DEVELOPMENT OF A PERFORMANCE MONITORING SYSTEM TO OPTIMIZE PV BASED SOLAR ELECTRICITY GENERATION

By

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CERTIFICATE OF APPROVAL

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Approved:

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TRONOH, PERAK

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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 reference and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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(PRADEEP MENON A/L VIJAYA KUMAR)

ABSTRACT

Demand for electricity in Malaysia has seen a substantial hike in light of the nation's rapid economic development in pursuit of achieving Vision 2020. The current method of generating electricity is through the use of conventional energy sources such as fossil fuels. However, consistent usage of fossil fuels has resulted in detrimental effects towards the environment besides the dampening amount of natural resources available globally. An alternative energy source that is capable of sustaining the demand is needed to ensure a sustainable future. Since its implementation through the Sustainable Energy Development Authority (SEDA), the Feed-in-Tariff (FiT) mechanism has established a total installed Photovoltaic (PV) capacity of 192 MW from 655 projects that are currently operational from the overall of 2628 approved projects in Malaysia. With PV based electricity gaining acceptance, it is important that the output power is monitored for efficiency assessment besides keeping track of maintenance schedules and also assessing the rate of return of investment among the company shareholder. The procedure of generating solar powered electricity is subject to various ever changing environmental factors such as cloudy skies and harsh dusty winds that cover the panel with dirt resulting in a descent in the performance of the PV panel. It is important that this vital information be communicated to the user such that necessary action can be taken. The proposed data acquisition system consists of a microcontroller that is interfaced with supporting electronic sensors to measure PV sizing data such as panel output voltage and meteorological data such as solar irradiation. In addition to that, a sensor based sun tracking system was attached to the PV panels to establish control over the position of the panel. The microcontroller is connected to a micro-computer, and through the use of a Wi-Fi adapter; access to the internet was established. This will enabled the collected data to be stored in an online cloud storage which provides an infinite storage space. An Android application was developed to extract the information from the cloud storage and display the data on smartphones and tables for portable monitoring. In addition to just displaying the data, the monitoring system will have a diagnostic mechanism that will be capable of detecting drops in efficiency of the system and suggest possible causes and also possible corrective measures to address the problem. The diagnostic mechanism is an algorithm that is capable in comparing the daily PV panel output power at a given solar irradiation with a database of predetermined panel output power at a given solar irradiation value that is saved in the controller. Any deviation of the logged values from the predetermined reference values will be alerted to the user via the Android application.

Acknowledgement

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CHAPTER 1

INTRODUCTION

1.1 Background Study

As Malaysia takes a step forward towards its goal of becoming a developed nation, it is reasonable to assume that there would be an exponential increase in energy demand in the coming years as energy usage is directly proportional to a nation's growth. Looking at it statistically, in the year 2007, Malaysia's overall electricity consumption was 72.71 billion kWh which had thus increased to 93.8 billion kWh in the year 2012 proving a rise in electricity demand of the nation which is in unison with the nation's development. An announcement made during the Tenaga Expo and Forum 2014 held from 10^{th} to the 12^{th} of June 2014, placed Malaysia as the second largest electricity consumer among its ASEAN members and between the years of 2008 to 2030, the world energy consumption is expected to increase by more than 55%.

The predominant method of generating electricity at present is through fossil fuel combustion amongst which includes petroleum, coal and natural gases. With the current trend of increase in consumer demand has placed these resources in jeopardy as these resources bear a strong possibility of getting depleted besides contributing to injurious predicaments to the natural environment of the planet. In fact, in the Copenhagen climate change conference held in 2009, the Prime Minister of Malaysia, Dato' Sri Haji Mohammad Najib bin Tun Haji Abdul Razak has pledged to reduce the country's emission levels by up to 40% by the year 2020, in comparison to the levels emitted in 2005 [1]. In addition to that, the influence that economic and political situations have over these natural assets has led to its prices being highly volatile causing insecurities among citizens worldwide. These factors give good reason for Malaysia to reduce its dependence on traditional energy sources and explore possibilities of renewable energy resources within its boundaries.

In Malaysia, the efforts are currently heavily inclined towards electricity generation via the use of biomass, wind and solar energy resources. These resources have proven to have a minimal impact on the environment making it sustainable and clean. In this project, the studies will be focused on the effective utilization of solar energy for electricity generation. The energy received from the sun on the earth's surface each year is truly enormous; approximately 10^{18} kWh which is many folds more than the current global energy demand. This understanding alone defines why the solar energy resource in Malaysia has potential to greatly contribute to the nation's solar electricity generation system (SEGS), which is being promoted aggressively under the 10th Malaysia plan, through the establishment of Sustainable Electricity Development Authority (SEDA). SEDA was established, after the Renewable Energy Bill 2011 was passed by Malaysian government in April 2011, upon which has pooled in its resources and defined its aim in developing and comprehensively harnessing electricity from the energy given out by the Sun.

With the development of SEDA, the direction and awareness of the federal government with regard to the increasing importance of solar energy is evidently positive. However, despite its promising returns in terms of environmental conservation, the conversion efficiencies, of solar energy in the form of solar irradiation to solar electricity with the use of silicon based PVs are relatively low and maximum power is produced only when the PV panel faces the sun directly. This is due to the low efficiency of individual solar cells which are clustered together to form a solar panel. Furthermore, due to the apparent trajectory of the sun and the local weather conditions, the output power from PV records a fluctuating trend of values. The need to develop an integrated performance monitoring and tracking system that will allow the acquisition of data concerning the installed PV system’s performance is vital. This information is needed for evaluation and optimization of the system besides proposing a comprehensive maintenance track.

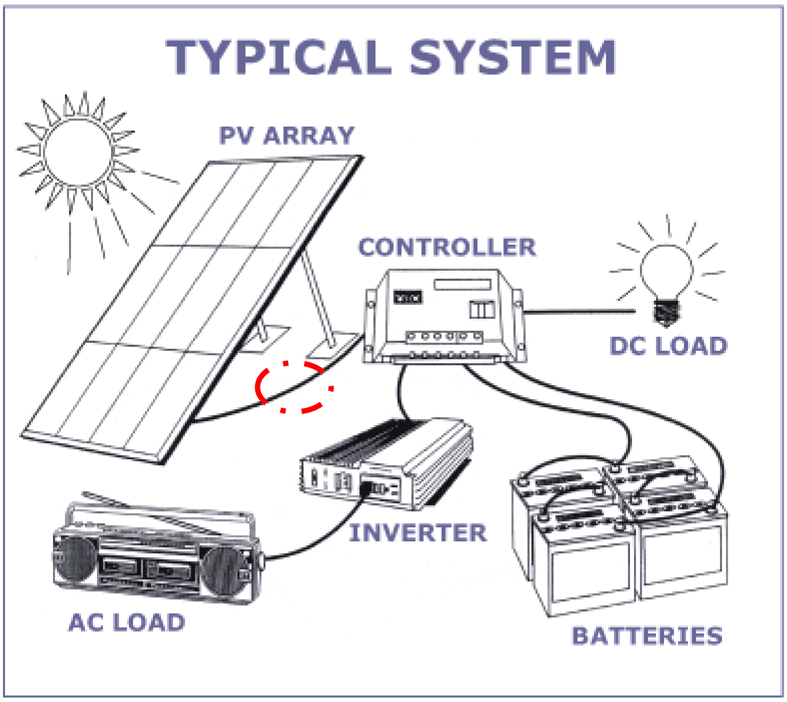


Figure 1: Solar Electricity Generating System Setup [2]

Figure 1 gives the typical setup of the PV based SEGS. From the figure, the key elements that go into the setting up of the system can be learnt. These equipment include the solar PV, charge controller, battery bank, DC load, DC-AC inverter and finally the AC load. The individual roles of the equipment are crucial in ensuring the well-being and longevity of the entire SEGS. The solar energy is harnessed by the PV array and fed into the charge controller. The charge controller function in controlling the direction flow of the charges ensuring there is not back flow of current from the battery to the solar PV which can be potentially dangerous. In addition to that, the charge controller is also capable of controlling the amount of power going to the DC load. The DC-AC inverter behaves to invert DC voltage into AC voltage such that it is compatible with the power grid and power devices of AC voltage requirement.

Again with reference to figure 1, the scope of the project takes into consideration the output DC power of the PV array. A more elaborate statement would be that the scope is not to improve the efficiency of the solar PV as this would require the molecular structure of the PV to be examined. The project work is to ensure optimized harnessing whereby the PV's output is maximized by mechanical means.

Research shows that optimized performance was achieved when three major criteria was met. These three criteria include;

- during cloudy skies, the PV is capable of maneuvering itself to a position of maximum light exposure [3]
- panels that are dirty should be frequently cleaned [14]
- should there be a faulty PV cell in the panel which drops the performance, the panel must be replaced [8]

A control and monitoring strategy that can dictate these factors is of dire need such that an optimized performance can not only be achieved but also sustained.

1.2 Problem Statement

As mentioned earlier, solar PV works with the availability of sunlight exposure. However various environmental factors such as cloudy skies and also harsh dusty winds significantly inhibit the performance of PV based SEGS. In order to optimize the output electrical power, there is a need for a comprehensive monitoring and control system that can effectively monitor and improve the performance of PV based SEGS besides reducing the overall cost, wastage, and also catering for any increase in demand. The system should also have a built in diagnostic mechanism that is capable of detecting any malfunction or drop in performance so that the information can be communicated to the correct authorities and maintenance activities can be carried out. The commercially available monitoring devices are too expensive and usually cannot be customized to fulfill these specific monitoring and control requirements. In addition to that, these monitoring devices only monitor the maximum output power of the entire PV system and not the individual PV modules. This makes fault tracing a difficult process as no proper lead can be retrieved from the monitoring system with or without the presence of a diagnostic system.

1.3 Objectives

The objectives of this project are:

- To optimize the performance of PV based SEGS by designing and integrating a performance and sun tracking system.

- To carry out field test on PV based SEGS by using the designed monitoring and control system.

1.4 Scope of Study

The project work for this study is aimed on conducting research with regards to the hardware and software sections of the control and performance monitoring system. The hardware portion capsules the designing and fabrication of a data acquisition system which is a combination of multiple different electronic components integrated together to perform the required function. In addition to that, the components utilized are programmable, such that the monitoring system can be customized to suit different applications, be it domestic or commercial. The software portion of the monitoring system was accomplished by developing an executable Android application based on Java programming that focuses on being user friendly. A single axis sun tracking system was designed and fabricated to establish a method of optimizing the efficiency of the SEGS. All sizing analysis performed uses solar irradiation data and PV panel voltage data obtained in Universiti Teknologi PETRONAS's Solar Research Facility.

CHAPTER 2

LITERATURE REVIEW

Figure 2 gives a diagrammatic representation on the formation of the fossil fuel, coal. From the information extracted, it can be retrieved that it takes over hundreds of millions of year for the formation of this particular resource. Understanding this figure in a more objective manner, it is understood that even the giant swarm plants that contributed in the formation of coal had solar energy stored in them as through the process of photosynthesis, solar energy is converted into chemical energy. This chemical energy was also consumed by the animals that used the vegetation as a source of food. After 300 million years, we obtain coal which is used to generate electricity.

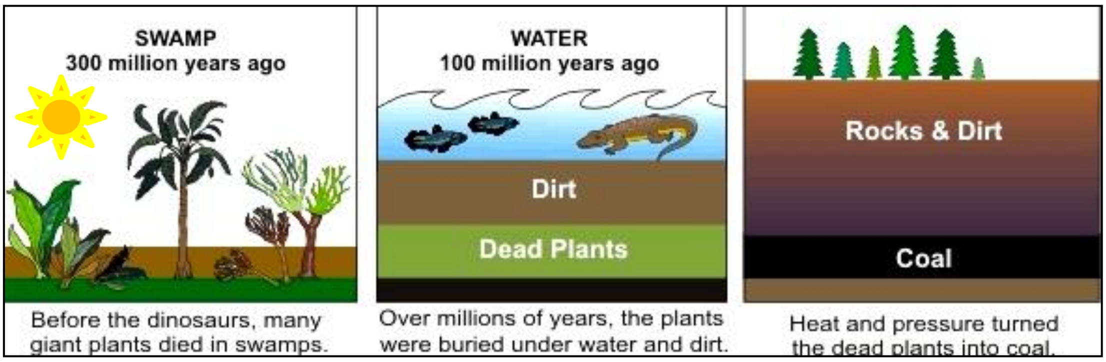


Figure 2: Formation of Coal [19]

Now consider the image shown in figure 3. The image shows the solar PV setup to generate electricity. It is apparent that the procedure used by the large swarm plants 300 million years ago to synthesize food and the procedure used by the solar PV to generate electricity is essentially the same. Both harness energy from the sun and convert it into chemical and electrical energy respectively. However a glaring difference among the both is that the process whereby the large swarm plants become coal that generates electricity takes over 300 million years whereby the solar PV can generate electricity within a fraction of a second under available sunlight. Therefore, the need to wait for a substantially long period is eliminated completely and a direct solution is readily available. We can also understand the significance of the Sun in the generation of electricity as both means of electricity generation has the Sun playing the role as the primary energy source.

Figure 3: Harnessing solar energy (image courtesy of 123RF.com)

Of all the planets that make up our solar system, the Sun is the only star found and planet Earth along with all the other planets orbit the Sun. The energy received from it is in the form of solar radiation which is further filtered to safe levels of exposure by the ozone layer. The sun is made up of approximately 74% of hydrogen, 25% of helium and the remaining is filled by trace quantities of heavier metals [4]. Having a surface temperature of 5500 K, the sun generates its energy through a process known as nuclear fusion of hydrogen nuclei to helium. It is accepted since prehistoric times as the main source of primary energy for all living things and the total amount of energy received daily is influenced by both meteorological and geographical aspects such as time of day and latitude respective.

In the modern world, we are faced with new challenges such as depleting oil reserves and sky-rocketing oil prices which has stirred political and social instability worldwide and subsequently leading to a shift towards of renewable energy sources for a sustainable future. The term renewable energy sources refer to energy sources that will not deplete upon consistent usage. A quick trip down memory lane shows us that, Becquerel discovered the PV effect in selenium in 1839 which proposed a conversion efficiency of 11% at a devastatingly high cost, $1000/W [5]. The application of photovoltaics ever since has travelled far from its initial application in outer space explorations where project cost is not an issue. The globally installed capacity of PV as of 2011 was 67 gigawatts [6].

Though a PV powered future promises many advantages which involve reducing the global carbon footprint along with meeting growing energy demands, the disadvantages that are currently surrounding the world of solar powered electricity seem to have paralyzed its growth. Among the problems that have raised reason to worry include the procedure that goes into manufacturing solar cells. Though it is globally accepted that the application of PV in harnessing and generating electricity is a sustainable and “green” method, the same cannot be said for the manufacturing process as most factories that produce solar cells or assemble a complete panel run on electricity generated via conventional power sources besides the individual procedures such as welding of the metal housing that contributes to pollution and simultaneous increase in carbon footprints.

To ensure that the problems surrounding the industry of solar powered electricity does not dampen the growth of the industry and interest of the general public towards this energy source, a bill was passed by the Malaysian Federal Government which resulted in the erection of SEDA. Besides actively promoting the use of renewable energy sources through tax exemptions and other incentives, SEDA is given the authority to administer and manage the implementation of the FiT mechanism which is mandated under the Renewable Energy Act 2011 [7]. With the emergence of the “Feed-in Tariff” scheme proposed by the Federal Government of Malaysia to promote generation of green electricity, a vast number of companies that have explorations in Malaysia have been investing in the solar market, whereby the electricity generated via harvesting solar energy is fed back into the power grid and in return for their generous efforts, the government will reimburse them with a favorable amount. In addition to that, there are over 1900 homes that are participating in this scheme, whereby the solar panels are installed onto the rooftop of houses [8]. This sudden increase in demand has seen lowering prices for PV systems. The smallest system of 4 kWp now costs around RM40,000 in comparison to RM50,000 to RM60,000 two years ago [8].

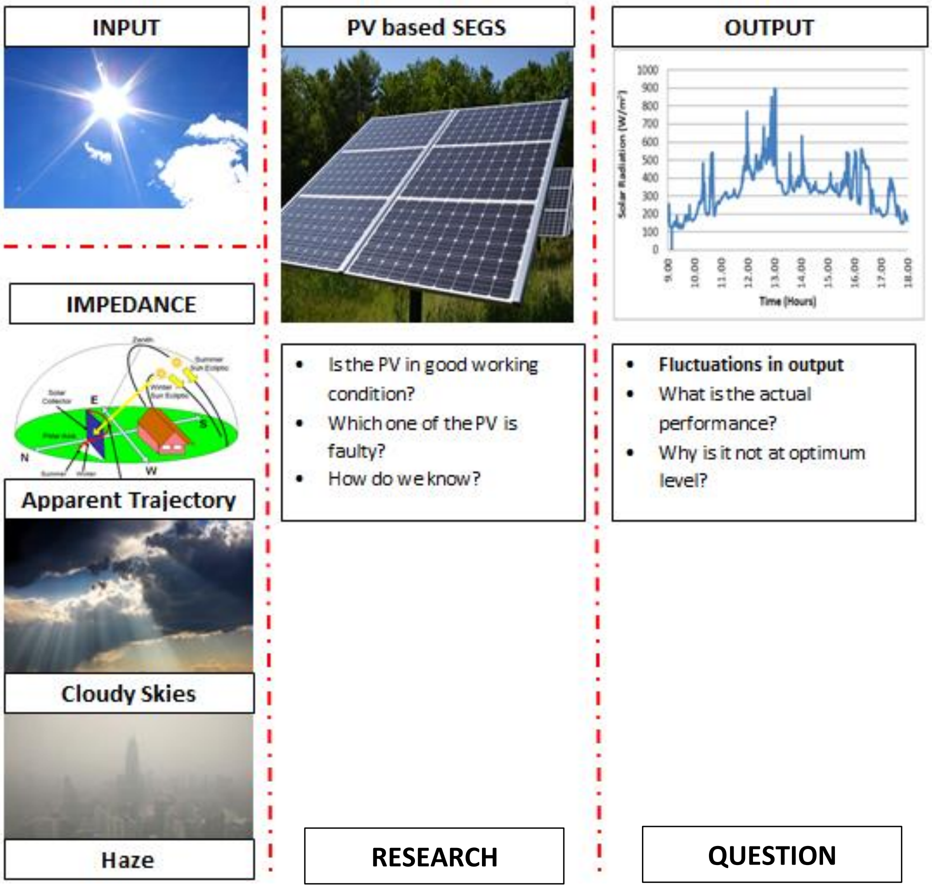


Figure 4: The overall scenario

Upon gaining a brief understanding on the factors affecting the generation of solar powered electricity and also the governing body that dictate the issues and businesses that surround the mentioned industry, it is important that the overall scenario of this literature be defined. Figure 4 gives a graphical representation of the literature showing the area of research along with the questions that will be answered. The input to all solar powered systems is the Sun which emits sunlight. This sunlight is to be harness by the PV array however there are a number of impedances that conflict with the amount of sunlight reaching the PV array. These factors are the apparent trajectory, the phenomenon of cloudy skies and haze. These three factors causes reflection when the light particles (photons) collide with the particles found in the mentioned impedances thus resulting in reduced light exposure onto the surface of the PV.

