Development of a Self-diagnostic System for Photovoltaic based Highway Signage Boards and Warning Devices

by

Calvin Low Eu Jin

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Dissertation submitted in partial fulfilment of
requirements for the
Bachelor of Engineering (Hons)
(Electrical and Electronics)

JANUARY 2016

Universiti Teknologi PETRONAS
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CERTIFICATION OF APPROVAL

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Approved by,

(Assoc. Prof. Dr. Balbir Singh Mahinder Singh)

Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
BANDAR SERI ISKANDAR, PERAK
JANUARY 2016

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein has not been undertaken or done by unspecified sources or persons.

CALVIN LOW EU JIN

ABSTRACT

Federal highways and state roads in Malaysia are sites of most traffic accidents. One contributing factor is the lack of or low visibility of road signage at dangerous bends or road corners. It is very important to have safety warning signage at strategic locations to warn drivers on conditions or hazards ahead by cautioning maximum allowable vehicle speed limit. However, signage boards alone by themselves are not enough. The relevant authorities have started to add flashing beacons to enhance visibility, but the availability of on-grid power supply often hinders their installation. This is now a non-issue with the advent of solar power. As and when more signage with flashing beacons are installed; scattered over a wide area, there is an operational need to monitor their performance status remotely for timely effective maintenance and repair. Therefore, this project objective is to develop a self-diagnostic system for photovoltaic based highway signage boards and warning devices in order to monitor and check their working status. This project consists of hardware and software components. The data requisition for all the required parameter for performance monitoring and self-diagnostic is done via the hardware system and raw data is transmitted wirelessly through the communication platform device. On the other hand, monitoring software is able to process the received raw data based on the algorithm designed to be integrated in the hardware system. All the processed information will be displayed and stored in a database. This self-diagnostic system is not only capable of identifying functionality of active devices but also able to analyse and report wirelessly each of the major sub-systems used in the highway signage boards and warning devices. Hence, this project is not only beneficial for maintenance purpose but also to create better awareness on road safety in order to save life.

ACKNOWLEDGEMENT

I would like to express gratitude and appreciation to Universiti Teknologi Petronas (UTP) for guiding me on my Final Year Project (FYP). The practical work requirement for graduation creates a new dimension to the knowledge learned in classrooms. In the FYP, I have to use the know-how to solve a technical problem. This experience and learning have undoubtedly prepared me for work challenges and demands in my career ahead.

I am indebted to my supervisor and mentor, Assoc. Prof. Dr. Balbir Singh Mahinder Singh. He was a guide and mentor to me throughout the FYP. He showed the finer qualities and best practices of an engineer, sharing pragmatic skills in handling complex technical problems. He also walked the extra mile; spending precious after office hours advising on the project, nudging me towards a steep learning-curve. On reflection, without his guidance and advice, I would not be able to complete the second phase of my FYP on an upbeat note.

My co-supervisor, Dr. Micheal Drieberg, played an important role in helping me think out-of-the-box. At one point during the project, I was undecided on how to connect, control and manage the modules wirelessly. His insights gave me fresh perspectives and a challenge on how to work-around, make things simple, low cost, yet present the same bottom-line result.

I like to record a very special thank you note to Ms. Lim Zi-Yi, a UTP postgraduate student. She gave very good suggestions on how I could improve the project algorithm to make the system more efficient, and in proof-reading my project write-up.

Finally, I like to extend gratitude to my family who has encouraged, nurtured and supported my studies, ambitions and career goal. Their understanding, motivation, encouragement and financial support are all a blessing. Without them, I would not be where I am today.

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CHAPTER 1

INTRODUCTION

1.1 Background

The utilization of non-renewable fossil fuels is fast depleting at an alarming rate and causing serious global environmental issues. The world is striving to find an alternative to mitigate or slow down its reliance on unsustainable fossil fuels for power generation.

Researchers have started to explore the vast potential of tapping into green and sustainable renewable energy, one of which is solar energy. Solar energy is radiant light and heat energy from the sun that converts into thermal or electrical energy by using photovoltaic (PV) effect. There are three categories of solar radiation- direct, diffuse and reflected. All these radiation can be converted into direct current (DC) electricity by using semiconductor material that exhibits PV effect. The PV effect is the formation of electrical current in the semiconductor material upon exposure to the radiation.

The set-up that uses a complete set of PV components for converting sunlight into electricity by the photovoltaic process is called a solar energy generating system (SEGS). Its main components consist of a solar panel, charge controller, battery, inverter and load. All of these components can be designated based on user requirements, scale of the system, location as well as its intended application. One such example can be found in roadway safety signage. This roadway safety device has developed, evolved and used widely in many advanced countries, as well as in Malaysia recently. Federal highways and state roads in Malaysia are sites of most traffic accident. According to a research report by the University of Michigan, Malaysia is the top 25 hazardous countries for road users, with 30 fatalities per 100,000 individuals [2]. One contributing cause is the lack of or low visibility of road signage, especially at dangerous bends or road corners. It is very important to have safety warning signage at strategic locations to alert drivers on road conditions or hazards ahead by cautioning maximum allowable vehicle speed. However, signage boards alone by themselves are not enough to attract the attention of drivers.

There are many initiatives taken by the relevant authorities to enhance the visibility of signage such as introducing flashing warning devices or beacons. Apparently the use of new technologies helped to reduce accidents, but the availability of power supply often hinders their installation along a highway at known isolated dangerous spots.

Recently, the introduction of more efficient and affordable photovoltaic based systems has promoted the installation of many standalone road safety and warning devices in areas without electricity. Nevertheless, there are many basic problems and issues with these devices that have to be resolved to optimize their implementation.

1.2 Problem Statement

PV based LED signage boards and flashing warning beacons are now a familiar sight on our highways. The challenge is how to operate them reliably round the clock, especially during night time, since the amount of solar electricity generated depends on the availability of sunlight throughout the day. Therefore, PV based LED signage boards and flashing warning beacons need to be maintained, serviced to stay functional and useful. There are many factors that affect the performance of a PV system; such as solar position, weather, dust and rain water stains on the surface of the solar panel. All these must be taken into consideration when the PV based LED signage system is installed.

Consequently, a LED signage board or flashing warning beacon will be efficient and effective if the PV system is sized properly and the path of the sun is tracked to maximize the amount of sun shining on the solar panel. Without a diagnostic in the system to do health check of the installed LED based signage or flashing warning beacon, the maintenance personnel will not know the performance of the system. Therefore, incorporating a self-diagnostic test is essential and useful in alerting system maintenance or service, as well as to optimize the system.

1.3 Objectives

The objectives of this project are:

- To study the problems faced by current available PV based LED signage boards and flashing warning devices on federal roads and highways.

- To develop a self-diagnostic intelligent system for monitoring, measuring and reporting the health status of PV based LED signage boards and flashing warning devices on the highway.

1.4 Scope of Study

This project discusses the system sizing and solar geometry in providing sufficient energy to power a highway installed standalone warning, flashing beacon. The beacon features a self-diagnostic test with capability to check the entire solar powered system performance. Test results obtained can then be used to isolate fault or give an indication where and when maintenance and service are required.

The highway beacon was designed according to a recognised standard for its technical specifications regarding regulation and control of traffic devices. The beacon assembled is intended to operate as a practical working replica that can readily be accepted and adopted by any highway authority in Malaysia.

The hardware of the self-diagnostic intelligent system consists of a microcontroller module connected to the solar powered beacon. It will monitor, control and manage sensors to an algorithm designed to provide system status in real-time. Operating electrical parameters identified can then be retrieved and data-logged for review.

1.5 Relevancy and Feasibility

Roads in Malaysia are prone to fatal traffic accidents which can be avoided. One known main contributing factor is due to inadequate or no proper road signage to caution drivers on road conditions ahead as a preventive measure[3].

This project is an attempt to bring the various components of electrical and electronics knowledge, and applying the know-how to promote road safety. The engineering focus is on harvesting free, clean, solar energy in the development of a flashing signage. This project demonstrates a good understanding of the fundamentals of solar power generation, electrical energy storage, microcontroller management, programming, power electronics, instrumentation and control, and wireless communication. A working prototype was fabricated to carry out field test. The solar powered flashing signage developed in this project has the potential to be commercialized, and patent has been filed. Once the intelligent flashing signage is mass produced, then implementation and proliferation soon becomes simple, fast and affordable on all roads.

CHAPTER 2

LITERATURE REVIEW

2.1 Power supply for beacon system

Road regulations and highway codes play a vital role on road safety. They raise public awareness, giving ample warning of hazardous road conditions such as sharp corner, slippery road, winding terrain, or a pedestrian walkway ahead. Researchers have found that a warning sign combined with a flashing device is more effective than just the warning sign, so more and more of these combinations are being implemented [4] . Flashing devices traditionally use incandescent light bulbs with high power rating. In the solar powered flashing beacon system, incandescent bulbs are not practical due to their high power requirement. As the general trend already shows, they will eventually be replaced by light emitting diodes (LEDs) [5]. LED units configured in an array are smaller, extremely energy efficient, brighter and last longer.

PV systems are basically on-grid or off-grid. An on-grid system is a semi-autonomous electrical generation system which links to the mains to feed excess capacity back to the utility grid. There is an inverter connected to the solar panels that converts direct current into alternating current with an ability to synchronize and interface with a utility line. The system will stop to work when there is a failure at the utility grid. This is not the case with an off-grid system which is independent of the utility grid and has a battery to store energy produced during the day. In this project the flashing beacon is an off-grid, standalone system.

