Tackling the Issues of Powering Mobile IoT Sensors and Systems Using Off-Grid Sources of Energy, the Case of the Real-Time Web-Based Temperature Monitoring System in Malawi

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Abstract. Design and implementation of Internet of Things (IoT) devices and systems face the need of these systems to be self-powered. This is due to a number of characteristic and fundamental factors such as responsiveness, system mobility, portability, energy supply source adaptability. IoT covers a wide range of devices and systems, and an important subset of these involves real-time monitoring and control, particularly for both home and industrial applications. Other than just powering fixed sensor systems, the integration of such systems to mobile or transportation systems is a very important attributed characteristic but becomes a bit of a challenge to both designers and users in choosing the right option of power supply to the IoT systems. This paper illustrates some of such challenges and some of the efforts implemented to counter them in the design and implementation of a temperature monitoring system for transportation systems of dairy products in Malawi.

Keywords: Power source · IoT · Web-based · Temperature · Monitoring

1 Introduction

Various industry forecasts project that, by 2020, there will be around 50 billion devices connected to the Internet of Things (IoT), helping to engineer new solutions to societal-scale problems such as healthcare, energy conservation, transportation, etc. [1]. IoT devices are supposed to be deployed ‘everywhere’ and to be accessed ‘any time’ from ‘anywhere’ [2]. This attribute of IoT is the most fundamental application and ability of the very aim and objective of embracing IoT in sensing and monitoring. The fact that there are hundreds of sensors and actuators enables the implementation of IoT the best choice that replaces physical presence of human beings in monitoring and controlling systems.

A very good example of such systems is a temperature monitoring system for cold-chain management that was implemented in Malawi [3]. This system enables managers

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to monitor their cold-chain assets using their mobile phones and laptops that are connected to the internet. The system also alerts the managers using the SMS service whenever high temperatures are detected. All this is done with an aim of reducing product damage and prevention of exorbitant losses.

The development of this Real-time, Web-based Temperature Monitoring System (RWTMS) has opened new opportunities for companies in Malawi, especially those in cold chain, to reduce their losses and expenses that arise due to poor monitoring of their both fixed and mobile cold chain assets. Although there are all these opportunities, the implementation of the RWTMS faces a very big bottleneck of an efficient source of power supply to power the system's operations like sensing, data processing and data communication.

In respect of paper structure, the rest of the paper is organized as follows: Sect. 2 presents methodology that was followed in coming up with a power supply system to the RWTMS. Analysis of the RWTMS power supply is outlined in Sect. 3 while Sect. 4 presents observations of results. Conclusions have been finally drawn in Sect. 5.

2 Methodology

2.1 Powering Mobile IoT Sensor Systems Using Off-Grid Power Supply Options

Study has shown that refrigerated shipments rise above the optimum temperature in 30% of trips from the supplier to the distribution centre, and in 15% of trips from the distribution centre to the stores [3, 4]. This calls for an innovative solution for monitoring the goods while in transit. Uninterrupted power supply is very crucial for the functionality of such a system.

In the implementation of the RWTMS, the power supply was approached in a very unique way. The following steps were employed: analysis of system's power needs and specification, brainstorming on the possible power supply options, implementation tests and use analysis of chosen power supply systems.

2.2 RWTMS System Power Supply Needs

The technology takes advantage of the presence of Open source technologies. Open-source software and hardware provide the opportunity to build low-cost information systems [5] that have brought to life new services and applications, made possible, directly or indirectly, by smart things.

The controller board was designed using Atmel programmable chips of designation ATMEGA 328/P which is a series of chips that are programmed using a wiring language of the calibre of **c++** [6]. The board is enabled to transmit data wirelessly using a GSM adapter module that uses harnessed power of an inexpensive sim800L set of AT commands pre-programmed at the launch of the programme code into the micro-controller (Fig. 1).