The area of research intends to identify methods of ensuring that the systems efficiency is unaffected by these phenomenon. In addition to that, besides environmental factors, the internal factors of the PV array also cause problems to the systems efficiency. A solar panel is made of an accumulation of solar cells clustered together to achieved the intended rated voltage. Having said so, the possibility of these cells to be degraded is rather high in high voltage farms that have an array of thousands of panels. Having a vast number of panels makes fault detection difficult and if compelled to do so, the labor charge is without a doubt expensive as the absence of an automated mechanism will require manual testing of output voltage.

With the strong influence these factors have over the generation of solar electricity, naturally the output curve will record irregular values with altering conditions. This makes monitoring difficult as the recorded values will deviate far from the calculated ideal values. In addition to that, degradation of solar cells will cause even more problems because a fixed reference would be difficult to determine.

2.1 Solar Geometry

The position of the sun at a given time plays a dominant role on the amount of sunlight that a PV module can effectively harness with maximum exposure. Planet Earth is subject to two forms of motion namely the rotation about its axis which brings upon the phenomenon of day time and night time and the other motion is known as the revolution of planet Earth around the sun. The revolution motion is made up of planet Earth rotation about its axis and simultaneously circumnavigating the Sun. Knowing that planet Earth revolves around the sun and a complete revolution is achieved upon a time period of 365.25 days, it has to also be known that in completing this revolution, 4 different phase is encountered, which are the Vernal Equinox on March the 21ST, the Summer Solstice on June the 21st, Autumnal Aquinox on September the 21st and finally the Winter Solstice on December the 21ST. In revolving around the sun, not only does the position of planet Earth alter, the angle the center of earth takes relative to the ecliptic plane of the earth also alters and this angle is regarded as the Angle of declination (δ). It can be retrieved that the angle of declination is ranged between $-23.5° \leq \delta \leq 23.5°$. [9]

2.2 Comparison of solar panel efficiencies

PV panels or commonly known as solar panels is the invention that enables electricity to be generated through energy given out by the Sun. From the statement of the Principle of Conservation of Energy, we can retrieve that energy cannot be created nor destroyed. It can only be converted from one form to another for instance, solar irradiation to electrical energy, which is what the PV does. In various applications which require PV cells, three main types have proven to be more efficient in comparison to the lot. Table 1 explains this statement.

Table 1: Critical analysis on efficiency of different types of PV cells

Type of PV	Description	Efficiency (%)
Monocrystalline Silicon PV	• Most common type of silicon chip • Consists of silicon in which the crystal lattice of the entire solid is continuous, unbroken to its edges, and free of any grain boundaries	12 to 15
Polycrystalline Silicon PV	• Multicrystalline from of silicon of high levels of purity • Obtained through a recrystallization process of polysilicon that are broken into chunks of specified sizes	11 to 14
Amorphous Silicon PV	• Non-crystalline allotropic from of silicon • Used for devices that require very little power	6 to 8

From the above table it is clear that the solar panel's conversion efficiency levels are still at its infancy. It is a common believe among developers that a system will guarantee more promising returns should it have a larger capacity which can cover-up for its low conversion efficiency. This believes leads to another problem posed by large capacity PV systems, whereby it requires vast land to accommodate the massive amount of solar panels. Utilizing flat panels only (panels place 180 degrees horizontally), having a converter factor of 10% to 20 % and a 20% capacity factor, it take 50 km^2/GW [8]. Today it is being built in Portugal a photovoltaic plant with a 64 MW production capacity which occupies a huge area of 400 hectares due to low (19%) individual collector conversion efficiencies [9].

2.3 Solar electricity generating systems (SEGS)

In generating electricity using solar panels, a number of supporting components are required to ensure that the system performs as is expected of it. These components include the charge controller, the rechargeable lead acid batteries and inverters. The ratings and models of each of these components should be selected based on the system type, site location and also the application

As mentioned, a number of factors need to be preconsidered in selecting the rating and model of the components being deployed in the overall SEGS and this action can be termed as PV sizing. The significance of PV sizing comes into play when in desining a solar power plant, it is important that the components are feasible to the intended output and will not be subject to harmful amounts of load which it is not desinged to tolerate. Oversized generators will increase generation cost and under sized generators will not meet the power demand and will not address the problems rather be prone to causing more problems [11].

2.4 Sun tracking system

The emergences of sun tracking systems have greatly impacted the industry of solar powered electricity generation by improving the efficiency of the output power generated by the system. The working principle of sun tracking systems revolves around altering the position of the solar panel to obtain the maximum exposure of sun light for maximum electricity generation. Both the apparent trajectory of the sun and also the position of the sun at the given time of the day have to be taken into consideration such that the position of the panel can be anticipated and feedback systems can be established. The types of sun tracking systems that are available is described in figure 5;

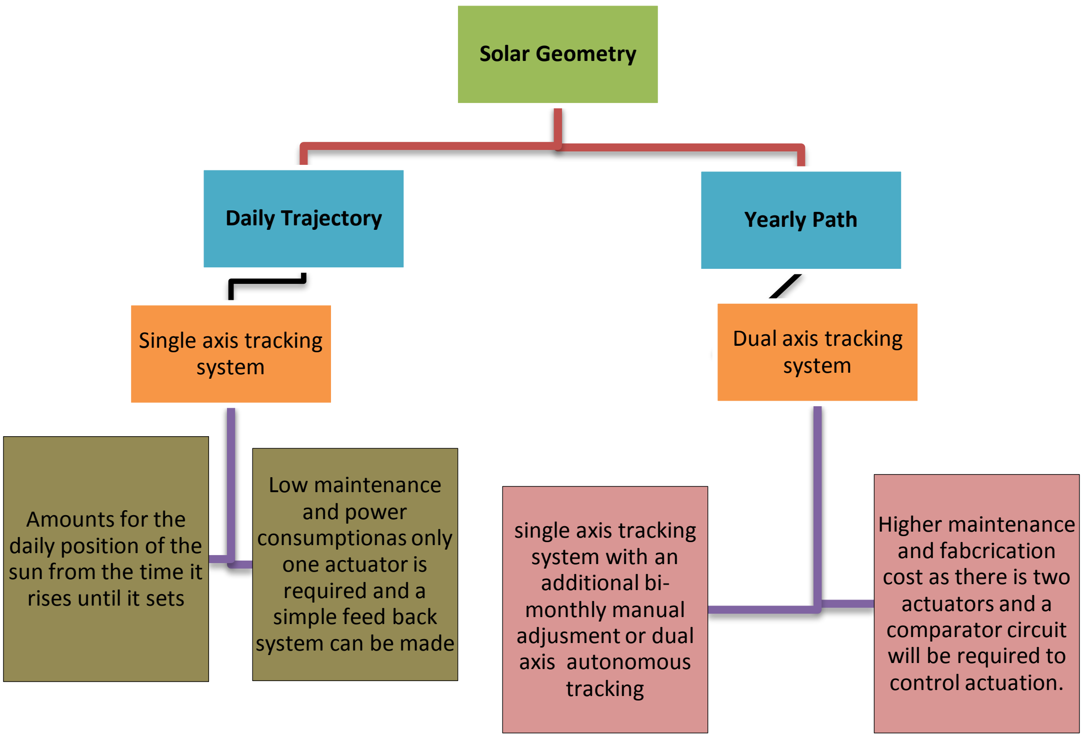


Figure 5: Types of sun tracking systems

Table 2: Critical analysis on the types of sun tracking systems

Main	Sun tracking system	Description	Advantages	Disadvantages
Single axis sun tracking system	Sensor based tracking systems	Utilizes light sensors that detect the highest exposure of sunlight at a given time and sends the signals to the controller to alter the position of solar panel.	Takes into consideration the ever changing position of maximum exposure of light due to the effect of cloudy skies	Light sensors may be expensive
	Time controlled tracking system	Has a pre-programmed instruction which informs the controller that alters the position of the solar panel based on the given time of the day	Reliable in the sense that it is not affected by light interference from reflective sources	Does not take into consideration the effect of clouds that interfere with the sunlight exposure
Dual axis sun tracking system	Sensor controlled	Has two actuators that reposition the PV with regard to the daily path and also the	Takes into account the apparent trajectory of the sun and is capable of	Having two actuators causes the system to be more expensive and drains more power to operate

		yearly path of the sun with feedback from two sets of sensors	finding the position of maximum sunlight exposure most accurately [7]	both the actuators

Most commercial PV farms utilize the time controlled tracking system as it has a simpler structure and also due to the fact that it has proven to increase the efficiency of the PV system. However as mentioned, the time module has pre-programmed instructions that alter the panels position at every selected interval (i.e. 10 degrees per hour) thus making it prone to problems posed by cloudy skies. Though this system does not propose the best method of increasing efficiency, it is better than using a flat panel. Usually the fixed angle solar panel is tilted at an angle which equals to the latitude. If the panels are positioned in the northern hemisphere, then the solar panels are tilted towards the south and vice versa [9].

A universal tracking system that can effectively track the position of the sun and significantly increase individual panel output can only be done by trackers that have sensors that can compare the solar irradiation and reposition the panel accordingly. The issue of expensive light sensors can be addressed when the pyranometer used as light sensor is replaced by a simple Light dependent resistor (LDR). The LDR's working principle is that upon exposure to sun light, the resistance drops and allows more current to flow through. Two symmetric photo-resistors can be used to track the position of the sun by intensity of light exposure. The photo-resistors are positioned on the same holder of the PV solar module, and are separated by a solid barrier to provide isolation for one of the resistors [13]. Having two LDRs will allows a comparative measurement to be established and this difference can be processed by a comparator circuit which can send instructions to a motor to control its position. The use of a tracking system is more expensive and more complex than fixed mounts: however they can become cost-effective in many cases because they provide more power output throughout the year and in many cases this increase exceeds 25% [14].

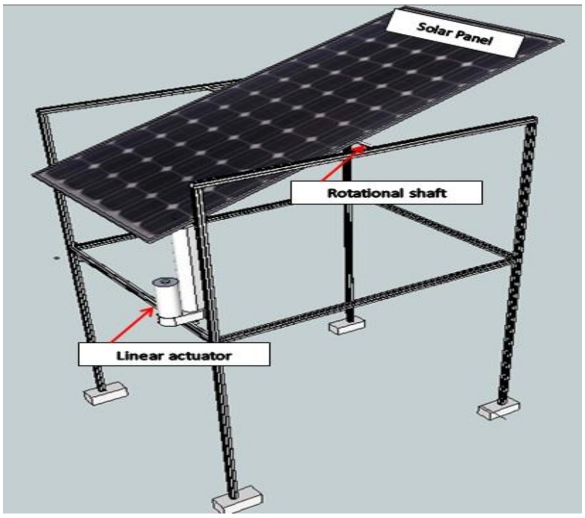


Figure 6: Sensor based sun tracking system

The LDRs however, due to manufacturing defects, will not ideally produce the exact resistance readings even when exposed to identical light intensities and can eventually result in the drop of efficiency when incorrect signals are sent to the controller. In addition to manufacturing defects, the LDR just like all electronic components are subject to wear and tear, especially due to continuous exposure to the ultraviolet rays of the sun. Over a period of time, under practical conditions, the LDR is bound to record a performance drop which will further degrade the system's legitimacy. The systems requires an automatic calibration feature that can record the drop or the difference in LDR values at the point where the sun is exactly 90° above the sensor when ideally the sensors are supposed to give the same resistance reading. Should the resistance readings retrieved from both sensors not align; the calibration system will readjust the resistance values making the two sensors to have equal resistance. In addition to that, the term universal tracking system can only be put into literal terms if this system can be integrated into PV systems of various ratings. Much calculation and trial and error methods are usually deployed by system integrators to ensure that the efficiency of tracking systems are realized and this will hike on additional cost into the construction of tracking systems. In addition to that, when the panel is rotated through the single axis, a region of shade will be created over the area that the panel is covering.

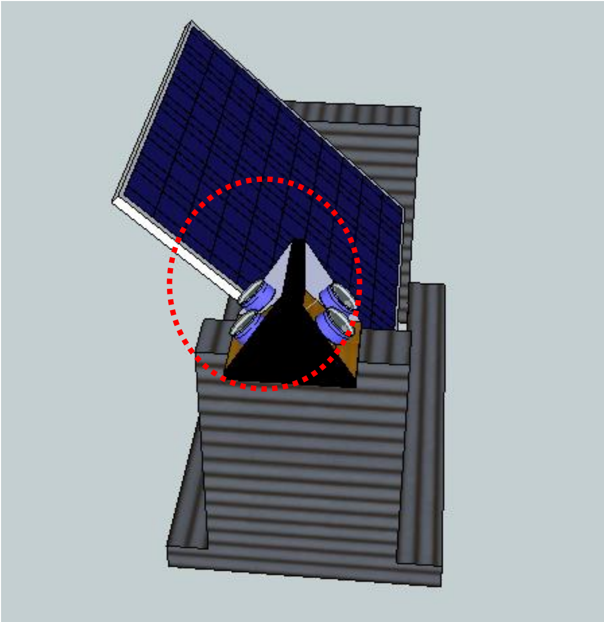


Figure 7: Shading phenomenon in tracking systems

The shading poses a serious problem because despite the fact that the sensors (circled in red) are supposed to be exposed to more sunlight however, the shading returns a sensor reading that shows the sensors on the right are exposed to higher light exposure. This will cause the panel to rotate to face the right side, however upon a certain point of rotation the panel would have moved beyond the sensor’s light path which will allow the sensor to return the intended values. This will lead to the panel again shifting towards the left. This process will repeat continuously until the sun moves beyond the path that will cause shading. The repetitive motion of the solar panel rotation will result in heavy strain on the DC motor controlling the system which will eventually lead to the damage of the motor.

2.5 Data acquisition system (DAS)

Among the terms utilized in this literature include angle, efficiency, power and many more. To obtain information regarding these measurements, a comprehensive monitoring and calibration system is required to not only keep the users up-to-date on the performance track of their PV systems, rather to also alarm them in case of an emergency breakdown or disconnection. The available monitoring systems usually keep log of the entire PV system output in comparison to individual PV module output. To understand the efficiency of your system, each panel’s efficiency data needs to be monitored individually and this will enable the technician or user to respond appropriately in the case of a breakdown. In addition to that, for PV farms that have solar panels with tracking devices attached to it, its main objective is to maximize the output of each individual panel, and monitoring the AC output only, defeats its purpose entirely. Table 3 gives the result of critical analysis performed on the current DAS systems to achieve a comparative measure.

Table 3: Critical analysis on different types of DAS

Reference	**DAS**	**Description**	**Monitoring**	**Control**	**Diagnostic**
DataTaker	DT80	An universal data logging system that enables online configuration and multiple sensors to be multiplexed into it	This system supports serial transfer of data and can be monitored from a computer	The system cannot receive any digital inputs that can stop or control any process	The logger cannot detect any changes or drop as there is no reference database for comparison
National Instruments	High-Fidelity Multisite Distributed Solar-Farm Monitoring System	An universal data logger that utilizes the LabView software for the ease of programming	The system allows monitoring via the use of LabView software that allows for real time monitoring	The system cannot receive any digital inputs that can stop or control any process	The logger cannot detect any changes or drop as there is no reference database for comparison

• ABB • General Electric • Siemens	SCADA	A comprehensive and complex monitoring and control software that provides holistic information regarding the plant	A network of high speed computers displays the individual numerical values of each intended process	The SCADA network allows for emergency stops and also auto shutdown	The network is preloaded with a database of values which will act as reference to compare

From the table which displays the results on the critical analysis conducted on the types of monitoring systems, we can retrieve that only SCADA systems offer monitoring, control and diagnostic alternatives. However SCADA systems bear a very high cost making it unreasonable to be purchased for small scale commercial solar farms that has a rated output power such as 100 KW that has approximately 400 solar panels that have a maximum power output of 250W individually. In addition to cost, SCADA systems does not provide a method of wireless monitoring as the process being monitored cannot afford interferences in wireless networks that delay data transfer. To give a more diagrammatic representation of the statement, figure 8 shows how these monitoring systems can be related to the capacity of a solar farm.