The table below compares the advantages and disadvantages of an on-grid and off-grid PV system.

TABLE 1: Advantages and disadvantages of On-grid and Off-grid system

Type of PV system	**Advantage**	**Disadvantage**
On-grid	• Constant power and performance • Reliable	• Expensive • No backup system • Difficult to install
Off-grid	• Less expensive • Easier to install • Have backup battery	• High maintenance cost • Lower efficiency • Not reliable

The off-grid PV flashing beacon is a better choice as it is more cost effective in the long term, easier to install and works solely on solar energy harvested when the sun shines. During overcast days and at night it draws its power from the storage battery. Therefore, the PV flashing beacon module and it electronics is a small Solar Electricity Generating System (SEGS). Figure 4 below shows the solar powered beacon project.

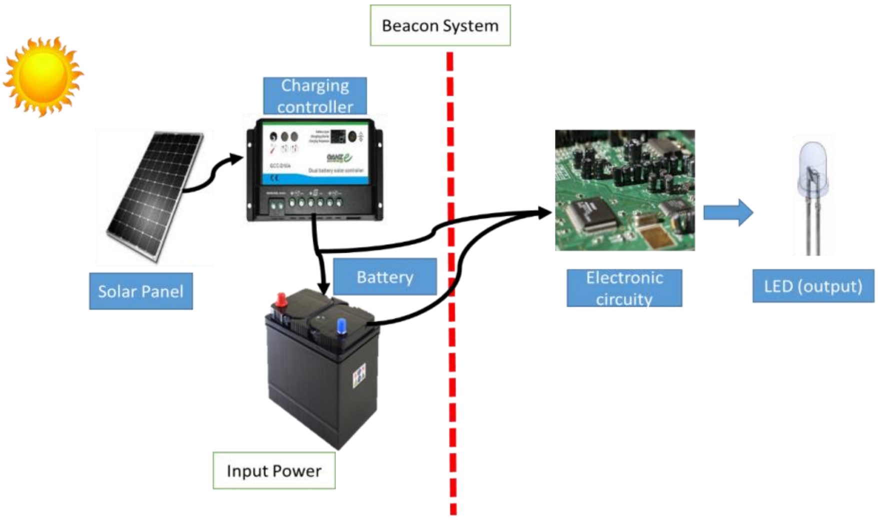


FIGURE 1: SEGS for beacon system

2.2 Solar irradiance and PV sizing

The power output of a solar energy system varies according to irradiance and local functioning conditions. It is therefore an important to design the PV system for continuous, reliable power under all anticipated environmental conditions. Conventional method for sizing a PV system is either empiric, analytic, numeric or hybrid based on location and required weather data. Most traditional methods are based on the annual system availability or reliability criteria also known as low loss-of-load probability (LOLP). The LOLP represents the level of confidence at which the system will satisfy the load. The load is defined as lost if battery drops below 20% state-of-charge point. At this point the system controller will disconnect the load from the battery, thereby avoiding a severe discharge that could damage the battery positive and negative plates. PV sizes are read from PV-sizing curves as a function of latitude, tilt angle, and average horizontal insolation during the worst sunlight months, for instance in December (in the northern hemisphere) or June (in the southern hemisphere). The required LOLP can also function to size battery storage capacities from storage-sizing curves. A LOLP of 0 means that the load will always be satisfied while a LOLP of 1 means that the load will never be satisfied. The LOLP is characterized by an average or long-term value and the distribution about that average value. For PV storage systems, the distribution can be wide and erratic. Consequently, continuous insolation and demand profiles for the expected life of the system are required to determine the long-term LOLP and its distribution. Since we cannot predict the weather, we are forced to rely on long-term historical data to define the insolation profile [6].

Egido and Lorenzo (1992) [7] proposed creating a reliability map for each LOLP value. The main disadvantage is the difficulty in applying it to locations where there is no daily radiation series data available. In this case, the authors suggested recalculate all the coefficients in the model to avoid significant loss of accuracy. On the other hand, Markvart, Fragaki and Ross (2005) [8] approximated PV sizing based on observed time series of solar radiation with the reliability of photovoltaic supply advantage factored into the length of time series data near the site where the PV system is being installed. The resulting procedure is then summarized in a sizing curve. Latest more advanced methods included the use of artificial intelligence (AI) techniques, fuzzy logic and artificial neural networks. Conti et al (2002) [9] was one of the first to propose the application of AI techniques in the PV system sizing. While Mellit (2006) [10] evaluated an improved approach for modeling of the optimal sizing parameters in isolated sites where meteorological data are not available. The advantages of AI-based techniques are that they offer a powerful alternative approach to conventional physical modeling. These techniques do not require knowledge of the internal system parameters and involve less computational effort.

However, one of the components in AI-based techniques requires the study of solar geometry to boost the harvesting of solar energy. For maximum solar insolation, the solar panel module has to be positioned in the best direction and angle to the sun tracking the earth's elliptical path around the sun [11]. Solar insolation received on a surface can be calculated using the established formula based on sun position throughout the year as follows:

$$I_{PV} = I_G \cos\theta \qquad (1)$$

where,

I_{PV} = Solar insolation normal to PV module

I_G = Global Insolation

θ = Angle of incidence

Equations (2) to (5) define the angle of incident in different types of solar tracking system.

For non-tracking system and horizontal surface

$$\cos\theta = \cos\phi\cos\delta\cos\omega + \sin\phi\sin\delta \qquad (2)$$

For non-tracking system and tilted angle

$$\cos\theta = \cos(\phi-\beta)\cos\delta\cos\omega + \sin(\phi-\beta)\sin\delta \qquad (3)$$

For one axis tracking system

$$\cos\theta = \sin^2\delta + \cos^2\delta\cos\omega \qquad (4)$$

For two axis tracking system

$$\cos\theta = 1 \qquad (5)$$

where,
δ = declination angle;
ϕ = latitude;
ω = hour angle;
β = slope;
γ = surface azimuth angle
Hour angle and declination angle can be calculated using equation;

$$\omega = (12:00\ noon - current\ time) \times 15^\circ \tag{6}$$

$$\delta = 23.45^\circ \sin\left[\frac{360^\circ}{365}\left(N + 284\right)\right] \tag{7}$$

where,
N = Number of the days of the year

Malaysia lies entirely in the equator where its tropical environment is characterized by torrential rainfall, high temperature and relative humidity, and daily abundant sunshine. Average daily solar insolation range from 4.21 kWh/m^2 to 5.56 kWh/m^2 [12], which equates to 4 to 6 peak sun hours per day.

2.3 Hardware components of flashing beacon system

In the flashing beacon system, the solar panel type and rating, size of the storage battery and LEDs array are chosen to present an optimal PV system. It is based on reliability of photovoltaic supply, numerical LOLP analysis, cost factor, material availability and simplicity. The solar panel is non-tracking and tilted for maximum sun peak hours.

To incorporate a self-diagnostic test feature in the off-grid PV beacon system requires two basic components- hardware and software. The hardware part includes solar panel, a pulse width modulation (PWM) charging controller or smart maximum power point tracking (MPPT) controller, a microcontroller, lead acid battery, different sensors, light emitting diodes, communication modules and a PC.

Two types of charging controller are studied for their suitability. The table lists their main properties.

TABLE 2: Types of charging controller, advantages and disadvantages

Type of controller	Advantage	Disadvantage
MPPT	• Minimizing power lost • Increase battery lifespan • Provide status of communication port	• Expensive
PWM	• Cheaper	• Decrease battery lifespan

In the final analysis, a MPPT is preferred as it is more efficient and offers more features. In particular, it can adjust its input voltage to harvest the maximum power from the solar array and then transform this power to supply varying voltage requirement of the battery plus load [13]. By comparison, the PWM is just a switch which connects the solar panel to battery. Furthermore, a low power, low cost MPPT model investigated comes with ability to monitor PV input voltage, charging current, charging power, battery voltage and RS232 communication for ease of interface to the microcontroller [14].

Another important component in the PV flashing beacon system is the storage battery. A battery stores excess energy generated by the solar array during bright days of high insolation and discharges stored energy back into the load at night or on cloudy days. It repeats these functions through numerous charge-discharge cycles over a wide temperature range during its lifetime. Correct battery type selection and sizing is critical to the success of this particular application. The battery has to be able to accept the highest power output from the solar panel without overcharge damage. The key elements in the battery selection are operating temperature variations, environmental temperature extremes and daily usage, charging and discharging rate, voltage regulator design, safety and low maintenance. The lead-acid battery is the ideal storage battery for a standalone photovoltaic system when connected to a solar charge controller. It has significantly lower initial investment costs and is commonly available.

Furthermore, battery sizing is easily calculated from the system load and battery capacity [15] .

For the transfer of PV system data monitored, control of the self-diagnostic test program, and management of set-up; a wireless communication link to a base station PC is proposed. Some of the options studied include ZigBee, TelosB mote, GSM and Ethernet. The pros and cons of each platform are tabulated as follows:

TABLE 3: Advantages and disadvantages for each type of communication platforms

Type of Communication	**Advantage**	**Disadvantage**
ZigBee	• Open source • User friendly • Suitable for low power application	• Shorter range • Not stable connectivity
TelosB mote	• Suitable for low power application • Integrated with sensors port • Longer range application • Open-source software operating system	• Expensive
Global system for mobile communication (GSM)	• Bigger coverage • Faster speed which can up to 4G LTE • Stable connectivity • Open source for software • Suitable for low power application	• Expensive
Ethernet	• Stable connectivity • High-speed • Reliable	• Not applicable for rural area • Complicated installation • Not wireless

Based on cost, availability, open source and user friendly program codes and relevance to the project, the ZigBee platform was selected [16].