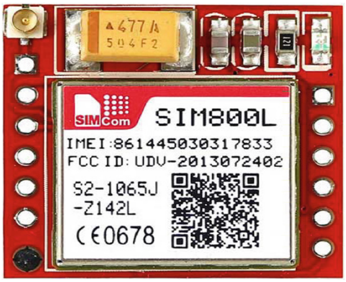

Fig. 1. The SIM800L quad-band network mini GPRS GSM breakout module used in the RWTMS.

Temperature value signal is supplied to the board using high precision DS18B20 temperature sensors. This steel headed DS18B20 digital thermometer provides 9-bit to 12-bit Celsius temperature measurements and has an alarm function with non-volatile user-programmable upper and lower trigger points (Fig. 2).

Fig. 2. The DS18B20 temperature sensor used in the RWTMS. (Source: Real-time, web-based temperature monitoring system for cold-chain management in Malawi)

The system was designed to be powered using a 12 V-direct current supply (12 VDC) to cover sensing (5 V sensor voltage), data processing (7–9 V Atmel chip voltage) and transmission (4.1 V GSM module voltage) power needs. This requires a minimum current specification of 1 Ampere (1 A).

2.3 Brainstorming Power Supply Options for the Transportation Monitoring Units

There were three power supply options that were suggested. The first one was the use of eight rechargeable 1.5 volts cells connected to form a 12-volt power supply. This would be charged prior to each and every deployment of the system into the refrigeration vehicle. The cells were Lithium ion battery type packed with terminals connected from negative to positive i.e. in series.

The second option was on the use of the same battery that is used to start the refrigeration system engine or the engine driving the vehicle. The last option was to use a solar panel connected to a 12-volt lead acid battery (Fig. 3).

Fig. 3. The 12 volts 7 AH battery used as a voltage supply for the system

3 The Analysis of the Adaptability of the Power Supply Options on the RWTMS

The power supply options were analyzed after running in-house tests and two options were tested on the refrigeration vehicles. The power supply options were tested based on three major factors namely: power specification, power recharge cycle intervals and easiness of use.

3.1 Power Specifications of the Power Supply Options

The system minimum requirements were identified to be 11 V at a flow of current of about 0.93 A. This was determined by varying the system input power parameters while checking the responsiveness of the system. Although this method proved to have some errors but it was noted that varying the power supply using a variable power adapter allowed good parameter analysis of the options of power supply.

Both the Arduino board and the Sim800L are provided with power light emitting diodes (LEDs). When the power being supplied is not adequate, the power LEDs lower their brightness. The other important indicator of the system's adaptability to power supply is the network LED found on Sim800L module. When power parametric specifications are below the minimum, the network LED keeps on blinking every half a second repeatedly. When the power supply is within the required range, the module finds the network and starts to blink at an interval of 3 s repeatedly.

It was noted that all the three options were able to produce enough power to drive the needed processes for the system. This is due to the fact that the power supply options' batteries were fully charged just before being connected to the system.

3.2 Power Recharge Cycle Intervals of the Power Supply Options

The power recharge cycle intervals were determined in terms of the time taken between two recharge actions for the battery to supply to the RWTMS. This factor can theoretically be predicted and practically proven using the Ampere-Hour rating of the power supply options. In general terms, the capacity of a cell/battery is the amount of charge that has been stored inside it expressed in ampere-hours (Ah). This is measured by discharging the battery at a constant current until it reaches a terminal voltage (usually 11 V for RWTMS) at standard room conditions.

It should also be emphasized here that the higher the battery capacity, the longer it takes to get it charged. This calls for a balance of the capacity and charging method capabilities of the source of the energy.

For the 1.5 V - 8 cells battery pack, the rated capacity was 2.8 Ah (2800 mAh). The battery that was being used to run systems on the vehicle had a rating of 40 Ah. The third option of the 12 V lead-acid battery was rated 7 Ah.

It was assumed that the RWTMS was drawing a constant 1.5 A of current. To find the time between recharges, the Ah rating was divided by the consumption rate of 1.5 A of the system. This yielded the following results as illustrated in the Table 1 below.

$$Recharge\,Time\,Interval = \frac{Ampere - hour\,rating\,(Ah)}{1.5\,A} \quad (1)$$

Table 1. The power consumption rate and recharge time interval for performance analysis of voltage supply for the system.