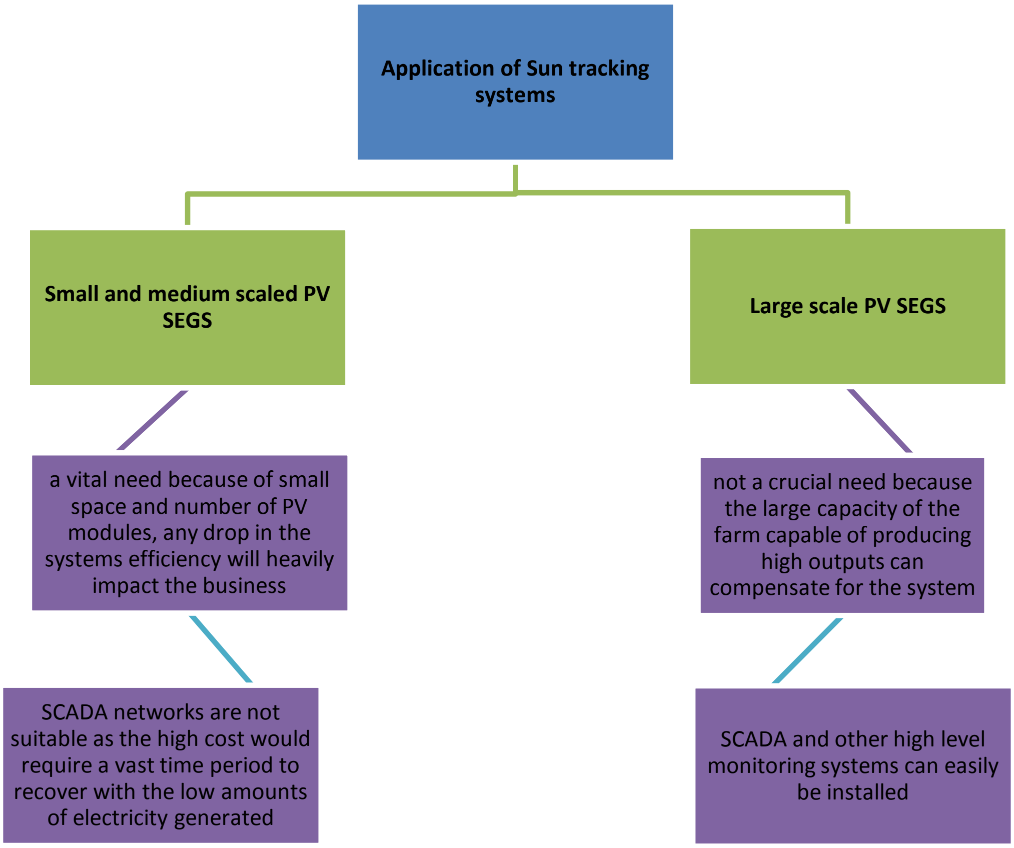


Figure 8: Application of monitoring and control systems

From the figure, it can be accepted that the project intends to cater for small and medium scaled PV based SEGS where the monetary resources are at limited release. The approach that the proposed systems takes whereby the analog sensor module is integrated with a microcomputer and an android application allows the data to be monitored remotely and problems to be made aware of promptly. In the current market, most cost effective monitoring systems behave just to display the data in the absence of a diagnostic system requiring the user to manually detect and trace problems.

That having been said, the main inhibitor for PV farm developers to install individual monitoring devices as proposed in this project is cost, because unlike conventional power plants, a 4 Megawatt solar farm may consist of approximately 4000 panels, meaning 4000 different transmitters and 4000 different signals for each of those transmitters. In addition to costing, wireless communication has been rendered unreliable as devices operating in its nature are prone to transmission losses and noise interference which is an unacceptable clause in monitoring systems. On another note, systems that use data transmission via wired networks do not certainly guarantee high efficiency of data transmission. A common characteristic of the mentioned data acquisition systems is the use of data loggers or microcontrollers for measuring and acquiring the signals and transmitting them to a PC through serial port RS-232. Usually, the data transmission through the serial port is limited when data acquisition at high sampling rates is required [15].

However in most PV farms, solar panels are arranged in sets, for instance a row of panels may consist of 10 panels and a block of them may consist of 40 panels. Individual sensors can be placed on each panel and the entire block can be controlled using a single transmitter reducing the cost entirely. In addition to cost, the Safety Integrity Level (SIL) of the farm may be at question seeing that panels are subject to high solar radiations throughout the day. Fire hazards are a strong reason for worry as the fire can be from a single panel which may later spread through the entire network. Having individual monitoring will enable early detection, not only in case of emergencies, rather if a panel is malfunctioning or requires repairing of some sort, allowing a more effective system to be realized.

A glaring difference between large PV systems owned by companies and off-grid PV systems installed at shopping malls and civilian homes are that the large PV systems are maintained by technicians that are well versed and possibly possess a considerable amount experience in the field of electrical and electronics, however the same cannot be said about off-grid PV systems that are installed at civilian homes. Therefore the need of a diagnostic and user responsive system is required to assist the user in troubleshooting or providing specific error messages that can be directed to a technical support member, should there be a problem with the system.

Besides simply having a system that can effectively monitor the meteorological data, it is required of the system to be able to cater to different layers of the community, whereby all people of varying professions and age should be able to use it and also it should be at par with the current technological development. Another limitation we have identified in conventional data acquisition systems is the difficulty of making any modification to the programs [15]. Therefore the need of the user interface to be both informative and also simple, without compromising its core functions is signified. The increased usage of touch screens in various different application systems has made this technology well versed among many. Although the usage can be divided by different industries, such as ABB, a multinational conglomerate that specializes in power products has its Robots being programmed by a touch screen unit known as the "Teach Pendant Unit". However vast the application of touch screens may be, its primary usage is in the smart phone industry. Since it was first revolutionized and reintroduced by Apple corp. in the year 2007, the global smartphone sales to the end users as of 2013 is 2.85062 billion units and the total smart phone users as of the same year,2013 is 1.75 billion users [16].

To enable fast processing of touch response and also switching of display, a processor of high processing capability is required. Therefore the best solution to facilitate the ease of use and also to enable high processing speed of touch screen systems would be to develop a smart phone application that will display the meteorological values along with prompt messages that can alarm the user of a possible problem in the entire monitoring or tracking system. The current systems do not offer a method of such sort as it utilizes the usage of voltage sensors and current sensors that will provide measurement readings only. The dust gets accumulated on the front surface of the solar panel and blocks the incident light from the sun. It reduces the power generation capacity of the solar panel. The power output reduces as much as by 50% if the panel is not cleaned for a month [17].

The absence of a method of alerting the user on the condition is among the reasons that the PV farm suffers losses and power wastage. This brings us to an understanding of the need of a diagnostic system that utilizes feedback signals to monitor that performance of the PV system. The improved system not only (as mentioned before) will provide readings such as panel voltage, current, angle of the panel, efficiency of the panel, and power output, the system will also be able to compare the voltage values achieved at a certain solar irradiation level when the panel is first cleaned (assumed to be able to give higher voltage output) with voltage values retrieved after a certain period of time with the exact amount of solar irradiation. Should the values be different, a feedback message will be prompted by the system. On another note, the controller will also receive feedback values from the accelerometer that will provide a means of measuring the efficiency of the motor being used. At a given solar radiation and also feedback from the LDR, the tracking system should ideally position the solar panel towards a certain position. The position can be detected by the accelerometer and should both these values not align, then a warning message can be sent just as information to the user.

In addition to a basic monitoring device, this system will also be able to log the meteorological values and save them in a secured databased, allowing authorized personnel to access the logged data for research or monitoring purposes. These data and monitoring activities can be done by using the android application that will be developed for the system or should the user prefer a serial option will also be made available to allow the user to jack their computer in and retrieve data directly into their computers.

Every system has its individual life span that can be known through the manufacturer data-sheet or sometimes through experienced usage of the system or device. Despite the specified period (stated under ideal conditions), systems seem to perform better if a regular maintenance track record is maintained. Besides simply increasing the system's life span, the accuracy of measurements and output obtained from the system can also be maintained. "Many times, managers and other workers won't notice a problem until they either hear strange sounds during the process, or experience some form of equipment failure. The trick is to prevent problems rather than to react to them later when it is too late [18]. Similarly all the components on the monitoring and tracking system require maintenance to ensure its proper functionality. This sort of maintenance is known as preventive maintenance since the activities carried out are to avoid major problems that would require replacement of expensive components. However it is difficult to keep track of when is the exact time the system requires maintenance, therefore a schedule will be pre-programmed into the system and at an appropriate or rather necessary time, the system will prompt a service message urging the user to perform basic maintenance activities such as cleaning of the panels, cleaning of the sensor housing and more if necessary.

CHAPTER 3

METHODOLOGY

In this chapter, the integration of the monitoring and control system will be clearly outlined. The methodologies used will be explained, there the overall flow-chart for the processes involved in given as Figure 9. The monitoring and control system that is being developed in this project can be seen from two major perspectives namely the monitoring portion and also the control portion that will make up the eventual complete system. The following flow chart gives a representation on how these two separate applications come together.

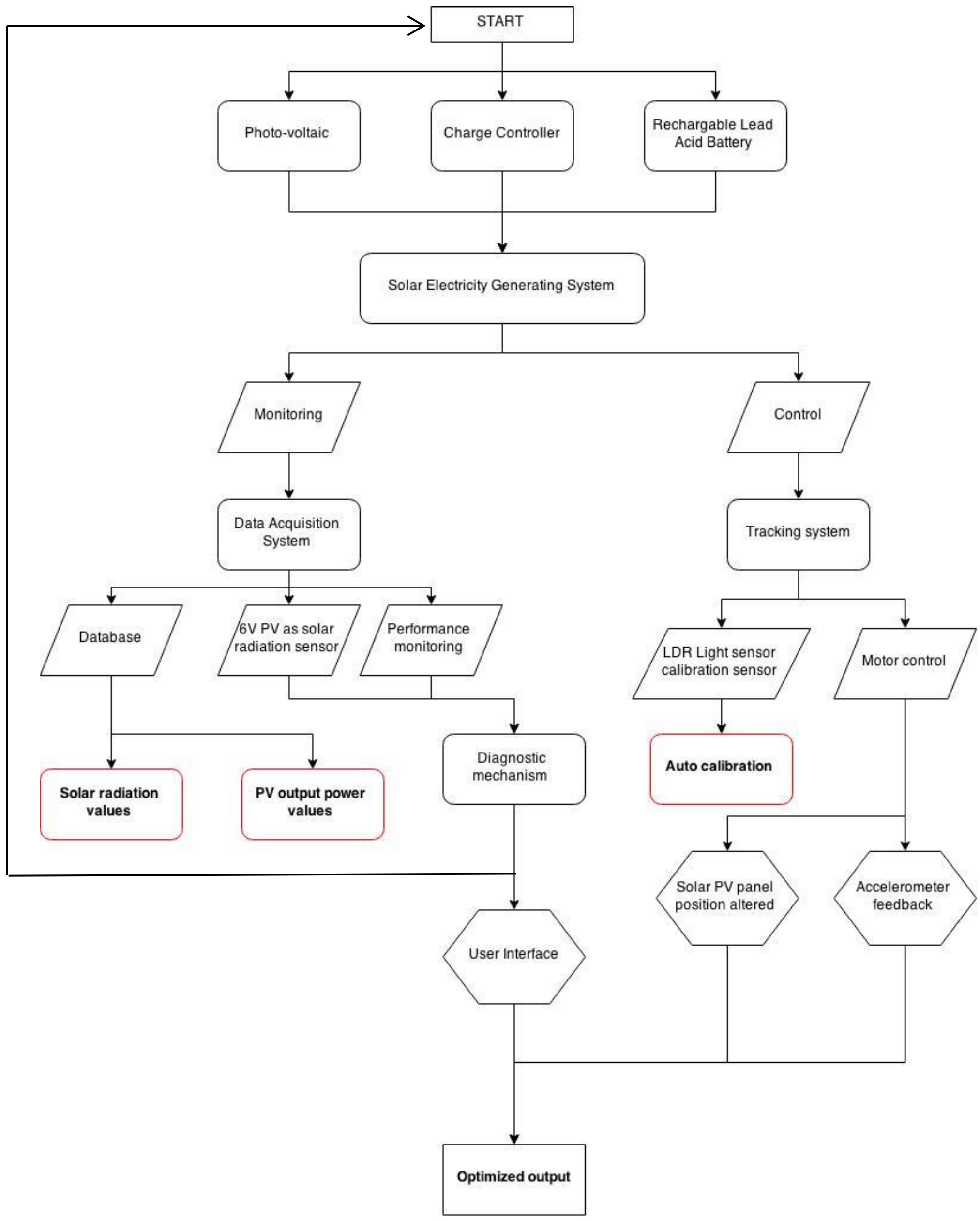


Figure 9: Flow chart of complete system

3.1 Monitoring phase

From the flow chart, it can be seen that the SEGS is divided into the monitoring and control phase. Looking at the monitoring phase, the main aim is to fulfill the requirements of the data acquisition system. The first portion of the DAS is the pre-saved excel database. This database will be created by logging the solar irradiation values obtained from the 6 VDC PV panel that will replace the pyranometer and also the output power from the PV system shown in **Appendix I** and saving it in an excel sheet. This database will act as the reference benchmark that the diagnostic system will use to compare the daily output power values from the system and provide an efficiency monitoring mechanism. The following flow chart will give a schematic representation of the diagnostic mechanism.

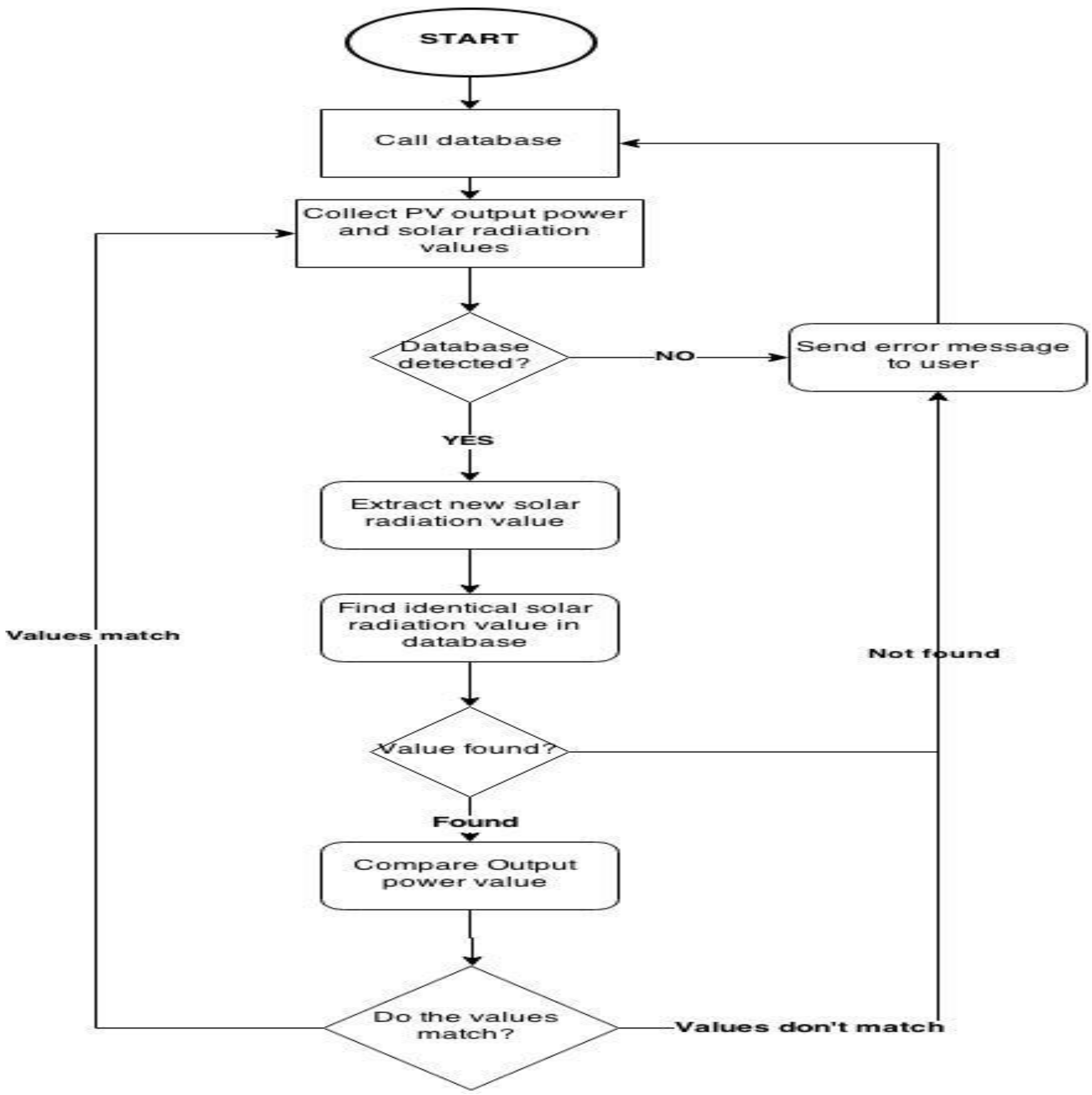


Figure 10: Diagnostic mechanism program flow

3.2 Control Phase

The second portion of the SEGS is the control phase which covers the sun tracking system and also the sensor auto calibration phase. The sun tracking system is a single axis tracking system that will consist of three PV panels that will be connected to DAS. The sun tracking system design can be referred to in **Appendix I**. The tracking system will consists of a high torque motor that will govern the positioning of the solar panels. The motor will be connected to the controller using a motor controller which can send PWM signals and alter the position of the panels based on the accelerometer's feedback signal. The auto calibration phase is related to standardizing the LDR's minimum and maximum values to ensure that the effectiveness of the sensor is increased. This is done using a digital potentiometer where the output resistance is adjusted by instructions send to it from the controller.