2.4 Related works and projects motivation

The author is motivated by the work of T. Ramachandran and team who successfully designed a renewable street light system using ZigBee wireless communication for monitoring purpose [17]. However, this project did not consider PV sizing and solar geometry which affect power output of the solar panel. This lapse is important because the solar radiation fluctuates throughout the day. Therefore, the performance of the system will not be consistent. Besides that, a MPPT was not considered which could have extended battery lifespan and reduced the power loss in the system. The graphical user interface (GUI) provided was also not user-friendly.

In another related project by SM Ekene et al [18], the team incorporated a self-diagnostic test for predictive maintenance of traffic light control system monitored remotely on Short Message Service (SMS) via Global System for Mobile communication (GSM). An alert is sent when the traffic light is not functioning properly. However, the system is not powered by solar energy.

Recently, a traffic safety products manufacturer from the USA- K&K Systems has developed more advanced highway signage boards and warning devices [19]. The latest solar beacon systems offered by this company comes with a MPPT. While another model called CrossTalk has the capability to wirelessly control and monitor one or multiple solar beacons remotely via cell modem or radio. Data can be displayed on a GUI accessed on the World Wide Web. However on the downside, PV sizing was not mentioned and there was no consideration for solar geometry. There is also no indication of how much each of these systems cost.

A careful search on the Malaysia Road Transport Department website did not return any document or specification relating to PV based flashing beacon or any roadway beacon. To this end, the US Department of Transport, Federal Highway Administration road safety standards defined in the Manual on Uniform Traffic Control Devices (MUTCD) is adopted for the PV powered flashing beacon [20][21].

CHAPTER 3

METHODOLOGY

The conceptual architecture of the project revolves around 2 main components- hardware and software. Both are complimentary in function. The internet is used to browse for required components focusing on availability, short delivery time, affordability and with supporting free access to open source code software [22].

3.1 System architecture

Based on literature review that was done, all hardware components were identified and have proceeded to procurement for proof of concept prototyping. Figure 5 below shows the proposed system architecture for the control room and in the field set-up.

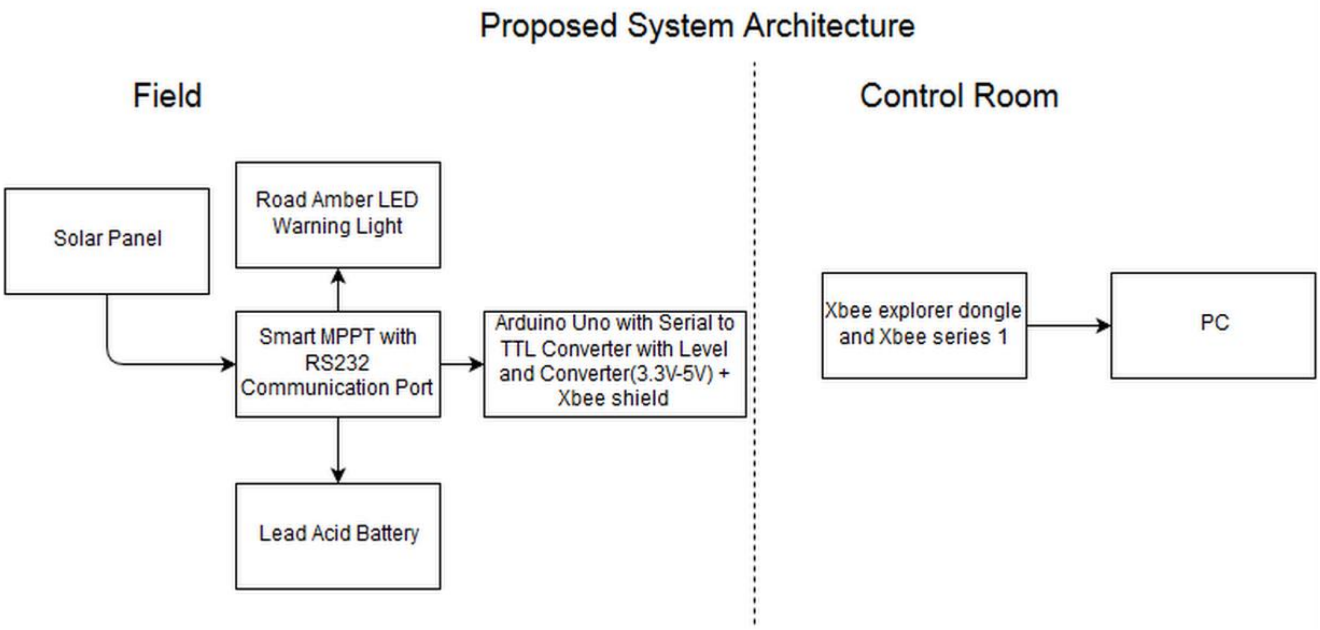


FIGURE 2: Proposed main hardware

3.2 Software component

The PV system parameters defined are monitored by sensors controlled and managed by a microcontroller. Data are transmitted wirelessly through the communication platform device to a base station PC on demand or triggered by a set clock to show system self-diagnostic test status. The base station PC can also display on its screen the project operating system values. System programming is in C++ language. A network of the concept is presented below.

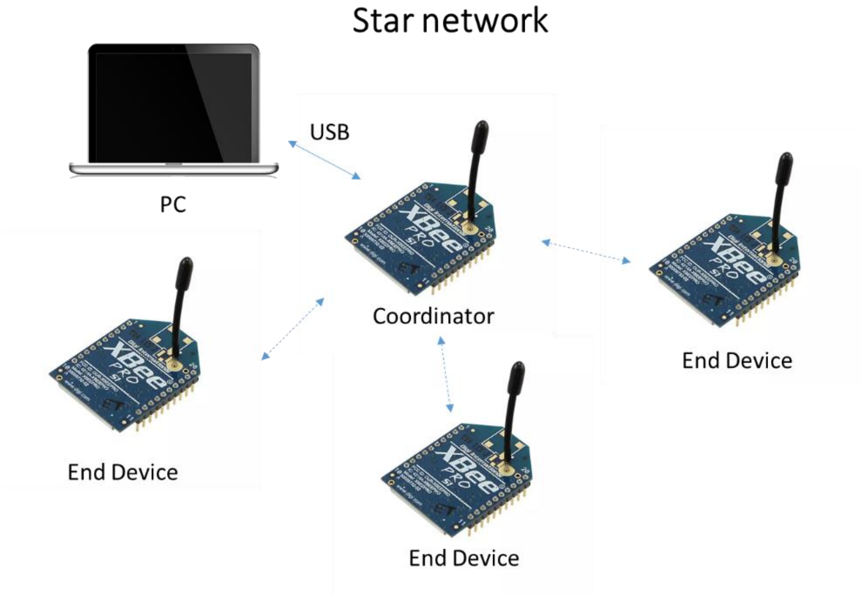


FIGURE 3: Star topology diagram

A star wireless network topology is adopted for this project because it is one of the most common network setup and easier to add multiple end devices, i.e., radio module with a microcontroller coupled flashing beacon. The end device collects all the raw data from the field through microcontroller and sends it back to the base station PC through a coordinator. The coordinator and base station PC are connected by using USB cable. Therefore, at least two communication platform devices are required for this project. In the prototype constructed to show proof of concept, there is only one end device due to cost and time constrain. Still, the network concept with myriad end devices can be applied for future enhancement work.

In the control room, there is a radio module and PC running an algorithm to monitor the end device. The figure below shows the flowchart for the program in the control room PC.