Power supply option	Ampere-hour rating (Ah)	Recharge time interval
1.5 V - 8 cells	2.8	1 h 52 min
Car battery	40	26 h 40 min
Lead acid battery	7	4 h 40 min

4 Results and Discussion

The following results were obtained. It was noted that the power coming from the battery pack was not enough to power the system for at least 1 h and 30 min. When the system was connected directly to the car battery, the system would consume much power to such an extent that when the vehicle engine was off for about 8 h, the engine of the vehicle would fail to start normally.

Lastly, the 12 V lead battery would power the system for about 5 h which is approximately the result that was achieved out of the theoretical solving of the recharge time interval.

4.1 Easiness of Use of the Power Supply Options on the RWTMS

The measure of easiness is based on the amount of time taken per recharge cycle and how that affects other systems on the vehicle. In reference to the results, it could be observed that the battery pack power option was not suitable for this application as travel time might exceed 1 h and 30 min in most cases. The car battery was also not very good an option because there are many systems that use the same power supply, e.g. indicator lights, head lamps, mirrors etc. It was observed that the vehicle could start on a hard-start as the power had been depleted by the RWTMS hence clients could not accept the system be installed on their vehicles. The 12 V lead acid battery seemed a viable option because it could act as a separate power silo for the system to stay on for about 5 h.

Possible power charge and enhancement systems were proposed so that the system could be powered continuously while it is being used. Two options were proposed: vehicle alternator system and a solar panel system. The arrangement proposed was to use a hybrid type of charging system by combining the solar and alternator charging power so that it charges the 12 V lead acid battery. A very efficient power charging with cut-off circuit was designed and incorporated so that it could cut-off the charging power supply whenever the battery was fully charged. The input power to the RWTMS was equipped with a power surge protection circuit using a voltage regulation method of using an adjustable three-terminal positive-voltage regulator capable of supplying more than 1.5 A over an output-voltage range of 1.25 V to 37 V. This voltage regulator is known as LM317 (Fig. 4).

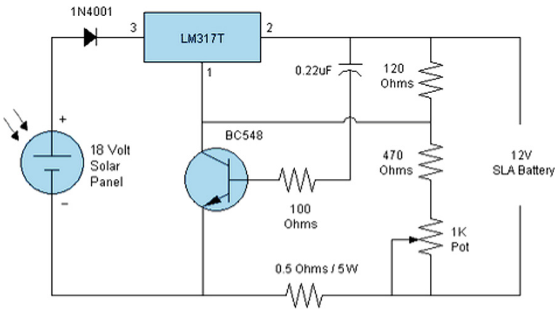

Fig. 4. The solar charging circuit for 12 volts battery used in the voltage supply for the system

4.2 Cost Evaluation on the Final Power Option for the RWTMS

This power supply was made using materials bought from an electrical store. The most expensive part was the battery which was bought at a cost about Twenty Five United States Dollars (US$ 25). The solar panel was bought at US$ 18 and the support electronics were acquired at a cost of US$ 10. The total sum of money spent on this power supply option was US$ 53.

4.3 Challenges Encountered in the Design, Implementation and Operation of the Power Supply Option for the RWTMS

One of the most prevailing challenges that were faced was to do with interoperability of system units for the achievement of an efficient source of power supply to power operations like sensing, data processing and data communication by RWTMS. The challenge was on how the 12 V lead acid battery could be connected to two power sources and be charged while it is supplying to the RWTMS.

5 Conclusion

In this paper, an efficient source of power supply to the real-time web-based temperature monitoring system for cold-chain management has been presented. This RWTMS power supply option has demonstrated a huge potential in tackling issues that arise lack of proper power supply to IoT sensors and systems more especially when they are mounted in equipment that is in transit. Our solution allows the hybridized charging system with a very good automatic cut-off and voltage regulation circuit. This work-in-progress will end up realizing some best savings in investment of power supply to efficient IoT systems.

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