3.3 Data Acquisition board

This section of the system is aimed to obtain the meteorological data that concerns the efficiency of individual solar panel units. These data include the measured voltage, the measured current, the calculated electrical power, the panel's tilt angle and finally the feedback from the motor controller. The angle data and feedback from the motor heavily relates to the operation of PV systems that utilize tracking systems in which the panel alters its position to obtain maximum output voltage. The given angle of the panel at a time of the day can be anticipated and set as a reference value which can be compared with the angle measured at that given time. This would produce a value that can measure the track record of the tracking system in terms of its functionality (i.e. are the motors working effectively, is the motor driver functioning). The angle can be measured using a triple-axis accelerometer that has the capability to detect the deflection in the X, Y and Z axes of the panel. The angle information is the feedback signal that will be supplied to the *Arduino Mega controller* for processing. If there is a significant change in the angular values of the panel, then the information will be recorded by the controller.

In addition to that, the voltage sensors and current sensors will record and display their designated values. The voltage sensor is a simple voltage divider circuit that can be plugged into the "Vin" port found on the Arduino Mega board. Seeing that the Arduino microcontroller can only process a maximum voltage of 5VDC and solar panels have voltage values that vary in accordance to size and type, it is important that the voltage divider circuit's resistance value can be altered to meet different types of panel voltages. Therefore 10K digital variable resistors are a suitable choice in this application. The value of the variable resistor can be calibrated by plugging the signal cable into a digital output port on the Arduino Mega to alter the resistance of the potentiometer to cater to the panel's open circuit voltage. The current sensor utilized will be a hall-effect current sensor. Using sensors of this type enable easy maintenance and servicing since, should the sensor give way, no wiring has to be cut out rather just the sensor wiring since the hall-effect sensors simply envelopes the current carrying wires (live).

It is a known fact that upon consistent exposure to rain and harsh winds, the panel is bound to develop a layer of dust which in turn will retard the efficiency of the system. This condition is common for PV Systems positioned at deserts or industrial areas. As mentioned before, the main cause of lack of importance given by those owning PV systems lies on the fact as to when the PV system should be cleaned. A drop in efficiency can be easily written off as reduced solar irradiation and this reinforces the need of a feedback system that can alert the user of the actual cause. The readings recorded by the voltage sensors on the first week of installation will be saved to create the database of values and we can use that data to match a specific or rather maximum voltage value to a value of solar irradiation. The logging activity of the given surrounding will be retrieved using a 6 VDC PV panel and voltage sensor that will be attached to the controller. Therefore, upon comparison of logged values over a period of time with the initially logged values where the environment can be assumed ideal (i.e. panel is in its cleanest and best condition); should a deviation be recorded the information can be communicated to the user.

To attain a clearer view the first step would be to manufacture a tracking system that will enable the working principle of the data acquisition system to be seen. The panels that will be used in this design are of rating 3W and the complete 3D design can be reviewed in **Appendix I**. This system, as can be referred, has a basic DC brushless motor that will be controlled via a motor driver. The PWM signals will be sent to the driver to control the speed and the position will be governed using the feedback values from the accelerometer.

To ensure that the tracking system being built in this study is more efficient in comparison to the time controlled tracking systems which are currently being used in the industry, a study was carried out. The experimental setup is shown in Figure 6 and Figure 7 below. The setup consists of two 250 Watt PV panels that are attached to two separate tracking systems. The system on the right of the figure is the sensor based tracking system and the figure on the left is the time controlled tracking system. A pyranometer was used and the data was collected using a DT80 Datataker as show in figure 7. The open circuit voltage of the panel was beyond the readable range of the DT80 Datataker therefore the output had to be fed through a voltage divider circuit to set down the DC voltage and current.

Figure 11: Experimental setup to compare time controlled and sensor controlled tracking systems

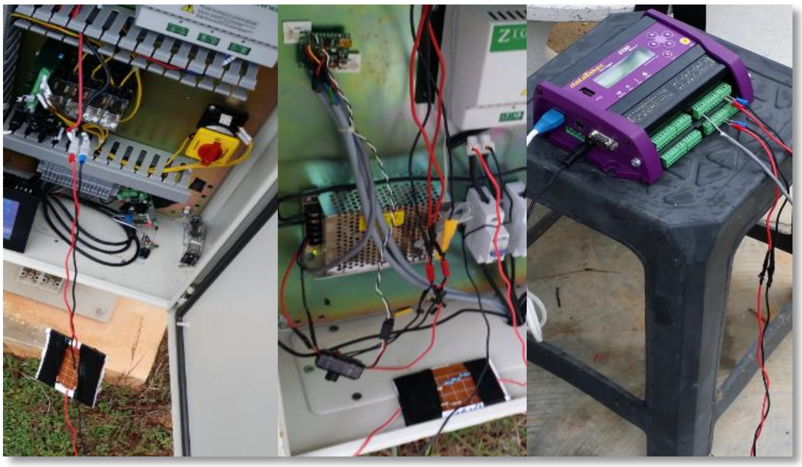


Figure 12: Voltage divider circuit and DT80 Datataker

In addition to the tracking system, the individual components have already been looked into with respect to the Gantt chart provided. The explanation will be done in terms of phases. The first phase was to serially read the resistance values from the Light Dependent Resistors (LDR). The testing setup is as shown in the figure above.

The problem due to different minimum and maximum values with respect to different LDRs can be solved using the “Map” function that enables a cut off and standardization of the LDR values such that a range can be created. In addition to that, the MCP 4161 digital potentiometers will be used to level the actual resistance values of the LDR. The next phase was to test the function of the ADXL 335 accelerometer to ensure that the sensor is capable of reading the values from the three separate axes.

Figure 13: MCP 4161 digital potentiometer

To enable the voltage of the panel to be monitored by the Arduino, the solar panel voltage needs to be stepped down to a level below 5 VDC such that the “V-in” pin can measure the voltage. To stick true to the main intention of bringing upon a universal system, the voltage divider circuit will be made using programmable potentiometers namely the MCP4161 that has 257 different steps and has a maximum resistance of 10 KΩ. The connection was first simulated using Proteus Professional 7. Upon testing the chip using Proteus the actual circuit was built on a solderless breadboard and the output was measured using a simple digital multi-meter. The use of this chip will enable the voltage divider circuit to be altered by the controller allowing different solar panels of different open circuit voltage to be connected and measured effectively.

3.4 Solar irradiation measurement

The following phase was to establish a reference parameter to enable the system to have a benchmark to enable comparison. The parameter that is of interest is the solar irradiation (W/m^2) which is usually measured using a pyranometer, however as a method of cost saving, an equally effective method is used which is taking the voltage reading from a 6 VDC solar panel and converting it to the solar irradiation values. The conversion factor is done by data logging both the solar panel (6 VDC) voltage and also the solar irradiation values using a pyranometer and then making the comparison.

Since the tracking system employed here is of sensor basis, whereby the LDR is used to track the direction whereby the exposure of the sunlight is at maximum, the phenomenon of solar panel shading does apply in this mechanism. The idea proposed to overcome this issue would simply be to elevate the sensor housing above the region that the shading would be if effect. The elevation can be determined via the following equation;

$$Elevation \geq \frac{Solar\ Panel\ Height\ (h)}{2} \quad (1)$$

The equation applies as the only region that will be causing the shading effects are the separate halves of the solar panel height. In tracking systems it is natural for the panel to be levered at the center thus elevating beyond the given height will cancel out the effect. To cater for a PV system that already has its base bolted down into the ground the housing is made rotatable to enable the sensors to be shifted to the optimum position.

3.5 Computer unit

A microcontroller is capable of collecting the meteorological data via sensors and storing it in its on-board memory. However, the Arduino Mega controller only provides a flash storage size of 256 K bytes of which 5 K bytes has already been taken up by the bootloader. To enable the microcontroller to be programmed and also to allow for external storage of the data a computer is needed. To stick true to the portable characteristic of the system, a credit-card computer known as the Raspberry Pi will be utilized in the system setup.

Figure 14: Raspberry Pi model B+

Having the Raspberry Pi (Pi) on-board allows the data acquisition system to be portable and also easily customizable. As mentioned before the Pi is a computer and utilizes the Raspbian operating system. The Pi has 4 USB ports of which one, though the use of the Arduino programming cable, can establish communication with the Arduino. The other 3 ports can be reserved for updating activities whereby a USB keyboard and a USB mouse can be plugged in and allow it to operate like a computer. Since the Pi is also a micro-computer, its storage space is still limited. However with a simple Wi-Fi adapter and the availability of a Wi-Fi network, the Pi can establish communication with the internet and store the logged data in a cloud storage system such as MySQL.

A database is a collection of information and an online database such as MySQL has the similar nature however is can be access with the use of a computer. In addition to that, the data stored are in an organized fashion whereby they are placed in tables that operate on the "row" and "column" basis. MySQL provides a platform to enable this database to be created and accessed and altered in accordance to its nature. For the data to be accesses from anywhere you are, an online database is necessary as it allows for you to simply connect to the internet and download the database. Since the function of the proposed system not only monitors the activity rather also records, therefore the database is a necessity rather than a cosmetic feature.

Since the meteorological value sheet will be arranged by the Raspberry Pi, the means of wireless communication should begin with the computer unit. Upon obtaining and arranging the data, with the use of a Wi-Fi module the data will be uploaded onto the MySQL database. In addition to that, the ability of the system to access Wi-Fi from the computer allows it to transmit maintenance signals or error messages regarding the PV System directly to the user via the Android application. Should the user prefer a monitor display rather than the android application, the computer unit can be connected to a monitor via a HDMI cable, which the Raspberry Pi does support or can be viewed remotely thorough another computer by using software called “Team Viewer”.

3.6 Android Application

In order to enable the system to be monitored wirelessly, an application proves to be the most cost effective method in comparison to submitting a new touch screen design. The use of android applications also enables the alternative of the wireless monitoring and logging system to be less complicated to the user. The software and programming language used to develop the android program is Java Programming language. The android application will display the voltage, current, tracker efficiency and output power. In addition to that, the error messages that the Raspberry Pi registers can be displayed as a prompt message letting the user know of a possible efficiency drop or a malfunction in the system. The complete operation and assembly of the system can be realized through the diagram below which shows how the individual portions of the design come together to form the monitoring and control system.

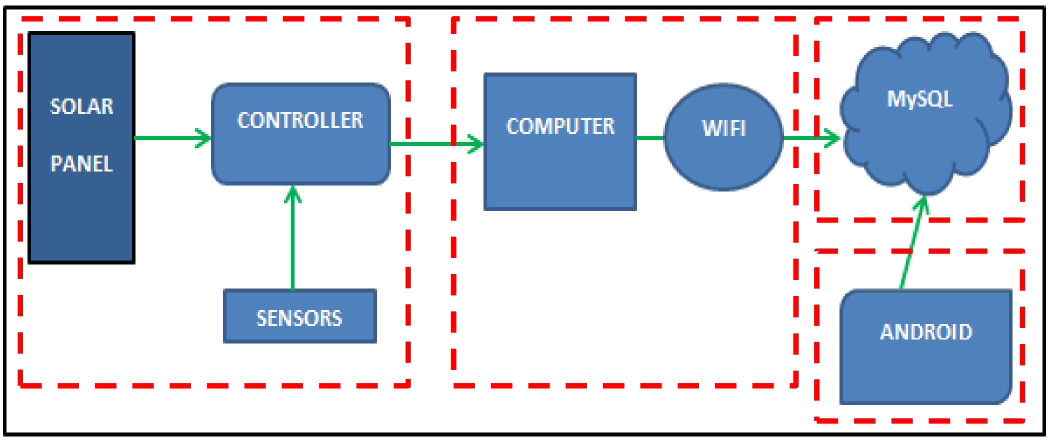


Figure 15: System layout

3.7 Project Tools

HARDWARE	SOFTWARE
• Arduino Mega 2560	• Arduino IDE
• Raspberry Pi B+	• Proteus 7
• WiFi Adapter	• Python IDE (PuTTY)
• Hall Effect Current Sensor	• MySQL WorkBench
• LDR	• MySQL for Excel
• Triple axis accelerometer	• MySQL Server
• Digital Potentiometer	• Matlab 2013
• DC Motor and Motor controller	• SolidWorks 2013
• 6 VDC Solar Panel	• Android ADK
• Graphic LCD display	• Eclipse
• Android Phone (Galaxy Note 1)	• Java for Windows
• Prototyping Board	

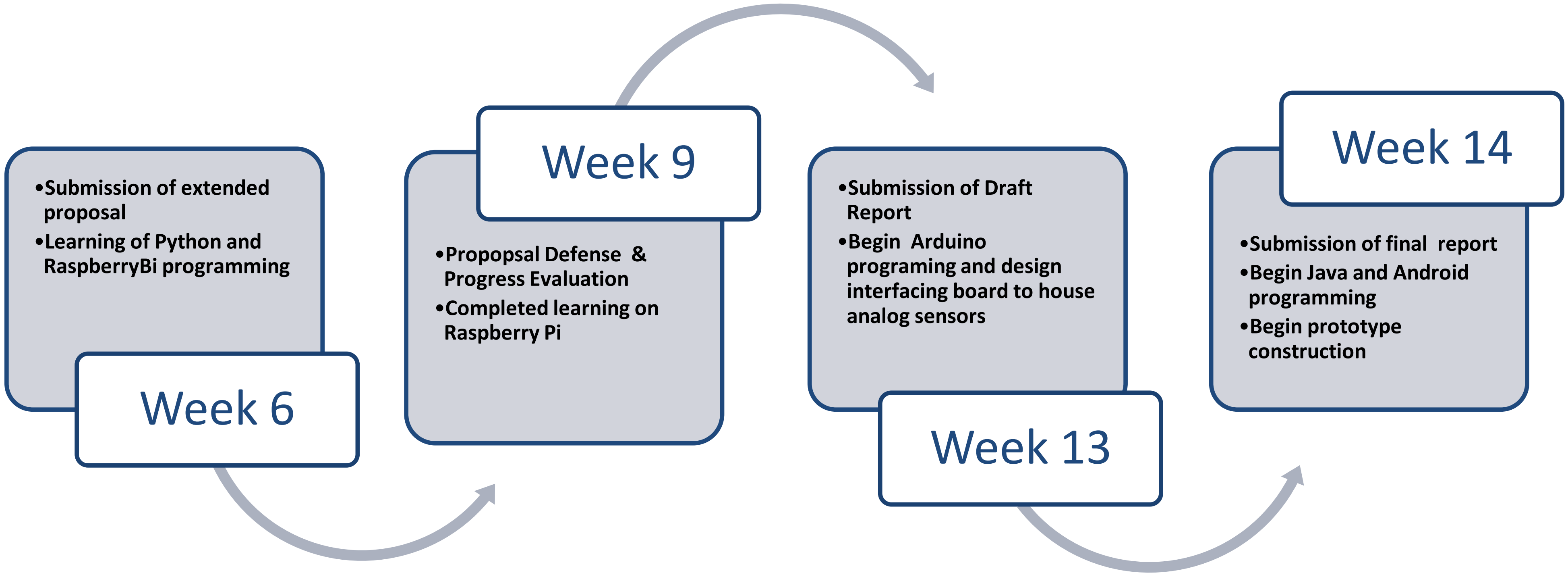
3.8 Gantt Chart (FYP I)

WEEK / ACTIVITY	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Literature Review														
Programming MySQL database														
Learning programming using Python														
Researching & Testing Raspberry Pi														
Learning on Java Programming														
Learn Android Programming Language														
Research the programming of Arduino														
Research the functionality of sensors and accelerometer														

3.9 Gantt Chart (FYP II)

WEEK / ACTIVITY	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Designing PCB														
Solder the individual components and test with Arduino														
Build the PV tracking system base														
Program and connect Raspberry pi to internet														
Develop the MySQL database and send data for storage														
Program the android application interface														
Carry out field testing and optimization														

3.10 Key Milestones



CHAPTER 4

RESULTS & DISCUSSION

The results section consists of three major subsections that are addressed here. These subsections are described by the figure below;

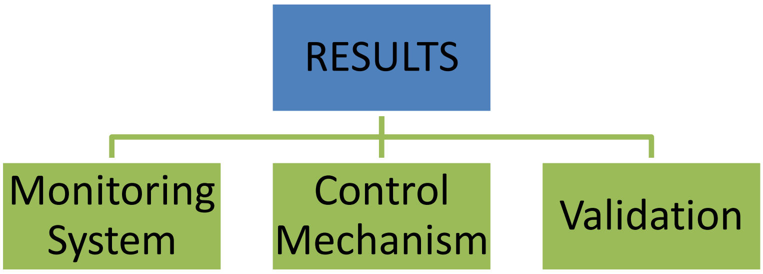


Figure 16: Major subsections

4.1 Cost-effective pyranometer

The initial portion of the project was to develop a cost effective pyranometer which can provide reading of solar radiation at a given period of time. The method utilized is by using a simple low rated solar panel and comparing the output voltage at a given time of day with an actual pyranometer and developing the equation to assign irradiation values to the output voltage. The solar panel was first tested under a Sun simulator in Building 19 of Universiti Teknologi PETRONAS (UTP). This method however had proved inaccurate as the intensity of the light given out by the simulator cannot be adjusted thus returning only one value for the given solar radiation. It was important that this step be done to ensure that alternative methods are also considered in setting up a PV based pyranometer that is reliable.