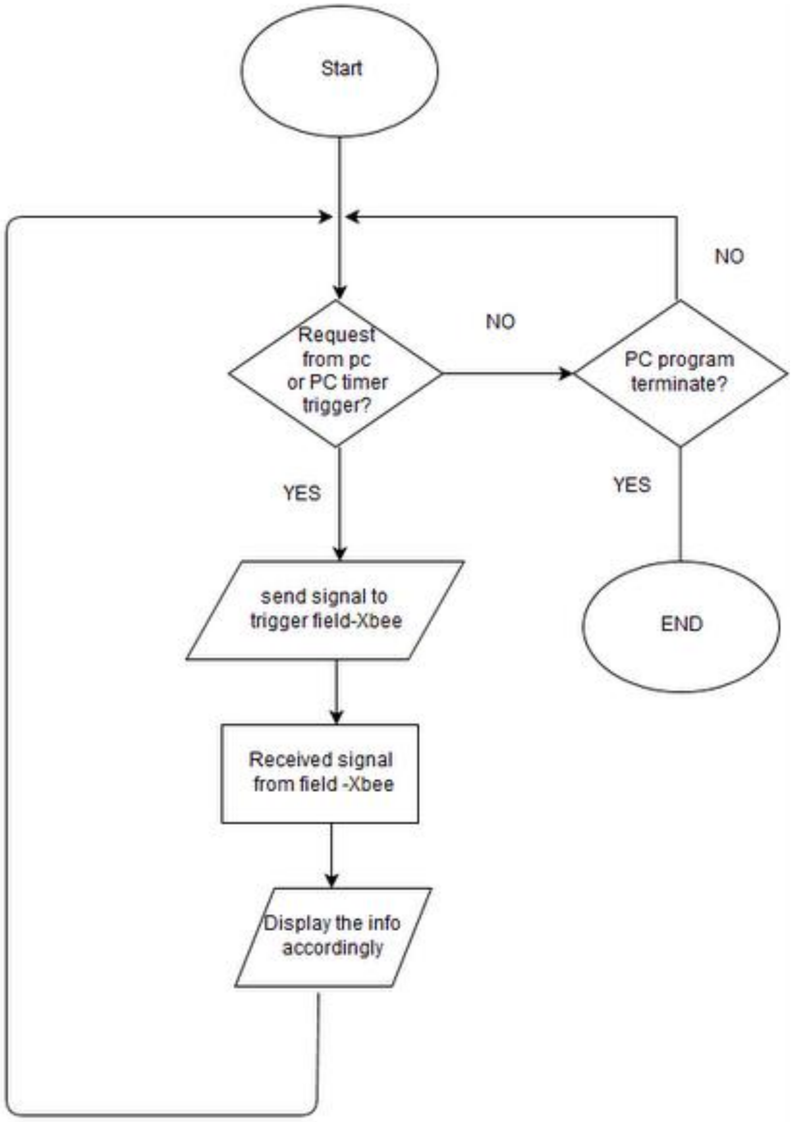


FIGURE 4: Program flowchart for Control Room PC unit

When the program is initiated, the PC will continuously check any request from user. If a trigger signal is detected, the PC will activate the field communication platform device and wait for it to respond, then standby to receive raw data sent. All data received are processed based on the performance algorithm and the GUI displays the process data accordingly.

The microcontroller in the field is programmed separately from that in the control room PC. The figure below shows the program flowchart for the field microcontroller.

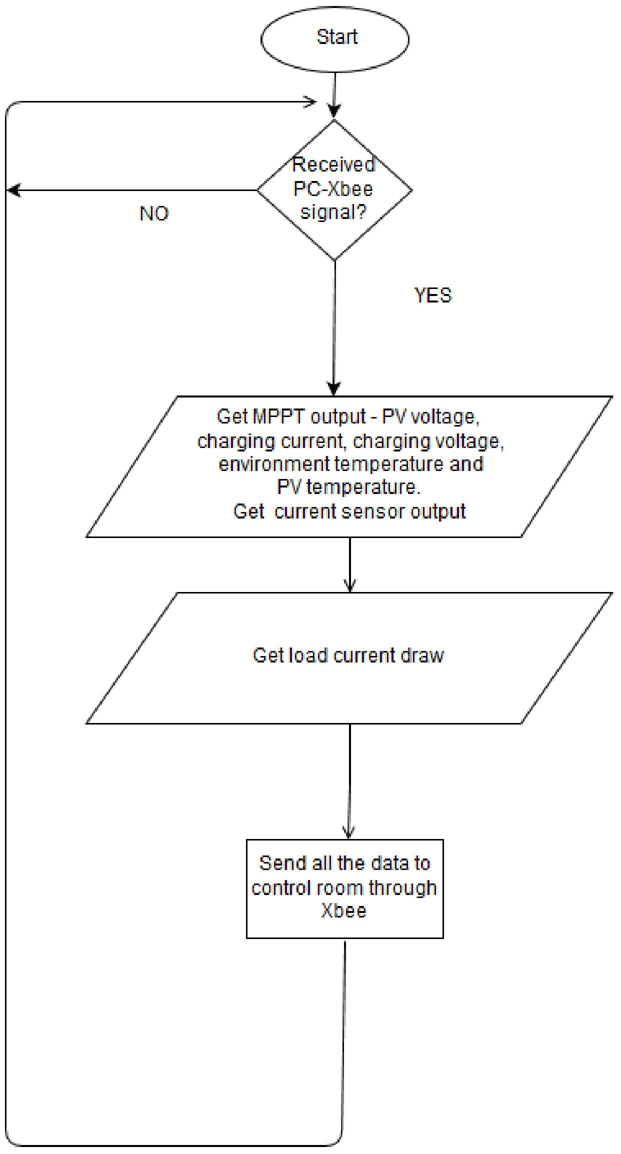


FIGURE 5: Program flowchart of field microcontroller

When the program runs, the field microcontroller will continuously check if a signal received from the control room PC though wireless communication platform device. When a signal is received from the control room PC, the field microcontroller will transfer data from the MPPT, flashing beacon, and other embedded sensors back to the control room PC via the radio module.

3.3 Key milestones & gantt chart

From project concept to final report and presentation took 14 weeks. There were a lot of uncertainty and confusion initially during the listing of materials and components stage. This was mainly due to the fact that what was originally planned could not be realized because some components were not available locally. It took some weeks before all parts or their replacements were found. Developments of software and hardware were also a difficult time. Things did not turn out well at first attempt to get the modules to talk to each other. There were a lot of debugging that took 4 weeks. Next, when it came to the finalization of the design concept, some of the assembled parts failed to work as expected. Then compatible parts have to be found. When all were working, the next step was experimenting and testing the entire set-up to collect data to show the proof-of-concept prototype is a success. Experimenting and testing took a good 3 weeks. The report and presentation was the easy part. The major milestones to project completion and other activities planned for performance-against-schedule tracking are as follows:

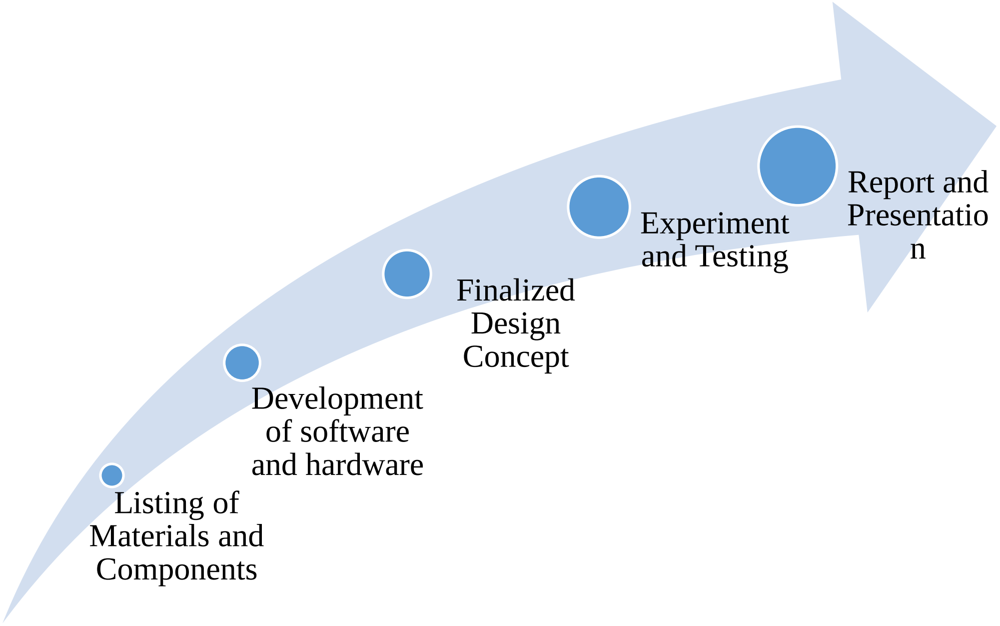
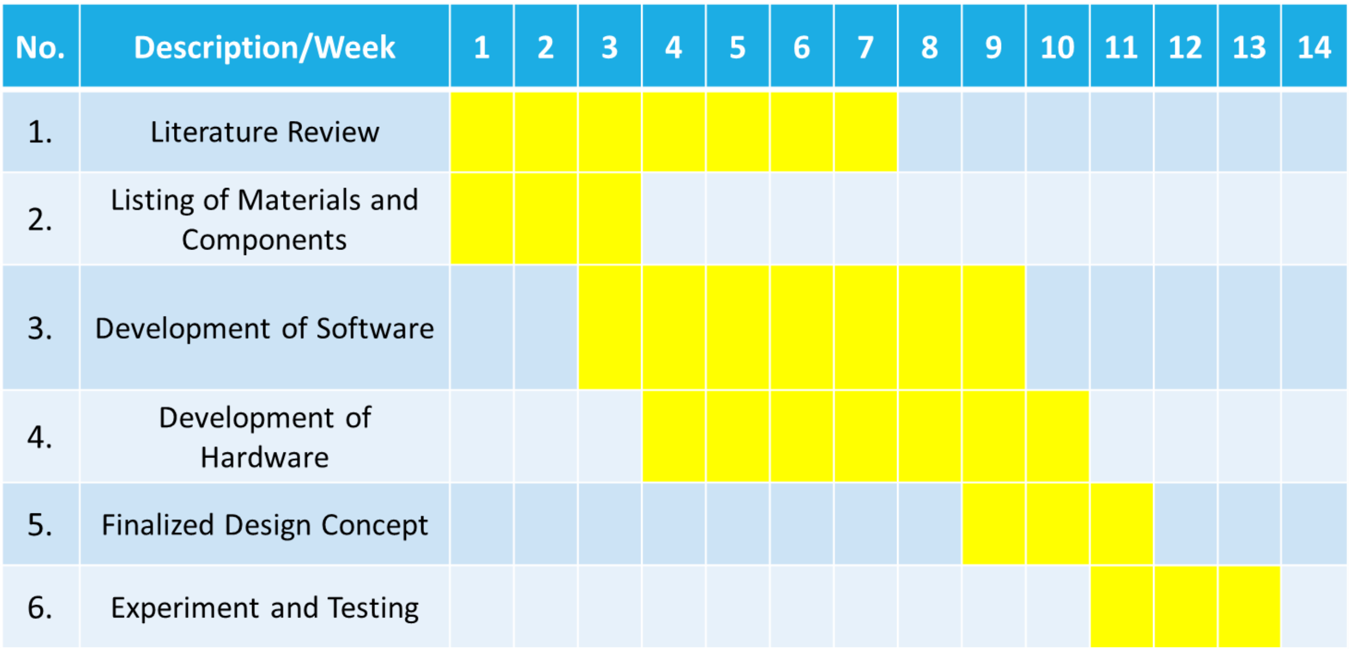


