy data from picking up the system about the solar electrical energy generation, the battery charge, and the surplus electrical power system can be obtained immediately through the bicycle surveillance network.

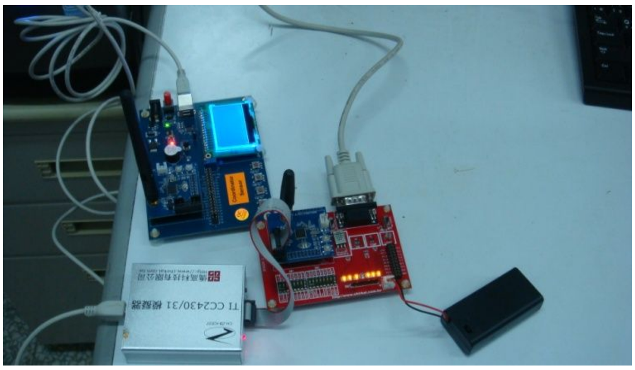
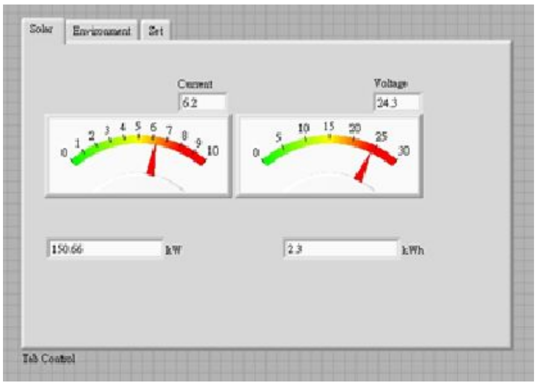


Fig. 7. ZigBee router based mote with red PC module

4. Conclusions

This study is carried out on a solar energy powered bicycle with the WSN far-end network monitoring solar energy transfered to electrical energy storage and its effectiveness analysis. In order to achieve this goal, a solar-powered bicycle with a ZigBee attached and a far-end wireless network supervisory system is setup. As a result, the user, through the wireless network in the bicycle's parking period may know the data on the amount of immediate solar illumination, the ambient temperature, and electrical energy storage capacity information through an internet interface.



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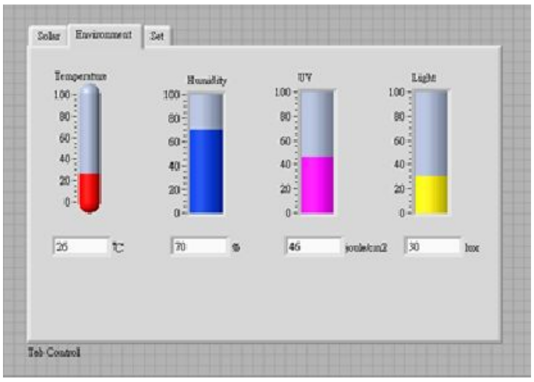

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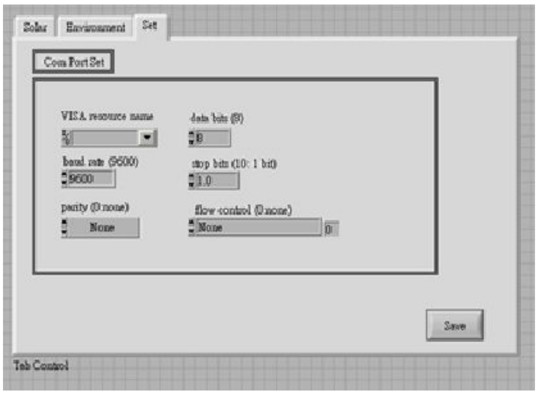

(c)

Fig. 8. The solar powered bicycle monitoring screen

The electric bicycle with two sets of 36Ah lead-acid batteries and a 50W solar cell in the back seat, upon which testing was conducted during sunny summer weather. Only depending on the built-in batteries to run, the bicycle traveled for about 66.5km; however, if the use solar cell is charged, the range increases to 94.4km. In the winter, the experimental results respectively are 64.4km and 85.9km. The experimental results were shown to verify the feasibility of the proposed WSN far-end network monitoring solar energy system.

Acknowledgements

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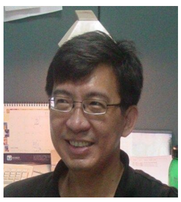

Chung-Hsing Chao received his doctor degree in power mechanical engineering from Tsinghua University. His research interests are emerging energy systems and electric machines.