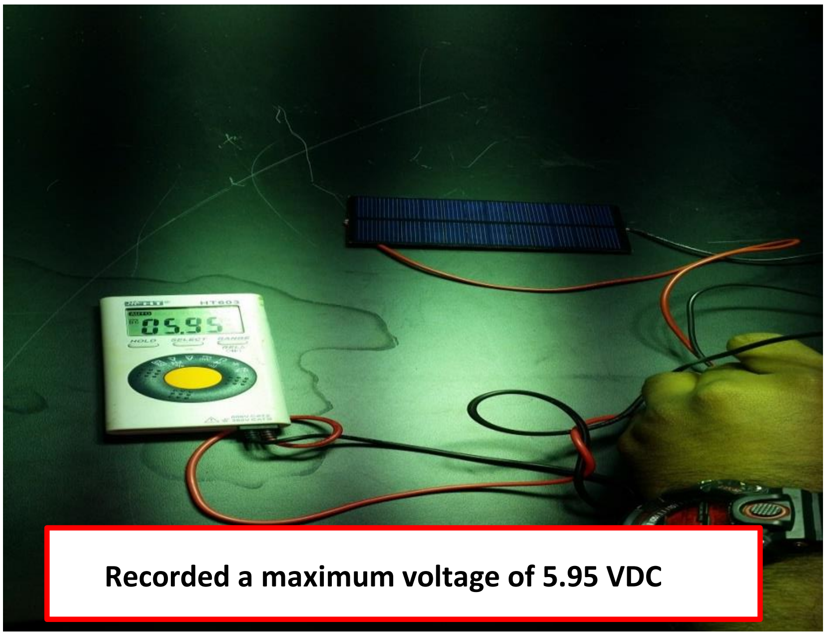


Figure 17: Output voltage of 6 VDC panel under simulator

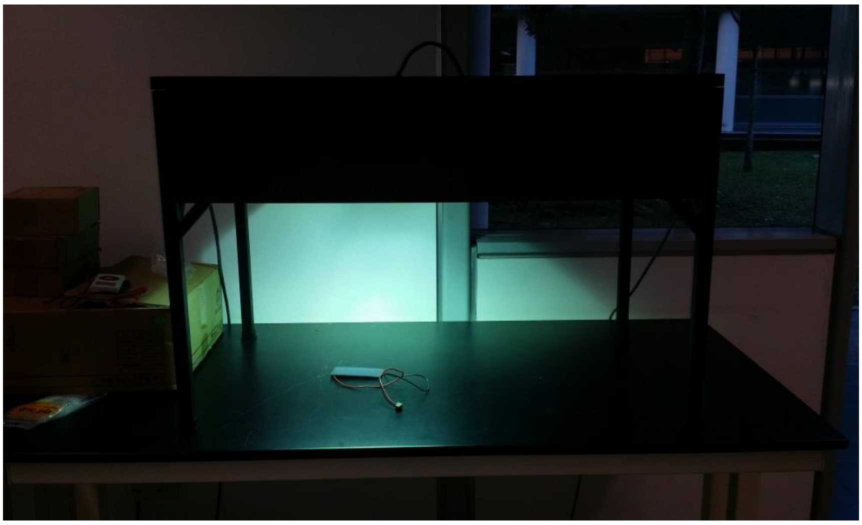


Figure 18: Experimental setup to measure maximum voltage output

To enable a distributed curve to obtain the panel had to be tested under daily sun conditions which would return more values enabling a curve to be plotted and compared. The experimental setup consisted of an actual pyranameter, the solar panel and a DT80 data logger. The logger will return values of both the pyranameter and the solar panel which was then compared to establish a factor equation. On the 12th of February 2015, an experiment was conducted to obtain a collection of values of the solar radiation (W/m2) and PV output voltage (VDC). The following graphs explain the values of the panel and pyranometer.

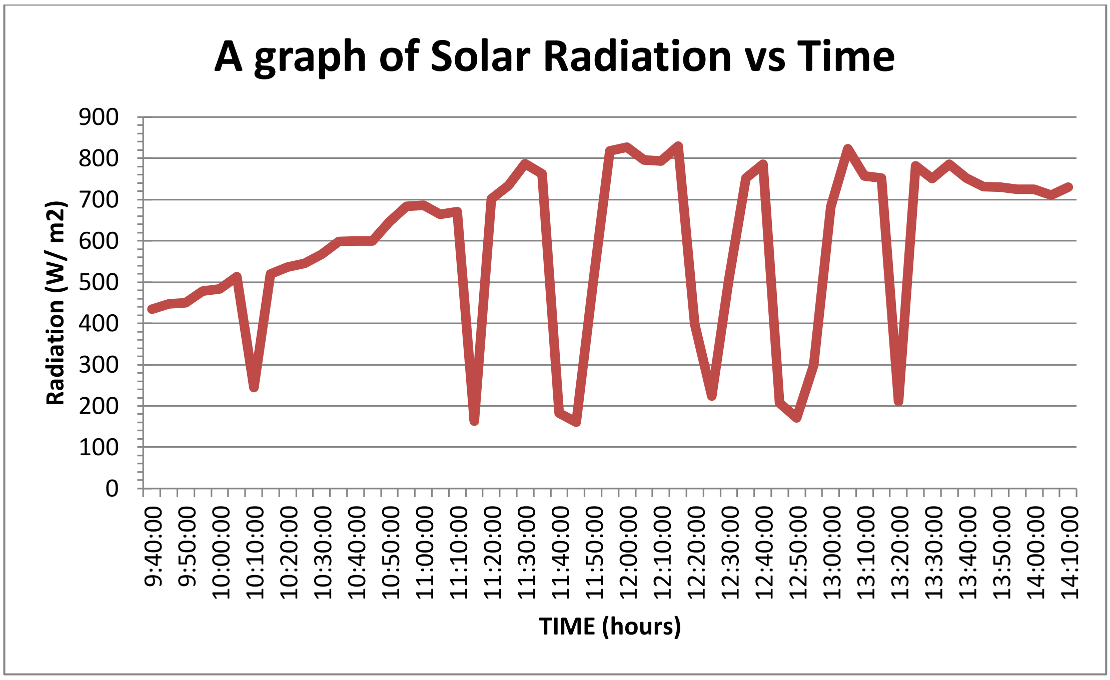


Figure 19: A graph of solar radiation vs time

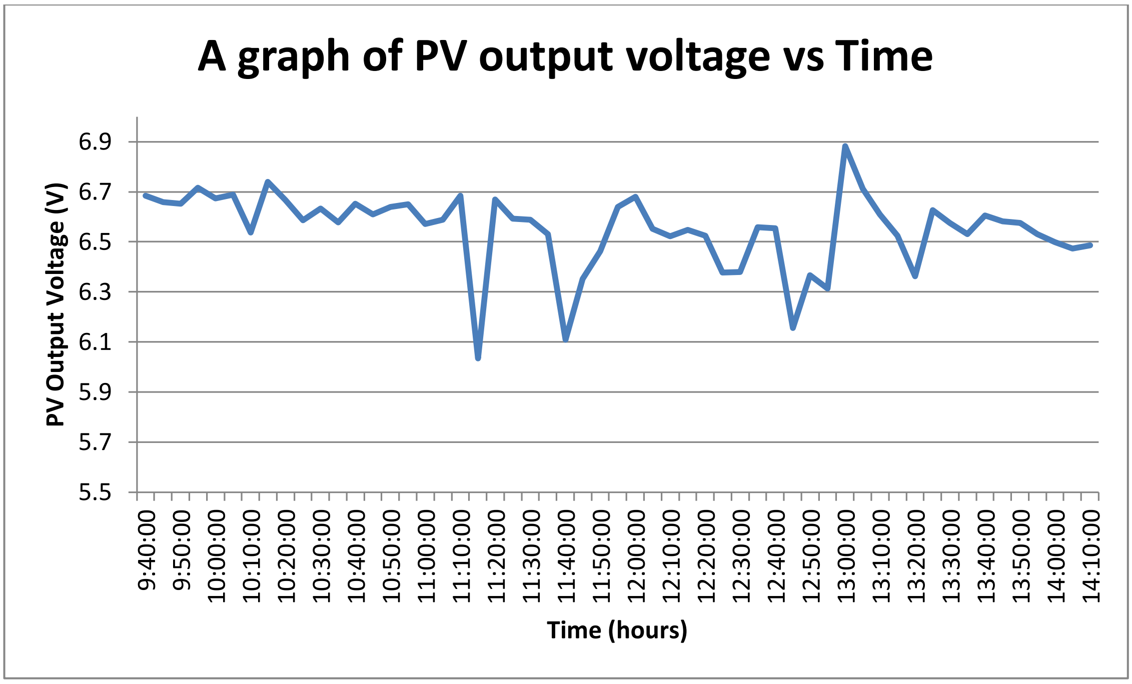


Figure 20: A graph of PV output voltage vs time

From the graph it is evident that the trend is not identical as the pyranometer is more sensitive in comparison to the low rated PV. The following graph gives the accumulation of values obtained by dividing the solar radiation values with the output voltage of the PV. It is important to note, the key element that is sought after through this method is not accuracy, rather a reference value to which the diagnostic database can be compared to.

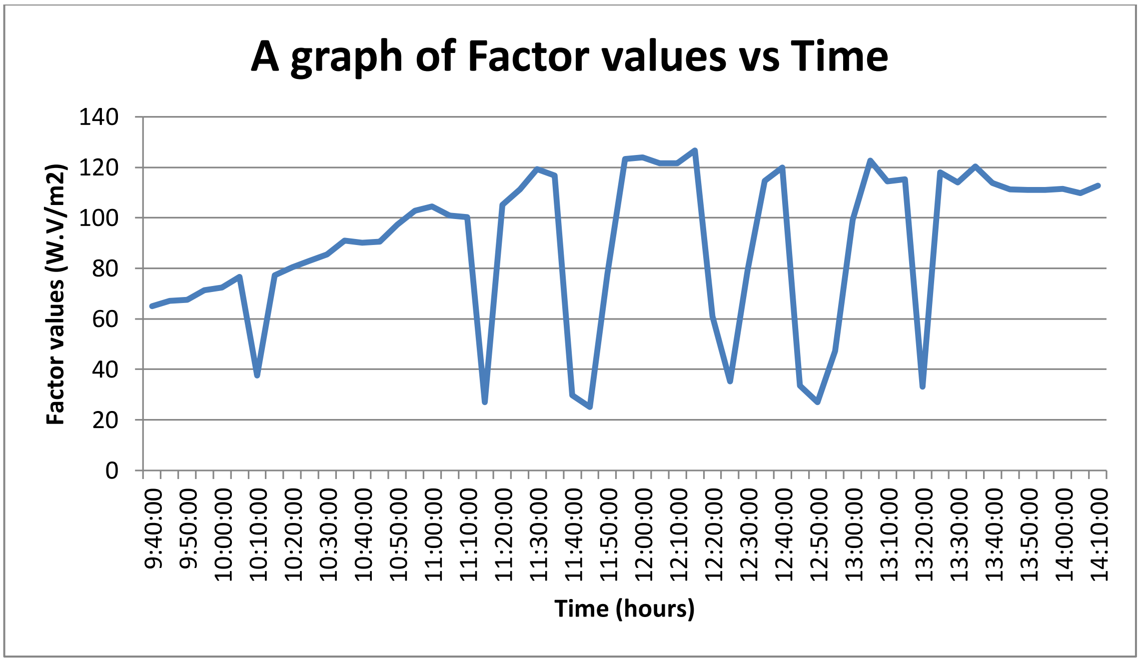


Figure 21: A graph of factor values vs time

From the above graph is can be retrieved that the trend is similar to that of the solar radiation for the obvious reason that it is the factors that converts the PV output voltage to solar radiation. Taking the average value of the accumulation of values that make up the graph above, the value obtained was $89.5793\frac{W}{m^2.V}$. Though this method of determining the precise multiplication factor has been condemned to return inaccurate values of solar radiation, the area of interest of this research is not to create a mechanism that can accurately return values of solar radiation rather give a reference value at which the diagnostic database can function. Therefore the accuracy of solar radiation value is not of high importance, rather a value that can give significance to the amount of power generated by individual solar PV is sought out for in this research. The equation generated for the controller to obtain reference values is as follows;

$$Solar\ Radiation\ (reference)\frac{W}{m^2} = \ PV\ output\ voltage\ (V) \times\ 89.5793(\frac{W}{V.m^2}) \qquad (2)$$

Since the recorded output voltage of the panel is beyond levels that can be safety translated by the Arduino, the panel's output voltage had to be fed into the potentiometer voltage divider chip. The voltage divider, as its name suggest will divide the output voltage in accordance to resistance values. In this data logger setup the solar radiation values were divided by half (i.e. 6V = 3V, 4V = 2V, etc.).

Therefore another equation has to be manifested that can be understood by the Arduino microcontroller. The Arduino has an analog-to-digital converter (ADC) that is capable of reading analog values from 0 to 2^{10} (ie. $0,2^1, 2^2, \ldots, 2^{10}$). Therefore the equation has to be adjusted such that is can be programmed and understood by the controller;

$$Solar\ Radiation\ (analog) = Analog\ value\ \times \frac{Solar\ Radiation\ (reference) \div 2}{1023} \qquad (3)$$

4.2 Data logging circuit

As mentioned before, the proposed system is a combination of multiple individual elements of different functions that is assimilated to enable a smooth and comprehensive data-logging process. The major part of the system is the analog sensor module which houses the sensors and voltage dividers that can process the raw analog data and convert it into a recognizable signal for the Arduino microcontroller. The first procedure included testing the individual components on the analog sensor module through the use of a breadboard.

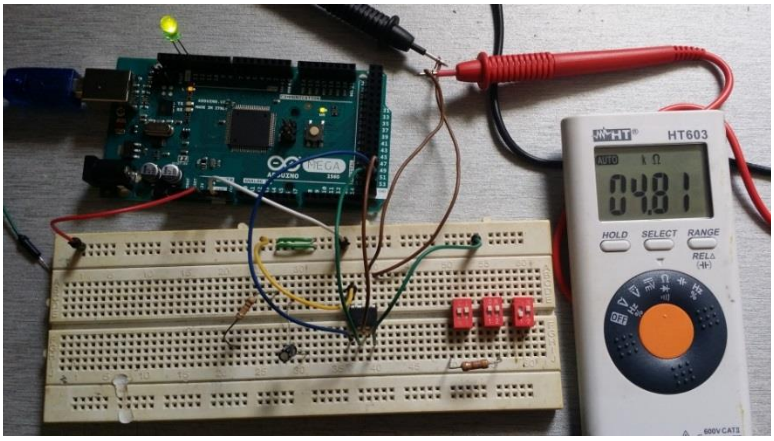


Figure 22: Testing digital potentiometer MCP4161

The component that was tested was the digital potentiometer from Microchip which is the MCP 4161. With 257 trimmer positions, this potentiometer is capable of adopting flexible values. In addition to that, a potentiometer on its own behaves as a voltage divider circuit that is capable of reducing the panel voltage to safe and readable levels. A point worth noting is that the Arduino Mega chip is incapable of translating voltages above the magnitude of 5 VDC; therefore it is vital that the voltage be reduced to levels that can be safely translated. The following Figure 15 will explain the function of the potentiometer as a voltage divider. The potentiometer has 3 pins whereby, pins 1 and 3 are positive voltage and ground connections respectively. Pin 2 known as the trimmer will output a voltage that has been divided by the potentiometer and can be connected to an analog pin on the microcontroller.

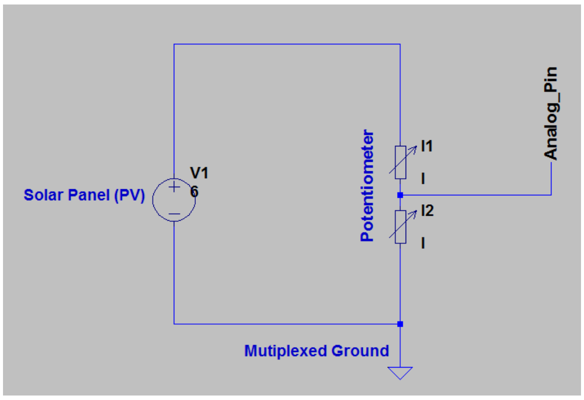


Figure 23: LTSpice drawing of potentiometer voltage divider

Though the proposed design stores the data collected onto an online database of MySQL, it is widely accepted that wireless transmission is subject to various interferences and in severe cases the interferences can lead to loss in internet connection resulting in loss of data. Therefore is it vital that an onboard storage capacity is taken into consideration to back up the data collected such that the system will be more robust and holistic.

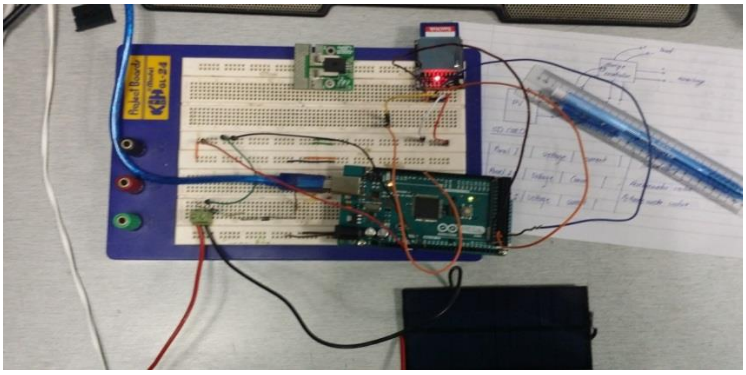


Figure 24: Breadboard setup of temporary solar panel logger

From the above setup, it can be observed that the panel is connected to SD card module. The SD card operates on the basis of Serial Peripheral Interface (SPI) which when the active low chip select pin is pulled low, will activate the communication. A 4GB SD card is used in this system but can be easily replaced with a card of a higher capacity.