FIGURE 6: Key milestones chart



No.	Description/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.	Literature Review	■	■	■	■	■	■	■							
2.	Listing of Materials and Components	■	■	■											
3.	Development of Software			■	■	■	■	■	■	■					
4.	Development of Hardware				■	■	■	■	■	■	■				
5.	Finalized Design Concept									■	■	■			
6.	Experiment and Testing											■	■	■	

FIGURE 7: Project gantt chart

For proper project management, work activities are organized towards meeting key milestones. A gantt chart is also created in order to keep track of the project activities running concurrently to minimize unnecessary delays and avoid confusion. The intention is to demonstrate a proof of concept, working prototype and present findings by Workweek 14. Going by the schedule, the finalized prototype has to be up and running no later than Workweek 11 for data collection.

CHAPTER 4

RESULTS AND DISCUSSION

This project involved two parts: hardware and software. For the hardware components, they are selected based on availability, whether they are affordable and on short delivery time. While for the software part, the main concern was on compatible between the program and the microcontroller. This is to ensure that all the hardware components are able to handshake with each other in order to create an integrated, holistic self-diagnostic system to work as it was intended.

4.1 Development of hardware components

The e-smart MPPT is the heart of this project. It functions to optimize power input from the solar panel in order to charge the battery efficiently. This helps to increase the battery lifespan and minimize solar panel size. The MPPT has 2 connections- to the battery and another to the load, in this case, the flashing beacon. To monitor the status of the flashing beacon, a current sensor is inserted in series. The MPPT also has a built-in RS232 communication port that outputs data on solar power and battery status. Since RS232 signals swing from -12V to +12V, a transistor-transistor logic (TTL) converter is required to convert the signals from 0V to +5V to be compatible for the Arduino Uno microcontroller.

The Arduino Uno microcontroller board on the other hand is the brain of the self-diagnostic system. It is programmed to receive and manage the diagnostic data from the MPPT and sensors embedded in the system, and then send them to the transceiver modules- Xbee Pro.

The battery provides the energy to power-up the flashing beacon amber LEDs, as well as the Arduino Uno microcontroller board. A DC-to-DC boost-buck converter is used to step down the high voltage and current from the battery before connecting to the Arduino Uno microcontroller board. This serves to protect the Arduino Uno microcontroller board from over-current.

The transceiver modules- Xbee Pro, is programmed to wirelessly communicate between the field set-up and the control room unit connected to a laptop with a graphical user interface designed using Microsoft Visual Basic. The Xbee Pro is mounted on an Xbee shield to extend its capabilities (A shield is a PCB that can be plugged on top of the Arduino Uno). Figure 11 below shows the system architecture of the field set-up.

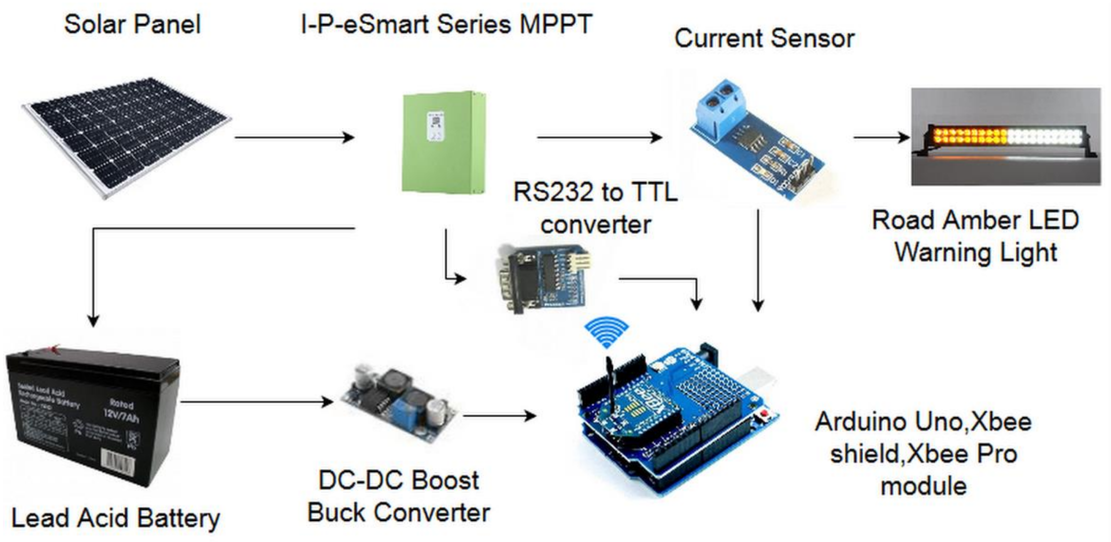


FIGURE 8: System architecture of field set-up

Figure 9 below shows the Xbee Pro module and Xbee USB adapter module connection to the laptop in the control room.

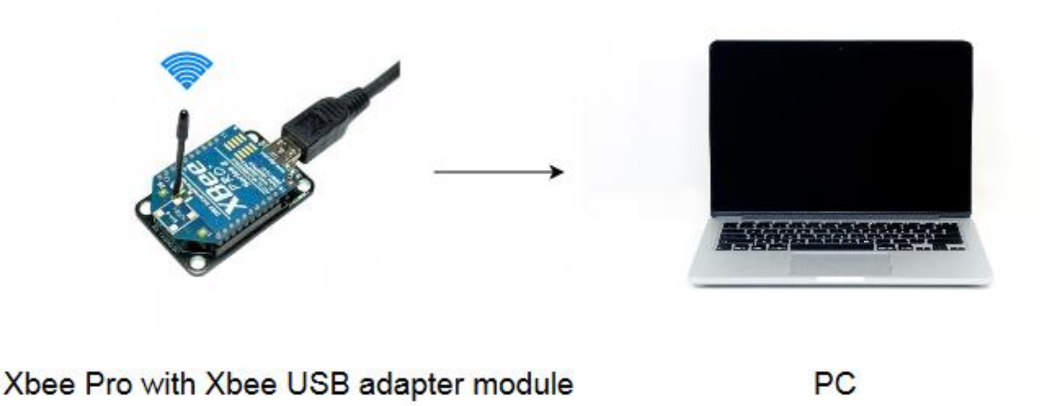


FIGURE 9: Hardware set-up in the Control Room unit

4.1.1 Selection of specific components

The photovoltaic based highway signage boards and warning devices self-diagnostic system requires many parts to construct. They include data acquisition device (in this case a microcontroller), sensors, transceiver modules, voltage converters, a monitoring system, and software. Each of the aforesaid have been identified and studied for best results. A table is drawn to show a summary of the selected hardware:

TABLE 4: Selected hardware or components for project.

No	Device / System	Hardware or Components
1.	Power system	- Solar Panel - MPPT - DC to Dc Boost Buck Converter - Battery
2.	Data acquisition device	- Arduino Uno
3.	Sensor device	- Current sensor - MPPT - Voltage sensor - Current sensor - Temperature sensor
4.	Communication device	- Xbee Pro module
5.	Monitoring system	- Computer with Microsoft Visual Basic

Using Fritzing software, a schematic drawing for a self-diagnostic system of photovoltaic based highway signage boards and warning devices is included to further explain how the various components are assembled.