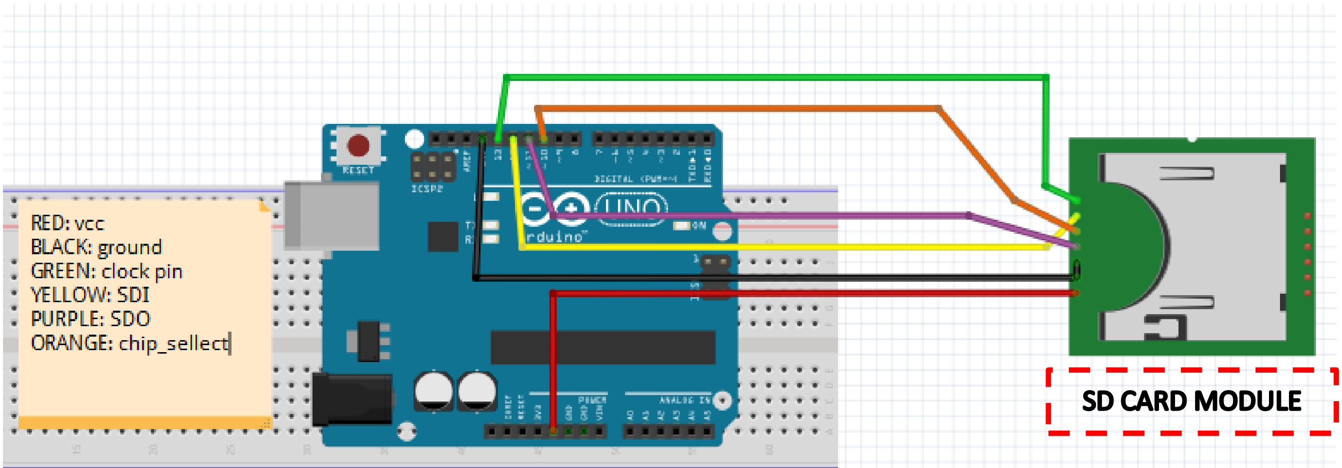


Figure 25: SD card connection to Arduino microcontroller

The fully interfaced breadboard circuit is shown in Figure 26. This circuit has multiple different components multiplexed together to enable individual operations of the data logger. Table 4 provides a detailed explanation of each component used in the analog data logger circuit.

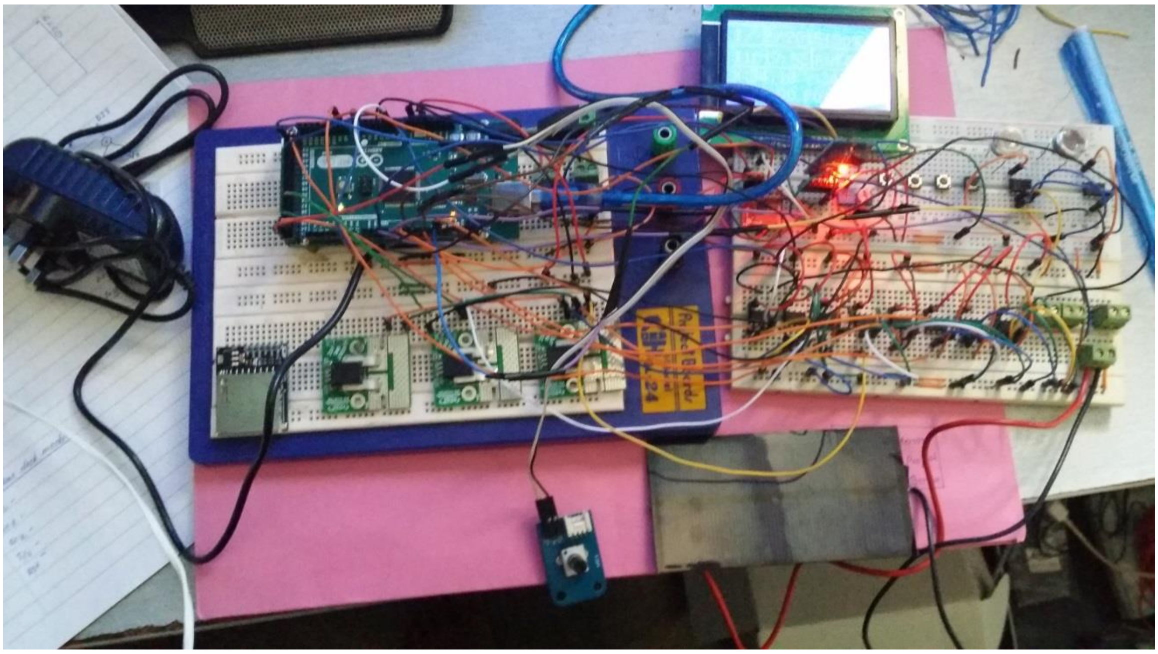


Figure 26: First breadboard setup of the completed data logger

Table 4: Description of components utilized in data logging circuit

Component	Description/Function
SD Card Module	Backup data storage alternative
Analog Potentiometer	To send feedback with regard to the position of the panel on the tracking system
Light Dependent Resistor	To track the region of maximum light exposure to reposition the panels on the tracking system
Real Time Clock Module	To provide systematic data with regard to the time of day
MCP 4161	A digital potentiometer chip which enables the auto-calibrating function and also
6 VDC Solar Panel	A replacement for the pyranometer that provides solar irradiation value
Graphic Liquid Crystal Display (GLCD)	On site display

Upon rectifying the function of the circuit on a breadboard, the components were soldered onto a Vera board and Figure 27 shows the product.

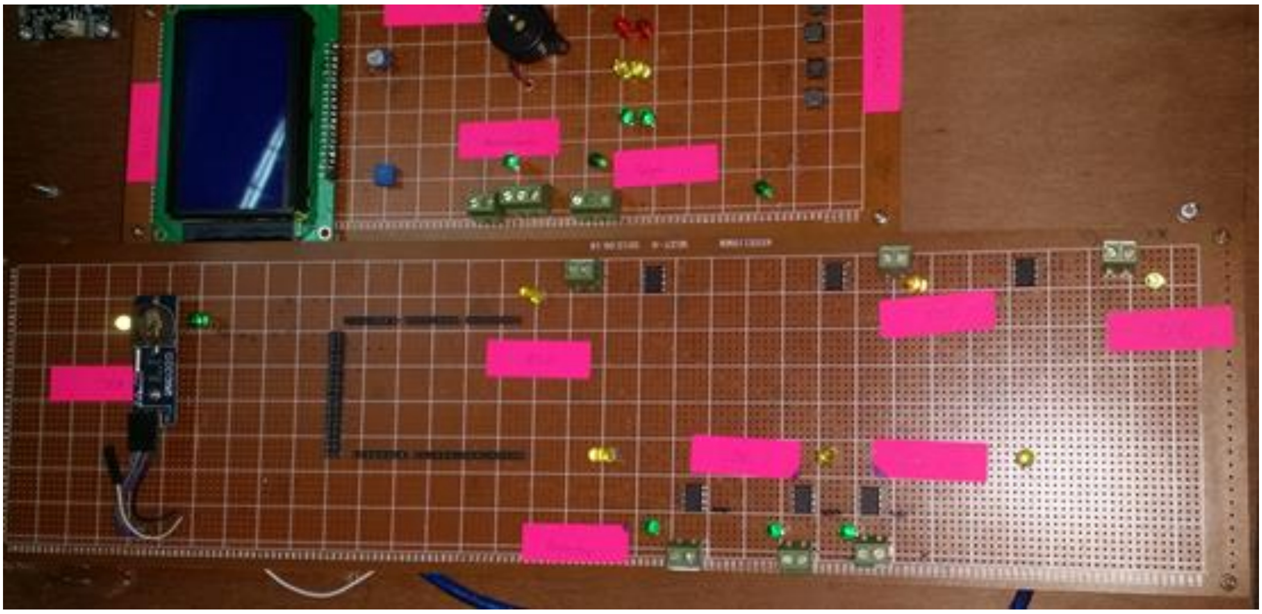


Figure 27: Improved Vera board assembly of the circuit

Figure 28: Graphic LCD output

Though soldering the components onto a Vera board proved to be crucial in fixing the wiring and components in a permanent manner such that when transporting the equipment the connection is not interfered with, the circuit was too bulky which added to the strain in making it portable. The difficulty in shrinking the size of the circuit on a Vera board came upon because the wires had to be pulled from one end to another and vertical soldering will impede the view of all the components used in constructing the circuit. In addition to that, though the ultimate idea is to produce a product that is marketable, the experimental stages compelled that all components used had to be localized onto one single board to allow easy viewing.

To address this problem, a Printed Circuit Board (PCB) was designed using EagleCad 2011. Through the use of PCBs, the printed conductor lining can go as thin as 0.1 mm and the design proved worthy as the board was reduced to a size that is smaller than an A4 sized paper. The functionality of the board was not hindered with and the third revision provided an opportunity to that by using a single layer PCB the size can be reduced by many folds, therefore much more can be achieved through the use of multiple layered PCB. Similar to the Vera board design, every component including the Raspberry Pi and the motor driver had been localized onto a single platform. In addition to that, the screw terminals utilized in the Vera board design was removed and replaced with pin headers as a considerable amount of difficulty was faced to wire the system when demonstrating the prototype. A point to note is that the PCB had been designed to suit the fabrication process of UTP's PCB fabrication laboratory whereby a two layered design was modified to be made as a single layered PCB. This was done by simply placing resistors at places where the linings were over lapping and then shorted over with a copper wire. Though this procedure would not pass off in the industry, for this level of research this design more than compensated for.

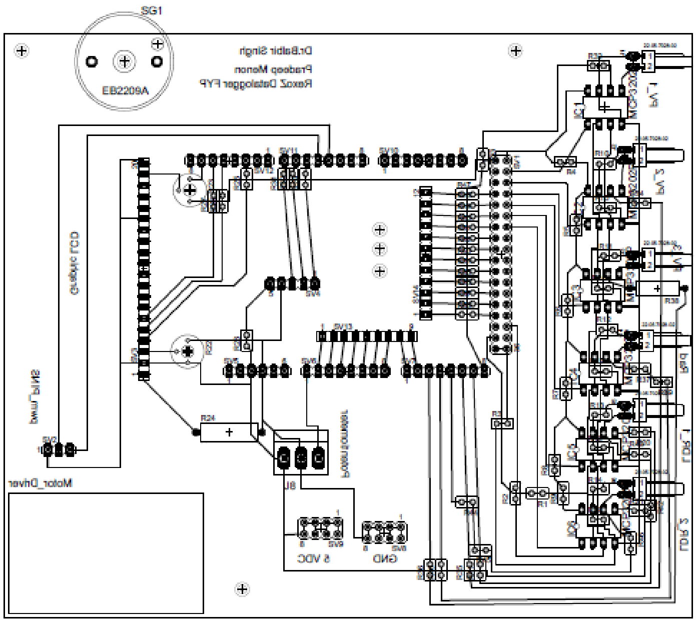


Figure 29: PCB design for data logging circuit

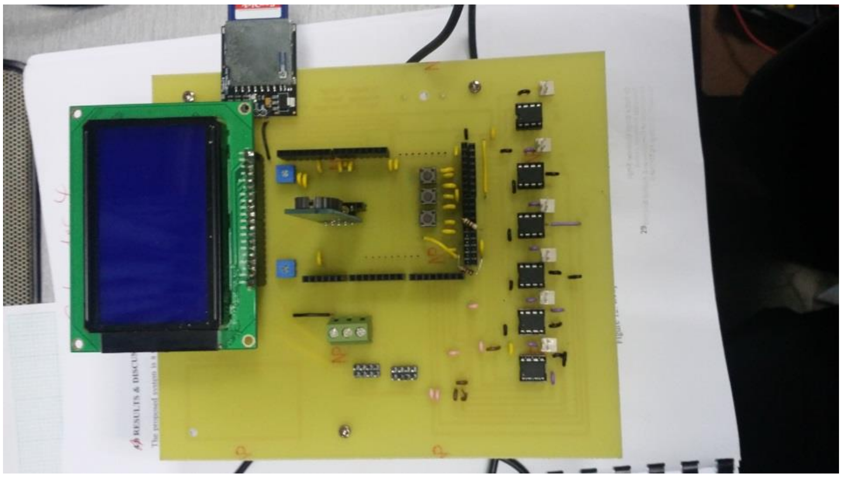


Figure 30: Assembled PCB of data logging system

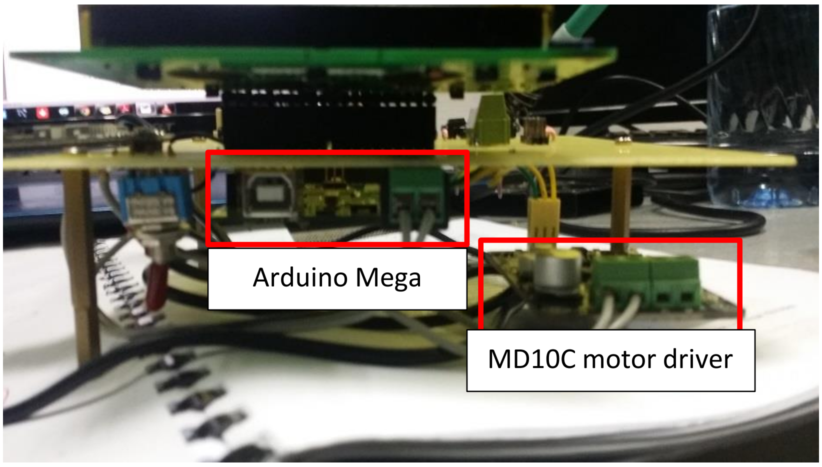


Figure 31: Arduino shield design adapted by the PCB

4.3 Single axis sun tracking system

In parallel with the construction of the data logger, progress was also made on the completion of the Single axis solar tracking system. The design is as shown in **Appendix I**. For the first part, the motor coupler was fabricated and attached to the high torque motor through the aluminium arm that will support the structure. Figure 32 will give a graphical representation.

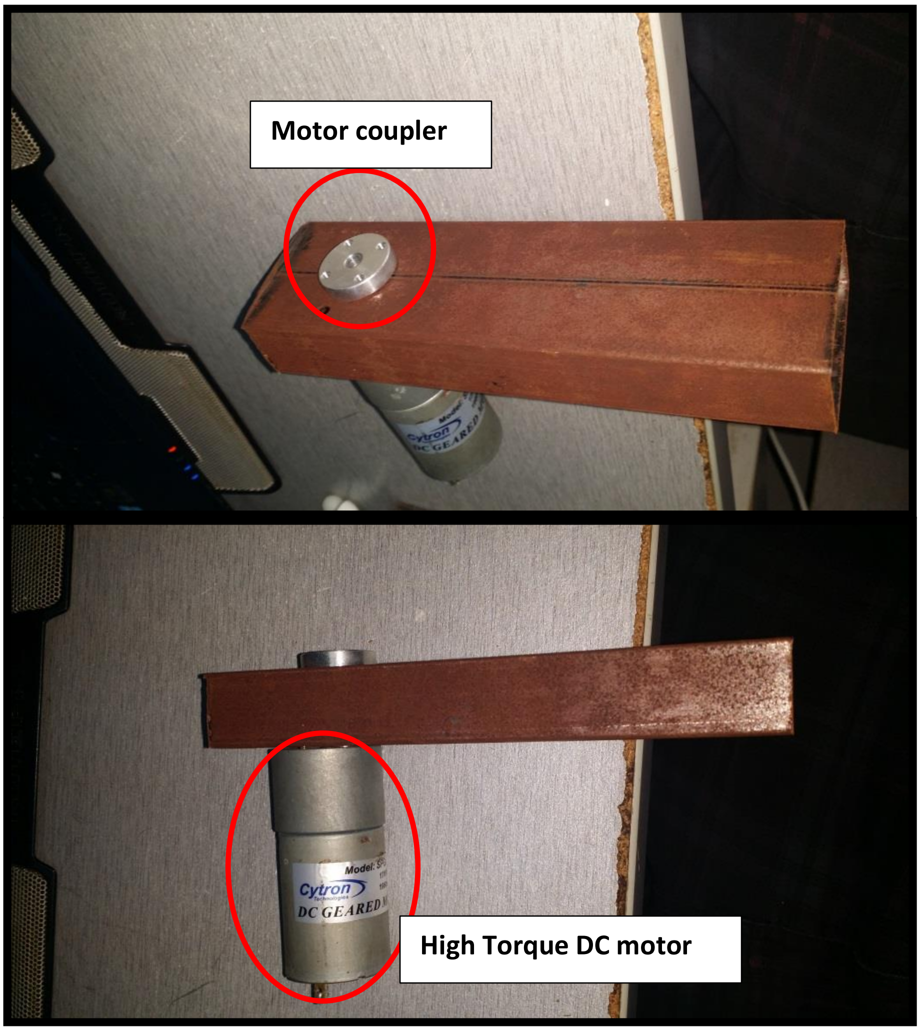


Figure 32: Motor attachment to arm

In addition to that, the casings that will house the three solar panels were also made using low tensile strength aluminium.

Figure 33: Aluminium housing for solar panels

These 3 individual sheets were combined to be made a single unit such that it can be attached to and be controlled by the motor of the tracking system. They were attached using the same material but with a length of 67 cm at each end.

Figure 34: Attaching the top support for the housing using rivets

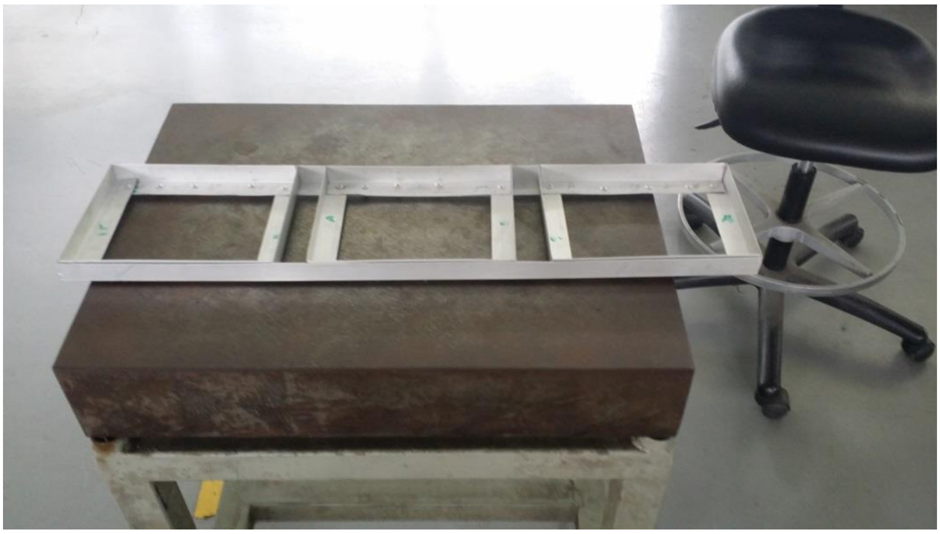


Figure 35: Completed structure of the joined casings

Upon joining the 3 pieces together, the entire unit has to been attached onto the motor coupler. This will allow the panels to be actuated to the required position with accordance to the signal sent out by the motor controller.

Figure 36: Motor coupler attachment onto the panel casing

Since one end was attached and driven by the DC motor, the other end requires a support mechanism and one that works best is through the use of a bearing that can accommodate for the turning motion of the motor. The metal arm had to be drilled through and the bearing had to be welded onto to the arm to ensure that it is permanently position at zero position. In addition, to not defect the casing an extra sheet of aluminium was attached to the casing unit. The entire frame was conjoined using a 10 mm screw with two lock nuts. Upon completing this, the structure resembled as such shown in Figure 37 and this is followed by the completed single axis tracking system.

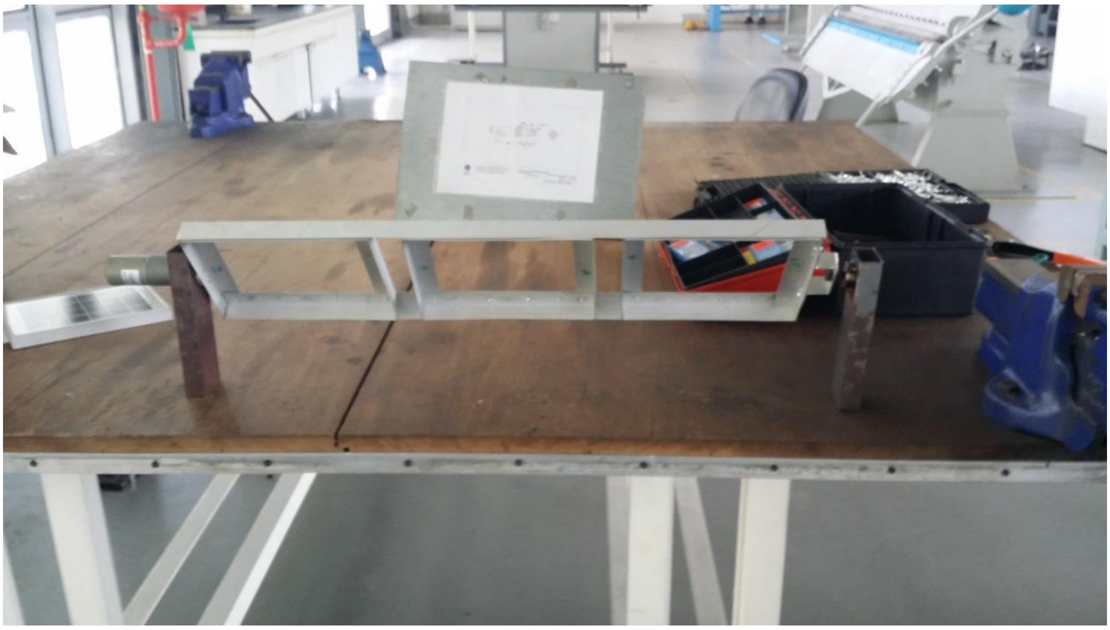


Figure 37: Completed structure in the absence of the base plate

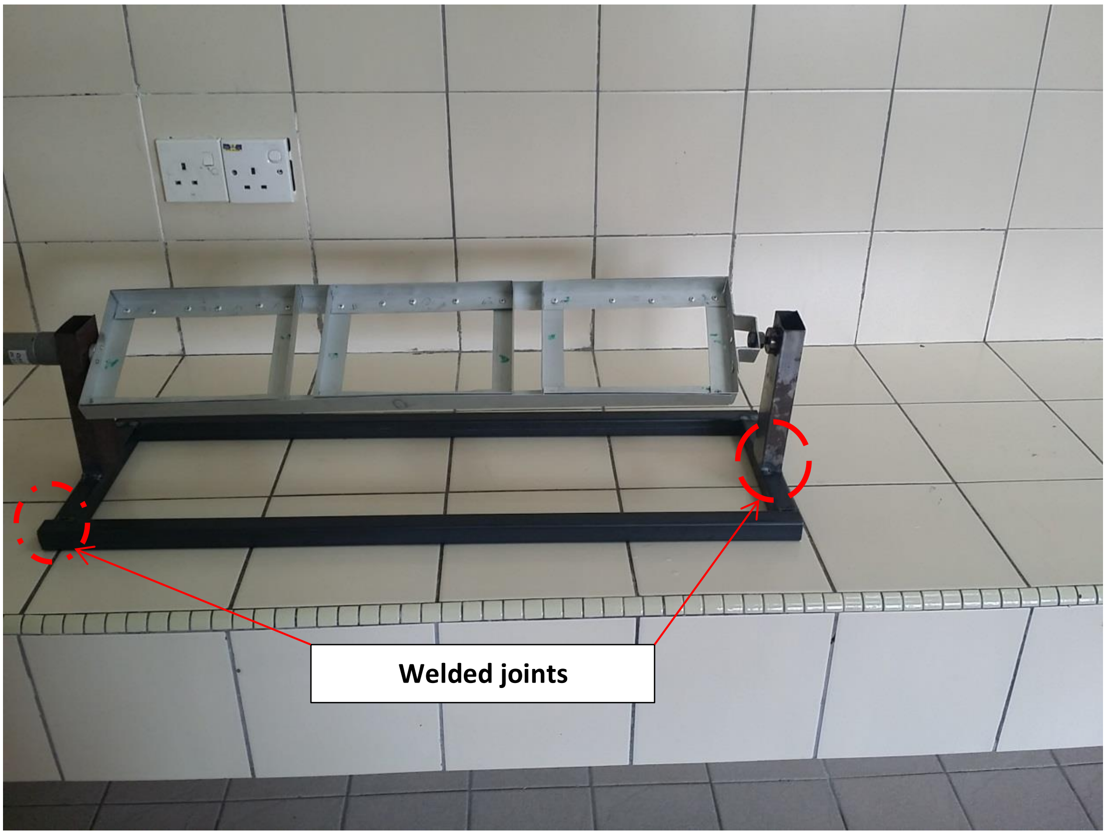


Figure 38: Completed single axis tracking system

Figure 39: Assembled tracking system

Unlike most sensor based tracking systems that utilize servo motors, the one designed in this project is maneuvered through the use of high torque DC motors. The reason behind the use of servo motors is that servo motors have built-in position control whereby the exact angle required for the panel to be position can be communicated to the servo.

DC motors function rather differently in the sense that the motor, when supplied with power, will run infinitely until the power source is disconnected. The DC motor's speed however can be controlled through the use of PULSE Width Modulation (PWM) whereby a pulse will modulate the amount of voltage entering the motor and this value will govern the speed of the motor. To enable position control of a DC motor, a potentiometer is used in this design. The potentiometer will return feedback on the position in the form of varying resistance.

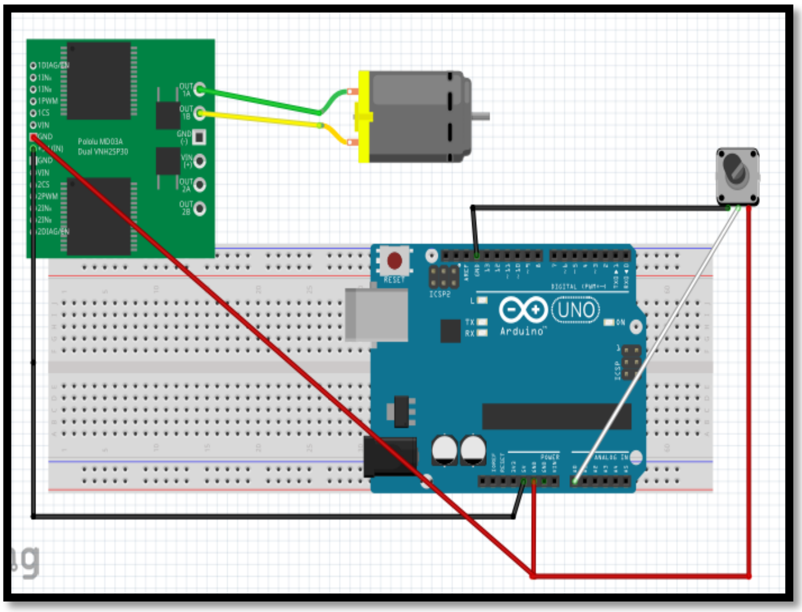


Figure 40: The circuitry setup of motor control

The potentiometer can only provide feedback on the position which is capable of ensuring that the panel is in a given position. To provide signals that can initiate the motor actuation, the sensors will obtain readings on the region of maximum light exposure and using the Map() function on the Arduino microcontroller will actuate the motors until it reaches the appropriate value of resistance.

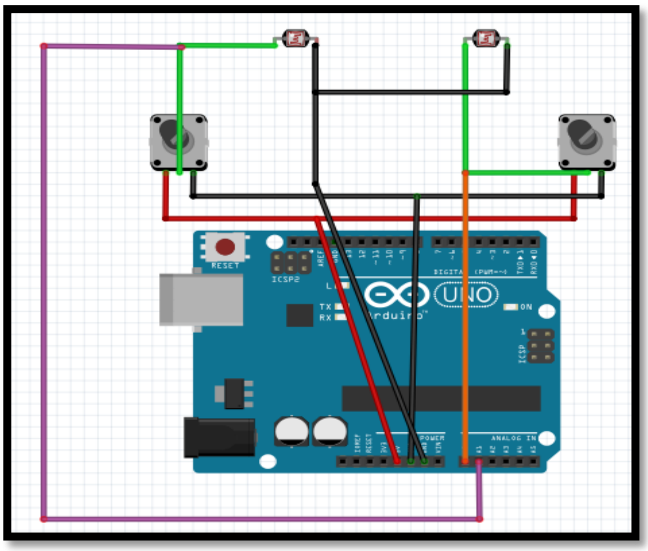


Figure 41: Tracking system sensors setup

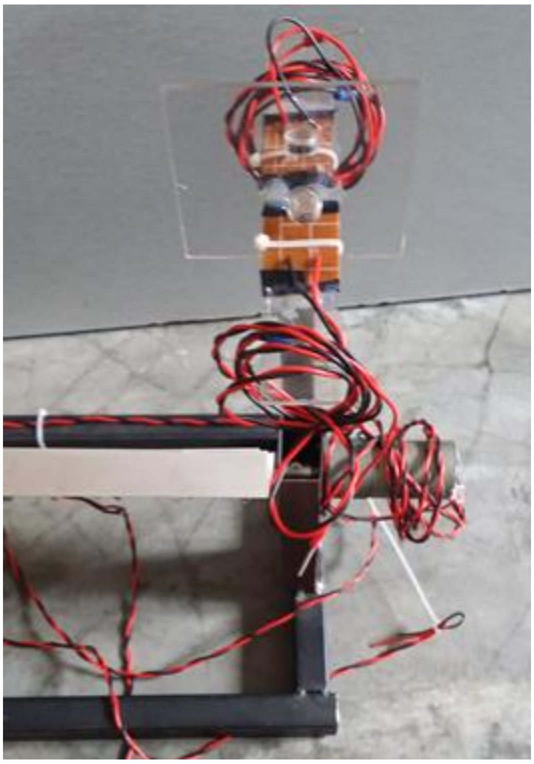


Figure 42: Sensor assembly on tracking system

4.4 Diagnostic system

A vibrant feature of this project is that a diagnostic system was programmed into it. The working principle of this system was explained earlier in the Methodology section whereby the Arduino microcontroller compares newly logged values at a given solar radiation value, with a pre-saved database of values.

The database was engraved into the Arduino code whereby every new value was referenced with the radiation value and the voltage associated with that radiation value is compared with that of the database. The database was developed by carrying out field test using the single axis tracking system and the PV based pyranometer. The results obtained from the testing are depicted in the graph below;

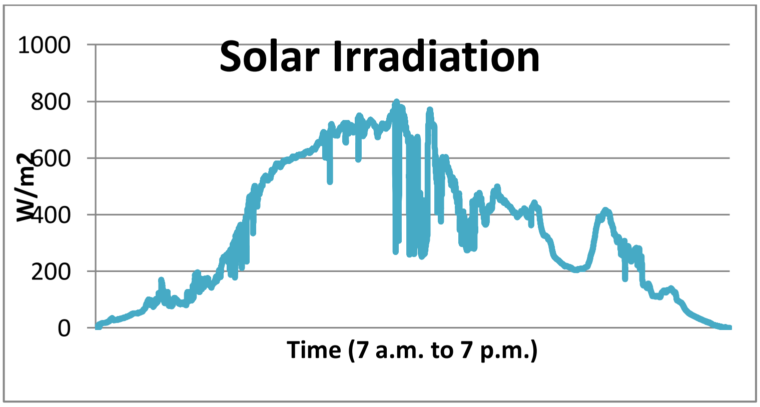


Figure 43: Solar irradiation data from PV based pyranometer

Since the proposed system will measure and compute the values of the panels individually, only the output voltage of a single panel from the single axis tracker was recorded. Figure 44 shows the graph of values;

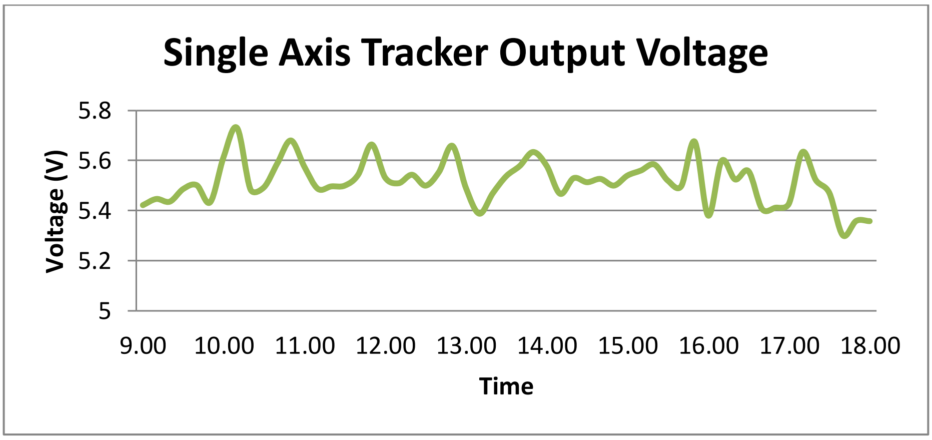


Figure 44: Output from one PV on single axis tracking system

The values were obtained in the form of an excel sheet. In the coding, the PV output voltage was stored in a single array whereas the solar irradiation values from the PV based pyranometer were stored in another array. The loop will then call the solar irradiation array when a new value is recorded and subsequently the solar irradiation array. The array is ordered in terms of ascending numerical weightage for both the solar irradiation and output voltage.

4.5 Raspberry Pi based online storage

The Raspberry Pi microcomputer behaves similar to that of a normal computer expect that it is incapable of supporting applications and tasks that take up high amounts of Random Access Memory (RAM). Since the Raspberry Pi has its own Debian based cloud storage in the form of LAMP, the data collected by the Arduino microcontroller can be serially communicated to the Raspberry Pi (Pi) and stored in its database. To gain access to this particular LAMP database, the Pi must first gain access to a network connection. This was done by using a simple “WiPi” wireless internet adapter which is shown in figure 43.

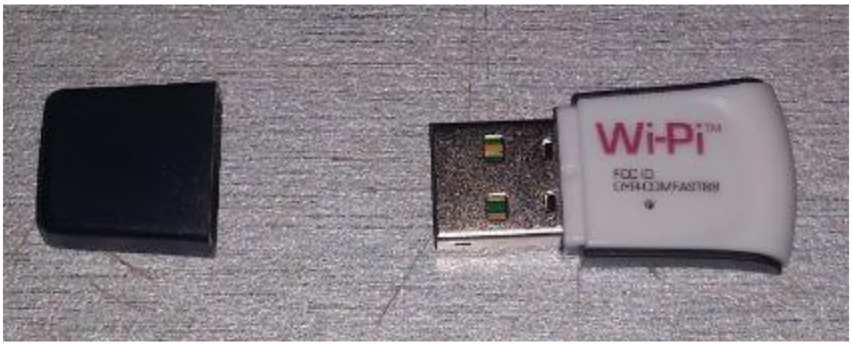


Figure 45: WiPi wireless internet adapter

The WiPi was simply plugged into one of the four USB ports found on the Pi and connected to a wireless network (WiFi). Upon gaining access to the network, the Pi's drivers were first updated to support the process that it will be running.

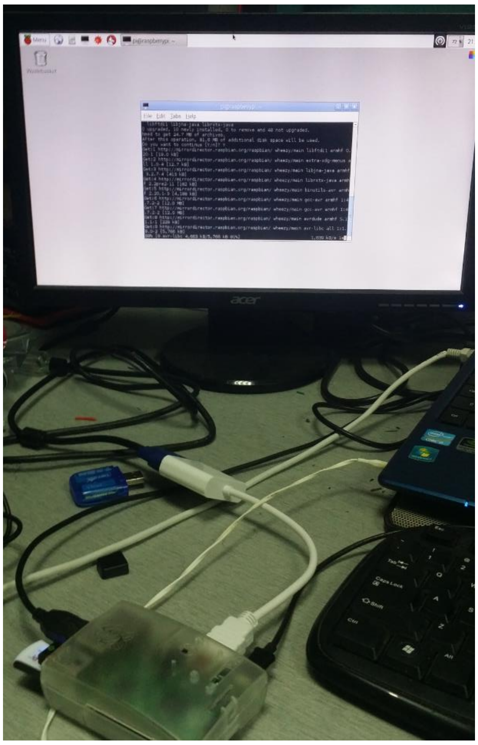


Figure 46: Raspberry Pi driver update for LAMP support

Upon the driver update, the first thing that was done was the installation of the Arduino IDE environment into the Pi's drive. This would allow the Pi to read the data from the Arduino such that the collected data can be uploaded into the LAMP could database.