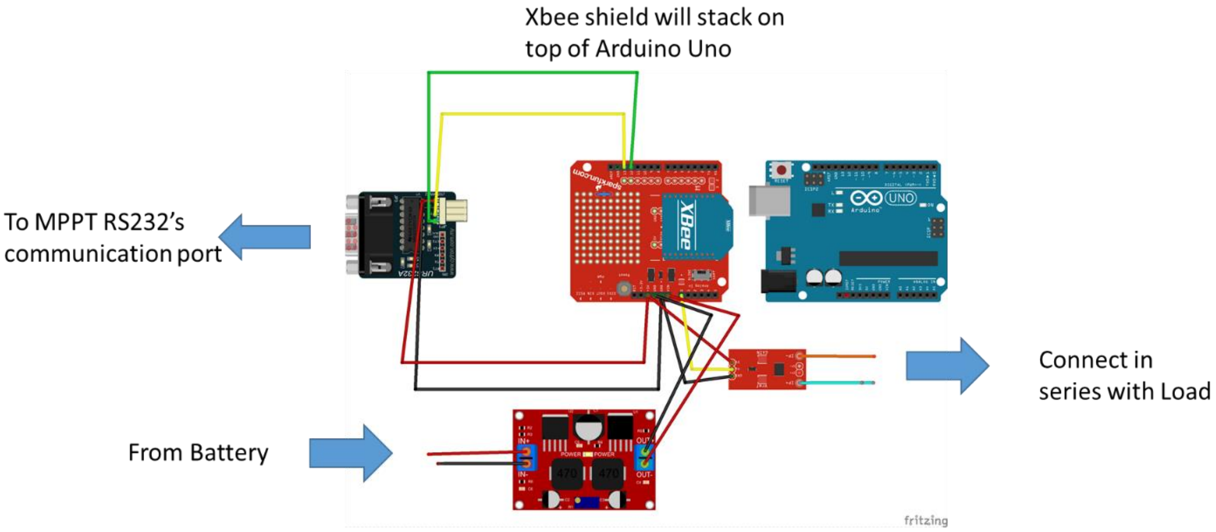


FIGURE 10: Schematic drawing for the self-diagnostic system

a) Power System

i) Solar Panel

There are 3 types of solar panels in the market- polycrystalline, monocrystalline and amorphous thin-film. In this project, the monocrystalline solar panel is chosen because of its efficiency and availability compared to others. A 5W solar panel rated at 17.28V, 0.29A and dimensions measuring 20cm x 29cm was acquired for the system. According to PV sizing calculation, this solar panel is able to provide sufficient power to the load and as well as to charge the battery. The figure below show the 5W monocrystalline solar panel with the tracking system.

FIGURE 11: 5W monocrystalline solar panel

ii) I-Panda eSMART series MPPT Solar Charge Controller

This MPPT is a low cost, intelligent charger that has better specifications and features than more expensive models on the market. The manufacturer claims that this MPPT on charge mode, peak efficiency can reach 99% and it can help to reduce the solar panel size by 30% to 60% than with a traditional pulse width modulation (PWM) charge controller. Moreover, the MPPT uses three-stage charging- fast charge, constant voltage charge or floating charge. This three-stage charging process is known to increase battery lifespan. Another good feature found on this MPPT is the automatic recognition of whether a 12V, 24V or 48V battery type is connected to the system, allowing user to conveniently configure a system to meet specific requirements. The figure below show the I-Panda eSMART series MPPT solar charge controller.

FIGURE 12: I-Panda eSMART series MPPT solar charge controller

iii) DC-to-DC Boost-Buck Converter

The MPPT load connector outputs regulated 12V dc. However, the electronics in the system requires 5V. Hence, a dc-to-dc boost-buck converter is needed to step the voltage down to 5V. The boost-buck module acquired has a switching IC and able to support up to 5A of current. This module further regulates and provides an adjustable output voltage to the Arduino Uno board microcontroller board, suitable for solar based low power application. The figure below show the 5A dc-dc boost-buck converter.

FIGURE 13: 5A dc-to-dc boost-buck converter

iv) 12 V Seal Lead Acid Rechargeable Battery

A sealed lead acid rechargeable battery is selected for this project. It is reliability and inexpensive as compared to other types of battery offered in the market. The battery is maintenance-free with long service life, compact, portable, and suitable for fitting into confined space. This sealed lead acid rechargeable battery is rated at 12V and has a total capacity of 7AH. The figure below show the sealed lead acid rechargeable battery.

FIGURE 14: Sealed lead acid rechargeable battery

b) Data acquisition device

i) Arduino Uno

An Arduino Uno microcontroller is used in this project. It is user-friendly and an open-source physical computing platform based on the ATmega328P. The microcontroller board has 14 digital input/output pins (6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, one USB connection, one power jack, an ICSP header and a reset button. It is simple to use. To power-up, the board can be connected it to a computer with a USB cable or use the AC-to-DC adapter. It can also be connected direct to a battery. Arduino users have access to the open source Integrated Development Environment (IDE) and library codes to program their projects. It is so much easier to write codes and upload them to the board. Using the IDE, an Arduino microcontroller in the field set-up is programmed accordingly. The figure below show the Arduino microcontroller.

FIGURE 15: Arduino microcontroller.

c) Sensor devices

i) I-P-eSmart series MPPT solar charge controller

This MPPT has a RS232 communication port which outputs information on PV voltage and current, battery charging voltage and current, air temperature and PV temperature. The MPPT therefore comes built with multiple sensors ready to integrate with other devices. The figure below show the I-P-eSmart series MPPT solar charge controller with built-in sensors.

FIGURE 16: I-P-eSmart series MPPT solar charge controller with built-in sensors.

ii) Current Sensor

The ACS712 is a breakout board using Hall Effect to sense current. It outputs an analog voltage signal that varies linearly with sensed current. This sensor operates at 5Vdc and supports up to 20 amps of current. Here, the current sensor is connected in series with the flashing beacon leds to measure the current drawn. The figure below show the hall-effect current sensor.

FIGURE 17: Hall-effect current sensor.

d) Communication device

i) Xbee Pro Module

Xbee Pro is a 2.4GHz transceiver module that takes the IEEE 802.15.4 protocol and wraps it into a simple to use serial command set. It allows a very reliable and simple communication between microcontrollers or computer systems with a serial port, supporting point-to-point and multi-point networks. The idea of using this module for wireless connectivity to project electronic devices is motivated by low-power and low-cost factors. The Xbee Pro module has higher power and longer range than the Xbee version. More importantly, this module is user-friendly and compatible with Arduino and PC. The figure below show the Xbee Pro transceiver module.

FIGURE 18: Xbee Pro transceiver module.

e) Monitoring System

i) Laptop computer

A laptop computer is used to carry out multiple set logical operations. These operations are used to diagnose and display all the data received from the field. It is also used to save, store and retrieve data in Microsoft Excel format files. At the same time, the laptop software has to be compatible and be able to communicate with the Arduino. The most appropriate software for interfacing and managing the communication traffic is Microsoft Visual Basic (VB) which is used to design the Graphical User Interface (GUI). Besides being an open source, another added advantage of VB is its user-friendliness. The figure below show the laptop showing visual basic GUI home screen

FIGURE 19: Laptop showing Visual Basic GUI home screen

4.1.2 Final development of the prototype

Once all the electronic components required were identified, selected, sourced and acquired; the parts are ready for assembly and integration. Then it is on to checking, testing, tweaking the electronics for optimum outputs and verifying end results. Along the way, emphasis was paid on wire management and components layout to ensure the project is presentable, good for demonstration. Figure 23 shows the electronics assembled in the control console while Figure 24 shows the proof-of-concept prototype.

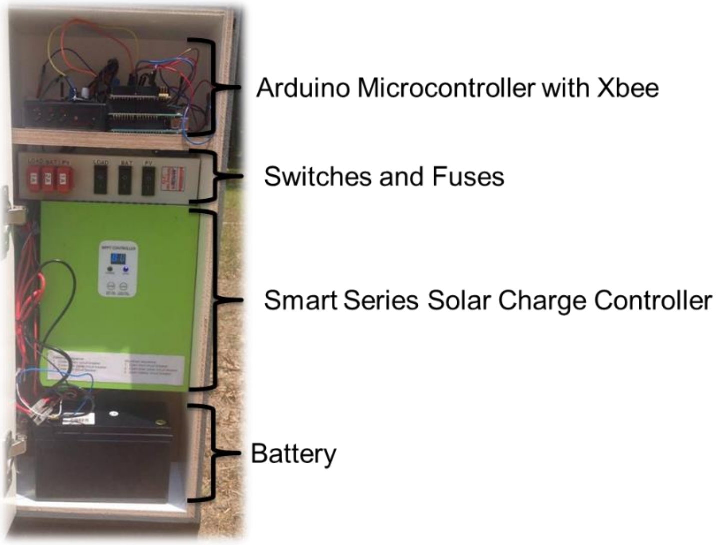


FIGURE 20: Control console electronics

FIGURE 21: Prototype model

4.2 Diagnostic system software

The GUI designed using Microsoft Visual Basic is meant to display data transmitted from the field in real time by clicking the interactive, touch screen buttons. There are other intelligent features in the GUI program such that the system can automatically trigger a system start sequence by setting the PC timer. It is also programmed to collect different sets of data for day and night hours. For daytime, system summary pass or fail is based on the average of data received. Whereas for night time, only load current drawn determines whether the system pass or fail; since other data are no longer relevant at that time of the day. A fail safe element included in the GUI program prevents accidental data lost when the screen is closed- all data are saved automatically on the hard drive. Furthermore, the program also creates a history of data captured in an excel file. This allows a user to record, trace and check system performance accurately, at will, over time for analytical purposes. Figure 25 shows a screen-shot of the GUI designed using Microsoft Visual Basic.

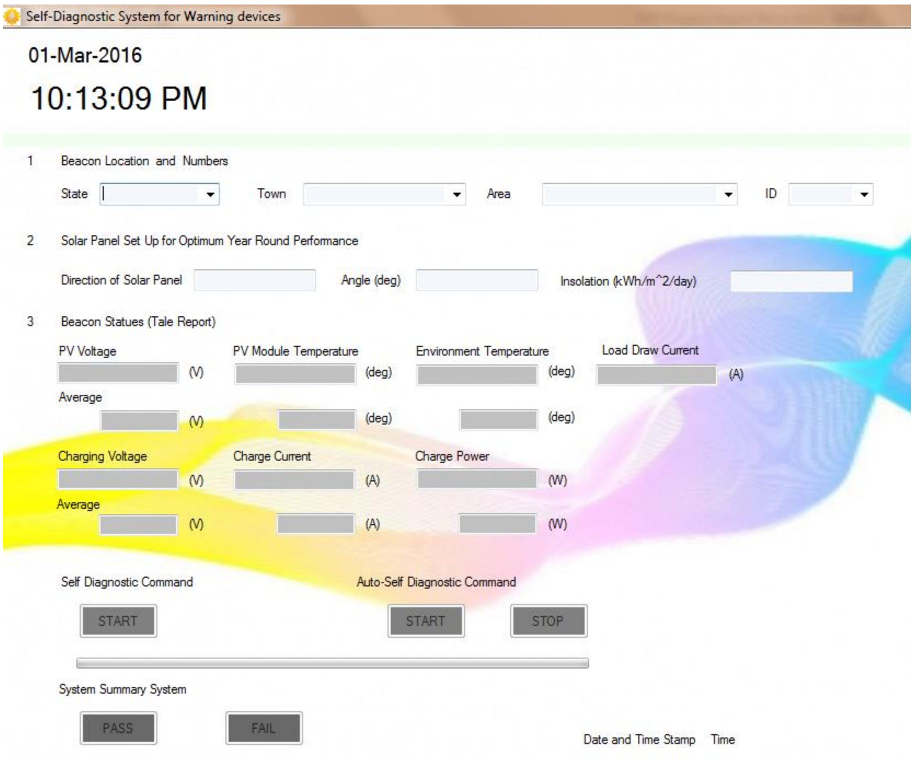


FIGURE 22: Screen-shot of GUI designed.

4.3 Field test results

Numerous field tests have been conducted to check system performance. Data were collected over time, automatically logged and saved in time-stamped Excel files. From these records, we can analyse system parameters tracked- PV temperature, PV voltage and charging voltage at different time of the day.

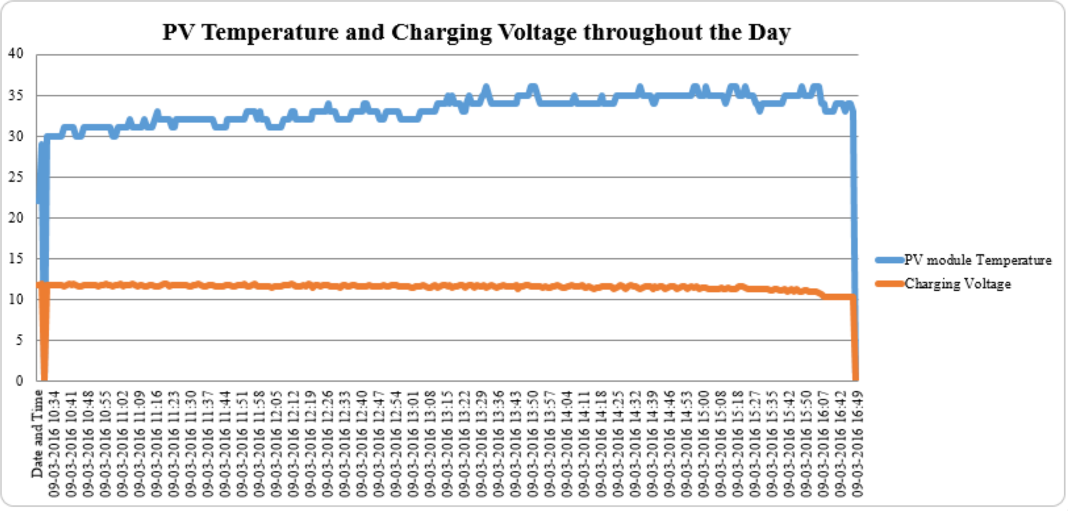


FIGURE 23: Graph showing PV temp and charging voltage at different time of day.

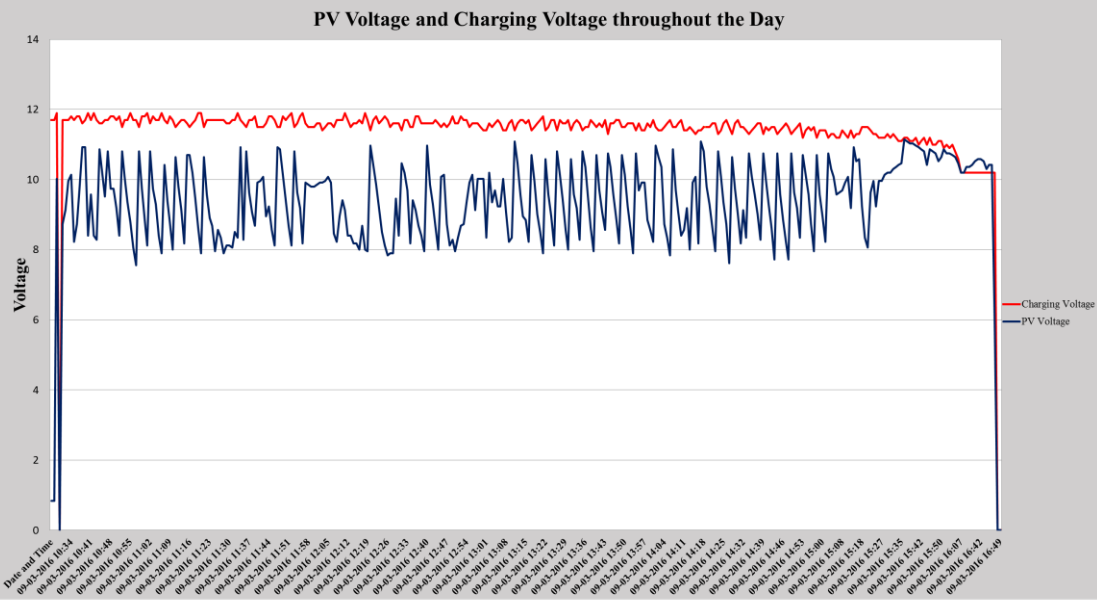
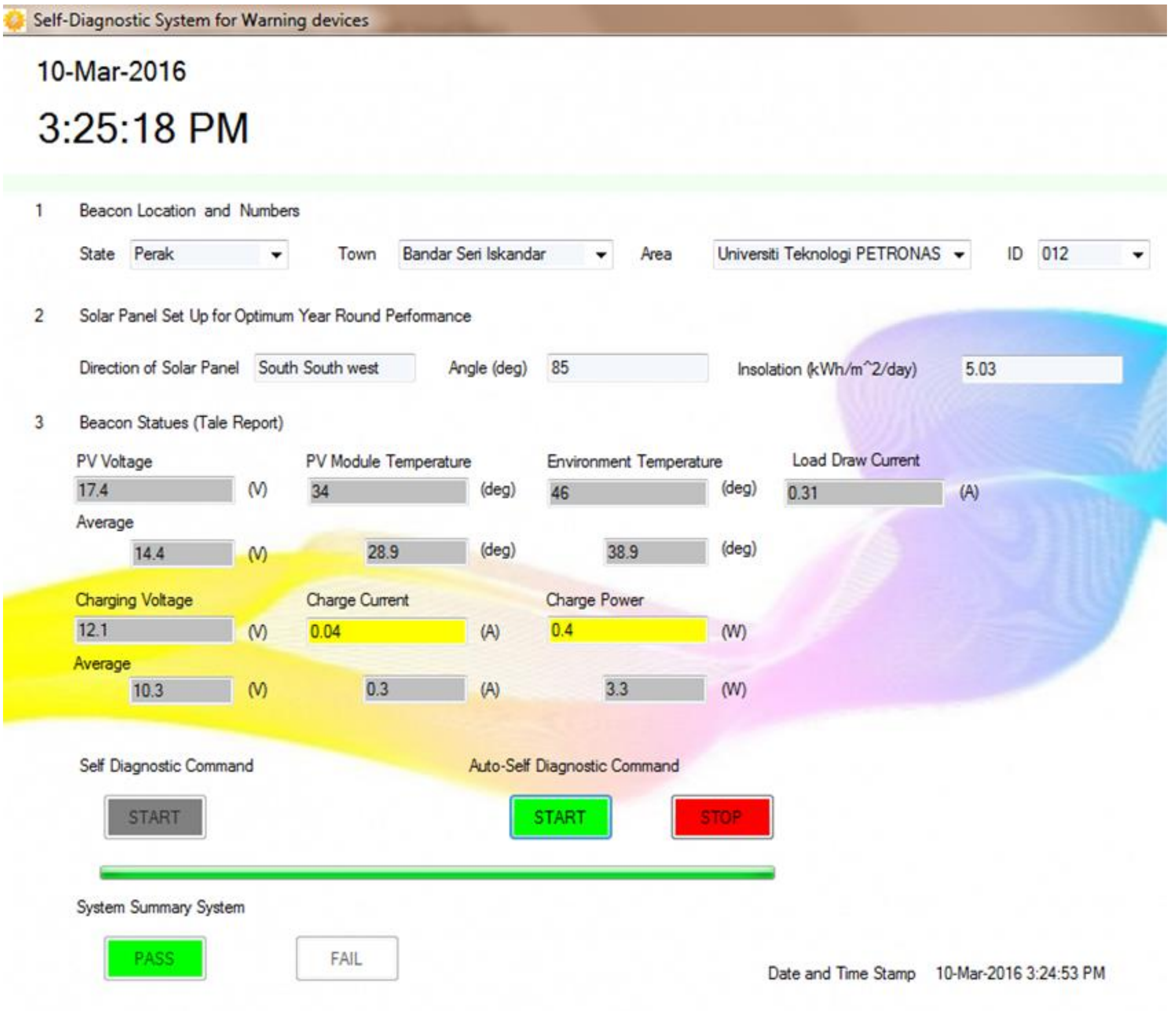


FIGURE 24: Graph showing PV voltage and charging voltage at different time of day.

From the graphs analyzed, MPPT outputs on a daily basis are stable. However, data should be collected over months and years to present an accurate and reliable picture of the robustness of the solar powered system.

The proof-of-concept prototype is working as expected. Data collected shows the solar panel is charging the battery, and the battery is powering the electronics and the flashing beacon. The PC is communication with the transceiver modules, and receiving data from the MPPT sensors. System data can be managed, retrieved, stored and read from GUI. In an event of system failure, the GUI will flag an alarm. A screen-shot of the GUI showing processed data values and returning a pass result summary.



Self-Diagnostic System for Warning devices

10-Mar-2016

3:25:18 PM

1 Beacon Location and Numbers

State: Perak
Town: Bandar Seri Iskandar
Area: Universiti Teknologi PETRONAS
ID: 012

2 Solar Panel Set Up for Optimum Year Round Performance

Direction of Solar Panel: South South west
Angle (deg): 85
Insolation (kWh/m^2/day): 5.03

3 Beacon Statues (Tale Report)

PV Voltage: 17.4 (V)
Average: 14.4 (V)
PV Module Temperature: 34 (deg)
Average: 28.9 (deg)
Environment Temperature: 46 (deg)
Average: 38.9 (deg)
Load Draw Current: 0.31 (A)

Charging Voltage: 12.1 (V)
Average: 10.3 (V)
Charge Current: 0.04 (A)
Average: 0.3 (A)
Charge Power: 0.4 (W)
Average: 3.3 (W)

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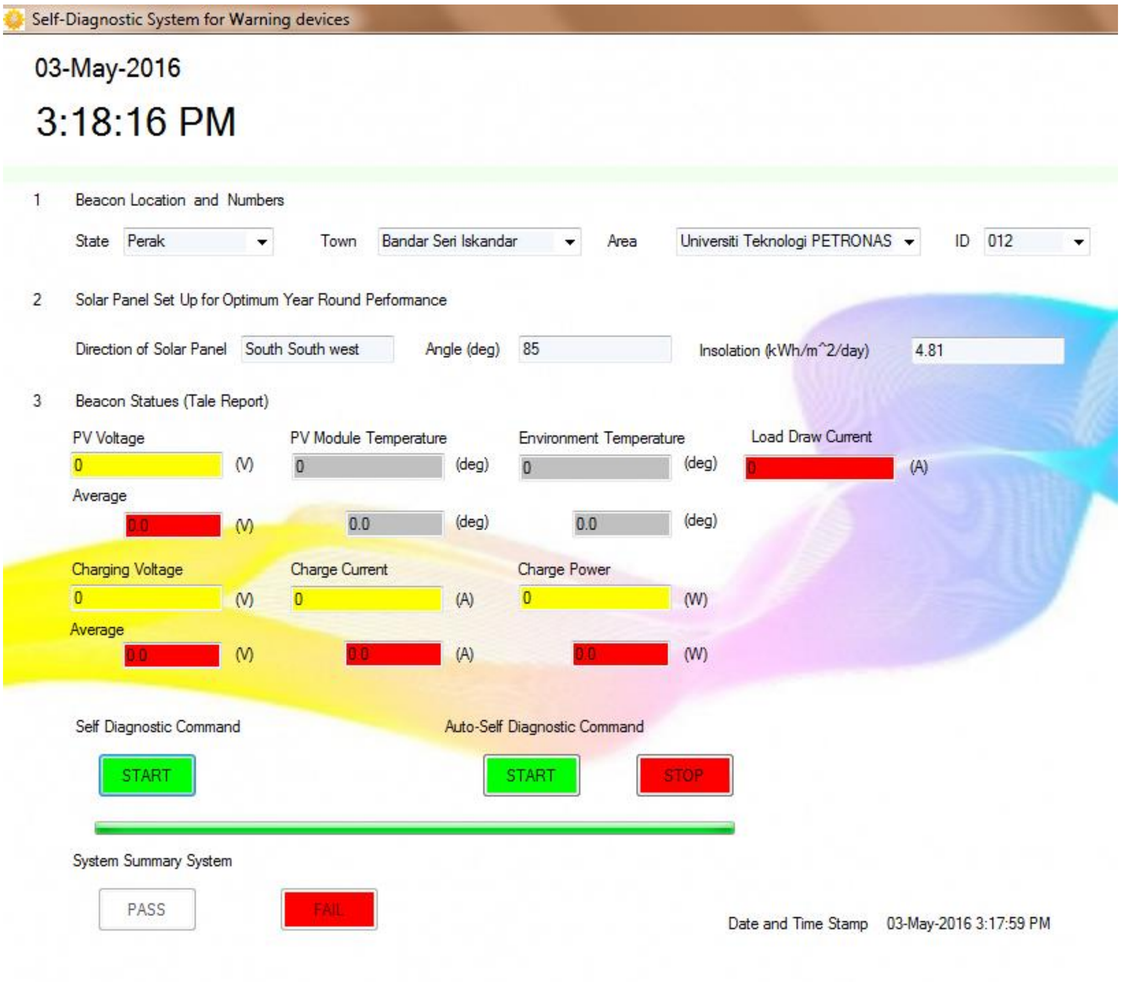
FIGURE 25: Screen-shot of GUI showing system Pass status.



Self-Diagnostic System for Warning devices

03-May-2016

3:18:16 PM

1 Beacon Location and Numbers

State: Perak
Town: Bandar Seri Iskandar
Area: Universiti Teknologi PETRONAS
ID: 012

2 Solar Panel Set Up for Optimum Year Round Performance

Direction of Solar Panel: South South west
Angle (deg): 85
Insolation (kWh/m^2/day): 4.81

3 Beacon Statues (Tale Report)

PV Voltage: 0 (V)
Average: 0.0 (V)
PV Module Temperature: 0 (deg)
Average: 0.0 (deg)
Environment Temperature: 0 (deg)
Average: 0.0 (deg)
Load Draw Current: 0 (A)

Charging Voltage: 0 (V)
Average: 0.0 (V)
Charge Current: 0 (A)
Average: 0.0 (A)
Charge Power: 0 (W)
Average: 0.0 (W)

Self Diagnostic Command

Auto-Self Diagnostic Command

System Summary System

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FIGURE 26: Screen-shot of GUI showing system Fail status.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The objective of this project is to develop a self-diagnostic prototype to monitor and manage a solar powered signage board with a warning device in the form of a flashing beacon. Featuring a self-diagnostic test capability in the system enables technicians to service the warning device more efficiently. A prototype PV powered flashing beacon was built, it worked as expected. System data were collected in real-time. The field set-up can be monitored and viewed remotely on the PC. This makes predictive and preventive maintenance pro-active thus minimizing potential system downtime. As a result, this promotes better roadway safety, helps to prevent accident and unnecessary loss of human lives.

5.2 Recommendations

There are many key-learning from literature reviewed; in the investigation of using alternatives for the hardware and subsequent in component assembly. As technology keeps advancing at a rapid pace, better and more effective methods of achieving the same objective will over-shadow what have been described, as this project progresses and takes shape.

An interesting wireless communication module alternative to ZigBee/XBee is TelosB mote which is getting popular due its integrated sensor based wireless enabled feature. The signal range is much wider as compare to the ZigBee/Xbee. It is also another IEEE 802.15.4 compliant open source platform that delivers low power consumption allowing for long battery life as well as fast wakeup from sleep state. Besides that, GSM should be taken into consideration since by comparison it has much stronger signal coverage and is a better choice once its cost becomes affordable.

For the microcontroller, Intel Edison is recommended for future enhancement rather than Arduino. The manufacturer claims that Intel Edison is a hardware and software platform that provides ease-of-development for a wide range of prototyping projects. The software platform is also able to create mobile-applications which currently are very popular. Through mobile-applications, future solar powered, wireless monitored signage boards and warning devices can be monitored at ease, anytime and anywhere.

This project has an implication and the potential to be an element to the Internet of Things (IoT) in the near future. Since the IoT is a network of physical objects embedded with electronics, sensors, and has instantaneous network connectivity; it can be leveraged for machine-to-machine communication (M2M) to collect and exchange data. Instead of using transceivers for wireless communication, this project can easily be adapted to take advantage of the growing popularity in cloud computing applications to allow objects to be sensed and controlled remotely across the internet.

Imagine a flashing beacon and warning device is equipped with sensors to monitor an approaching vehicle speed, weather and road condition. If it is raining heavily and the road is slippery; sensors will detect these hazards and transmit the information via internet to the vehicle. Once the vehicle knows that there is a danger ahead, it will alert the driver to slow down. If the driver ignores the warning, then the vehicle which has a smart built-in system will slow itself automatically. This is an example of a futuristic scenario how sensor-to-machine and machine-to-machine communication can play out for this project.

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