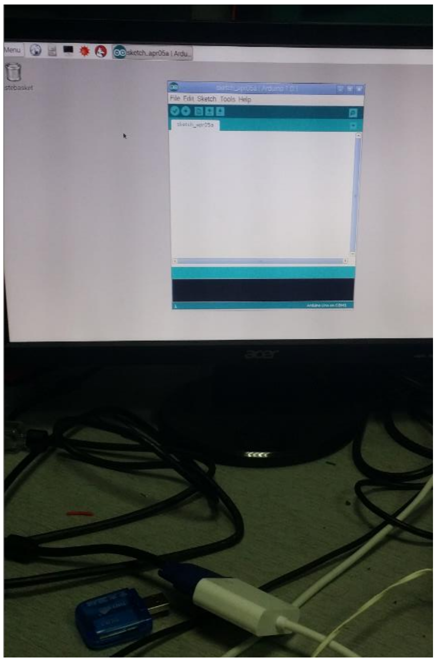


Figure 47: Arduino environment in Raspberry Pi

4.6 Android programming environment

The proposition of remote monitoring was done via the development of a simple preliminary android application that is capable of demonstrating the connection between the Pi's LAMP database and the application. Though the application is still at its infancy and can only be viewed via the Eclipse Android Emulator on a computer, the main aim is to again define the boundaries to which this project is capable of exploring. Figure 46 shows the emulator setup and programming environment.

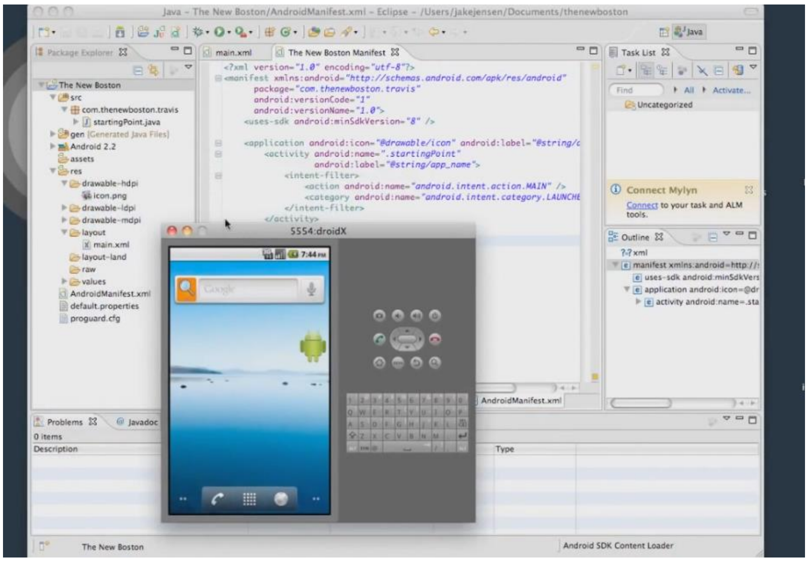


Figure 48: Snapshot of Eclipse Android emulator

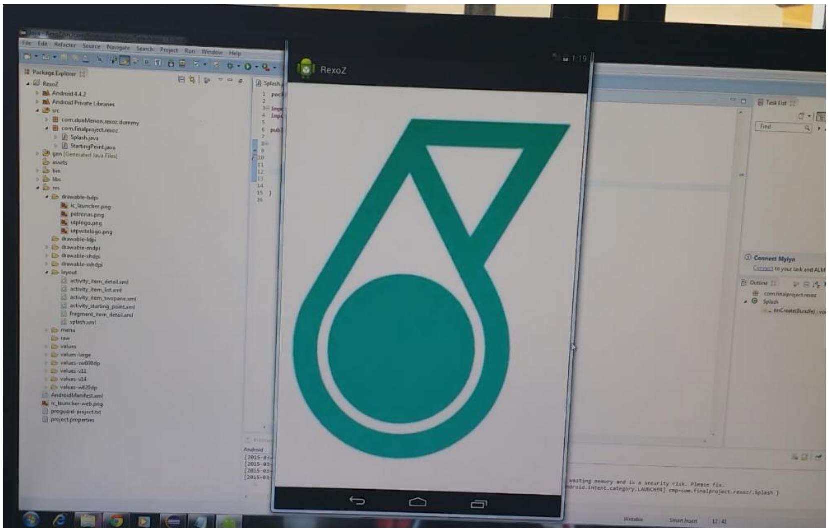


Figure 49: Displaying PETRONAS logo on emulator

No prominent results were obtained for this section as it is not the main objective of the project to develop the android application rather as an extra that will place the value of this study at a higher level.

4.7 Large scale single axis tracking system

The work done on the miniature single axis tracking system is heavily based on the real scale model found in the Solar Research Facility in Universiti Teknologi PETRONAS. The sensor based tracking system had a number of flaws which interfered with the smooth data logging process. The first problem diagnosed was the motor controller attached by the contractor which was soldered incorrectly. This problem was first attended to.

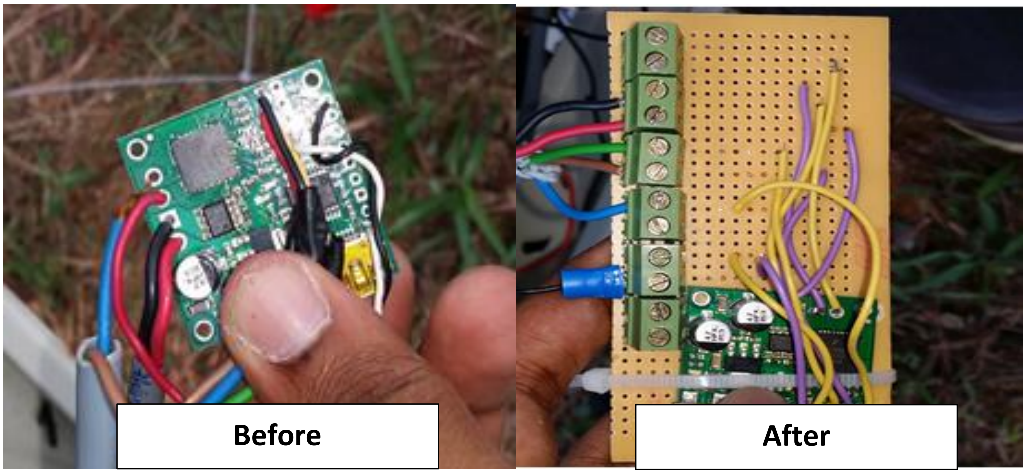


Figure 50: Rectification of motor controller

Upon completing the motor controller, the sensor had to be rectified. The sensors from previous testing were facing a problem due to shading of the panel causing the pendulum motion of the panel. The sensors had to be elevated and isolated as shown in figure 51 (a).

Figure 51: a) New sensor design and placement b) Older design of sensor placement

The need for this elevation is because the large size of the panel was causing a significant shade onto the sensor network of the tracking system. This made the system heavily vulnerable to numerous problems such as motor over current and also due to high load onto the comparator circuit, the curcuit could have been damanged.

After seeing all the problems through, data was logged to compare the output voltage from both the sensor based tracking system and time based tracking system. The figure below represents the experimental setup;

Figure 52: Experimental setup of data logging session

The panels rated voltage is that of 37.1 V which exceeds the level that the DT80 datalogger can safely measure. Therefore a voltage divider circuit was made which divided the voltage and brougth the maximum output of the panel to 6.3 VDC. Having done that, the output of the voltage divider circuit was directly connected to the DT80 logger.

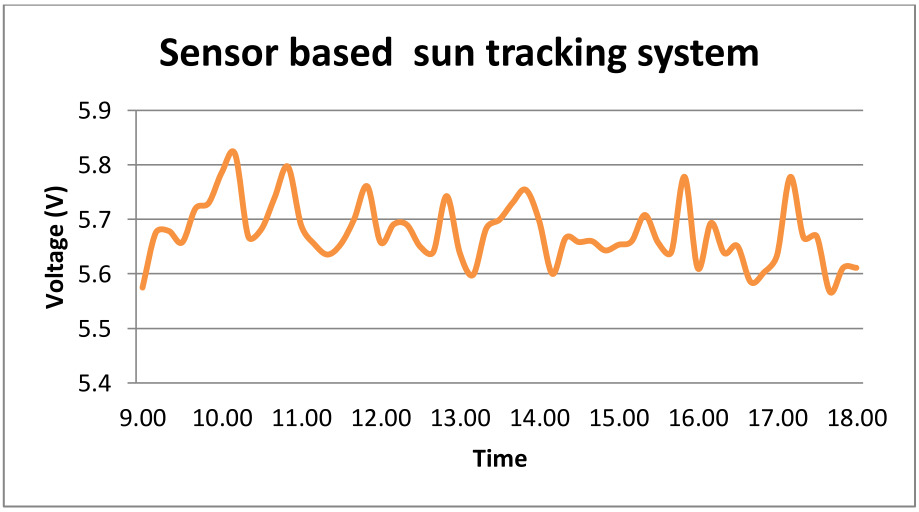


Figure 53: Output voltage of sensor based sun tracking system

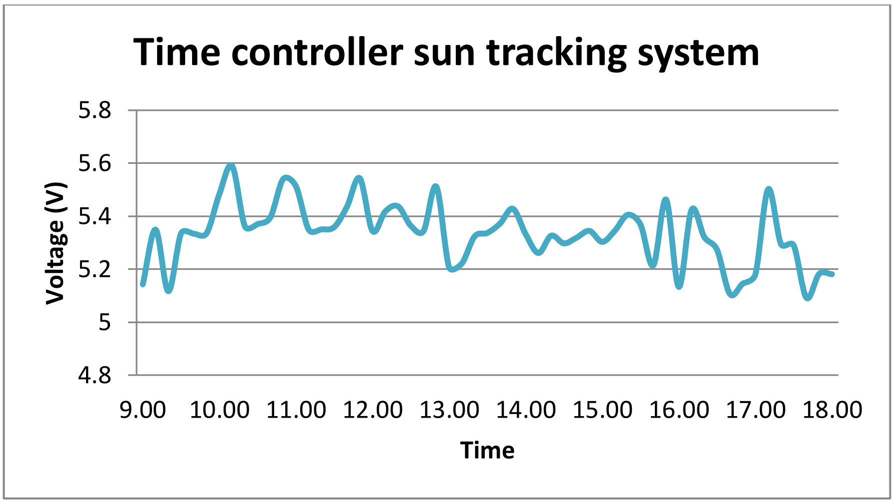


Figure 54: Output voltage of time controller sun tracking system

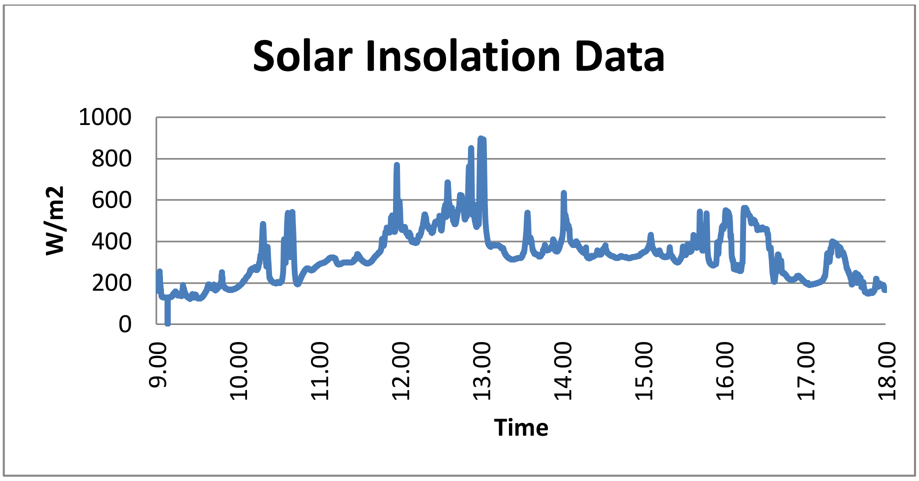


Figure 55: Solar irradition for the given day of experiment

From the graphs above, it can be said that the sensor based sun tracking system is more efficienct in comparison to the time controller tracking system that is widely utilized by the indutry today. However, the data shown above is only for a single day and more elaborate testing is required to draw up a definite conclusion. The importance of this portion of the study is to ensure that the proposed system is enveloping among the best solutions that are available today and cultering them together to form a comprehensive system.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

The objectives of to design a portable data acquisition system to monitor and control PV power generation is of very high significance. This would allow the monitoring process to be holistic and assist in improving the efficiency of SEGS. Most farms utilize monitoring systems of the AC output power to the grid which would not be the most effective seeing that the fault tracing process, in case of a breakdown, would be tedious. By obtaining individual panel data, if five or six panel in a farm having around 4000 panels were to have problems, this system will enable the user to detect and rectify the particular problem.

The overall objective, though far sighted, is to integrate the monitoring device directly to the panel thus reducing the cost and making this system readily available for the consumer. This is among the best solutions for making the system more cost effective and enabling more people to invest and educate themselves about the many wonders of solar electricity generation system. In addition to that, the data obtained from the monitoring system can also be communicated to stakeholders and they can obtain information with regard to how the system is benefitting them. The combination of sustainable engineering solutions and stakeholder engagement and education holds the key to the nation's heightened commitment towards utilization of sustainable energy resources [7].

Recommendation for future work concerning the study would include the development of a optimized remote monitoring system via the use of Android API 11. This would allow for any mobile device supported by Android to access the application. In addition to that, the MySQL database would also need further refining whereby the tabular data that can be stored online such that the SD card module would serve its purpose as a backup data storage device.

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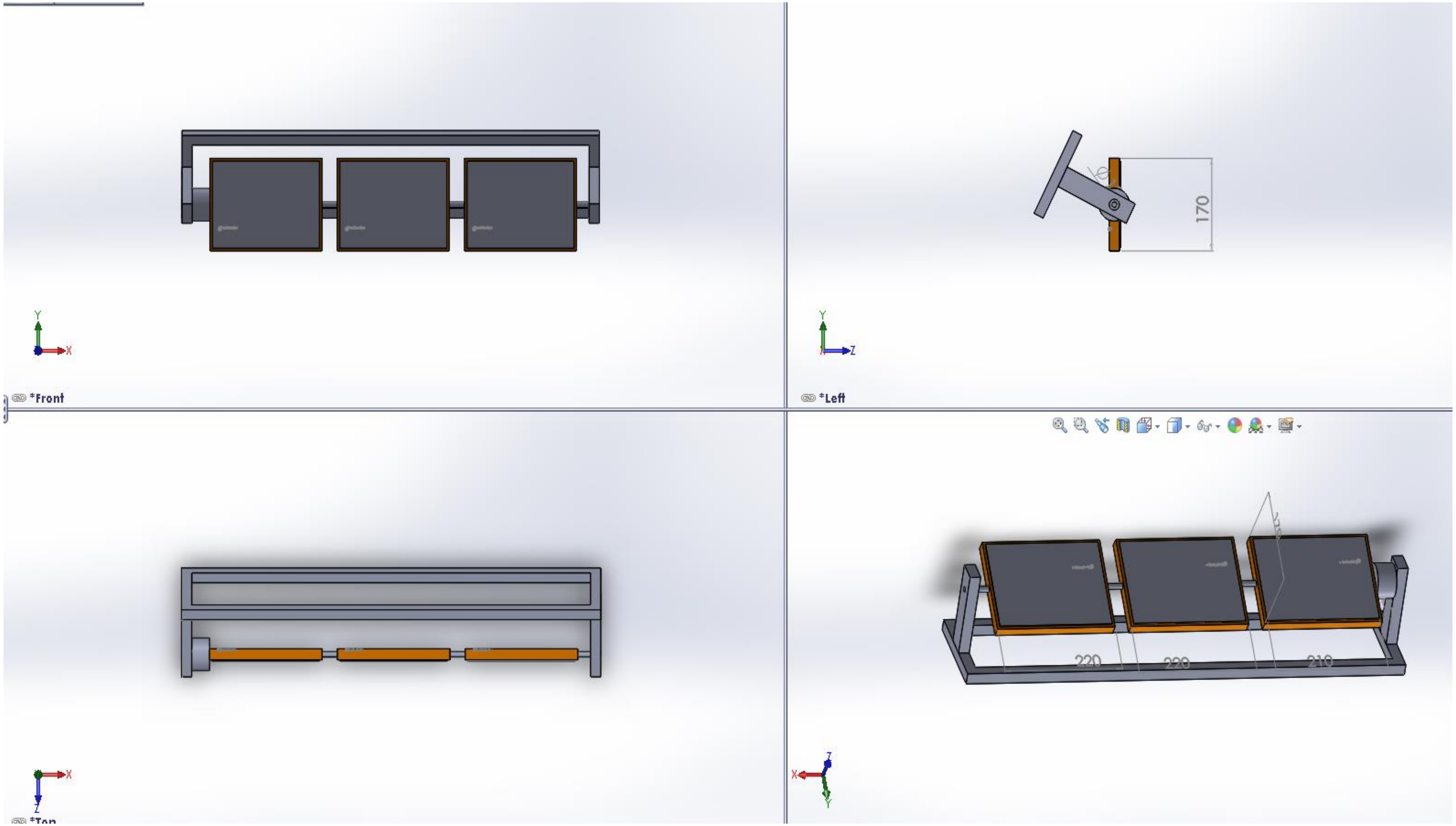
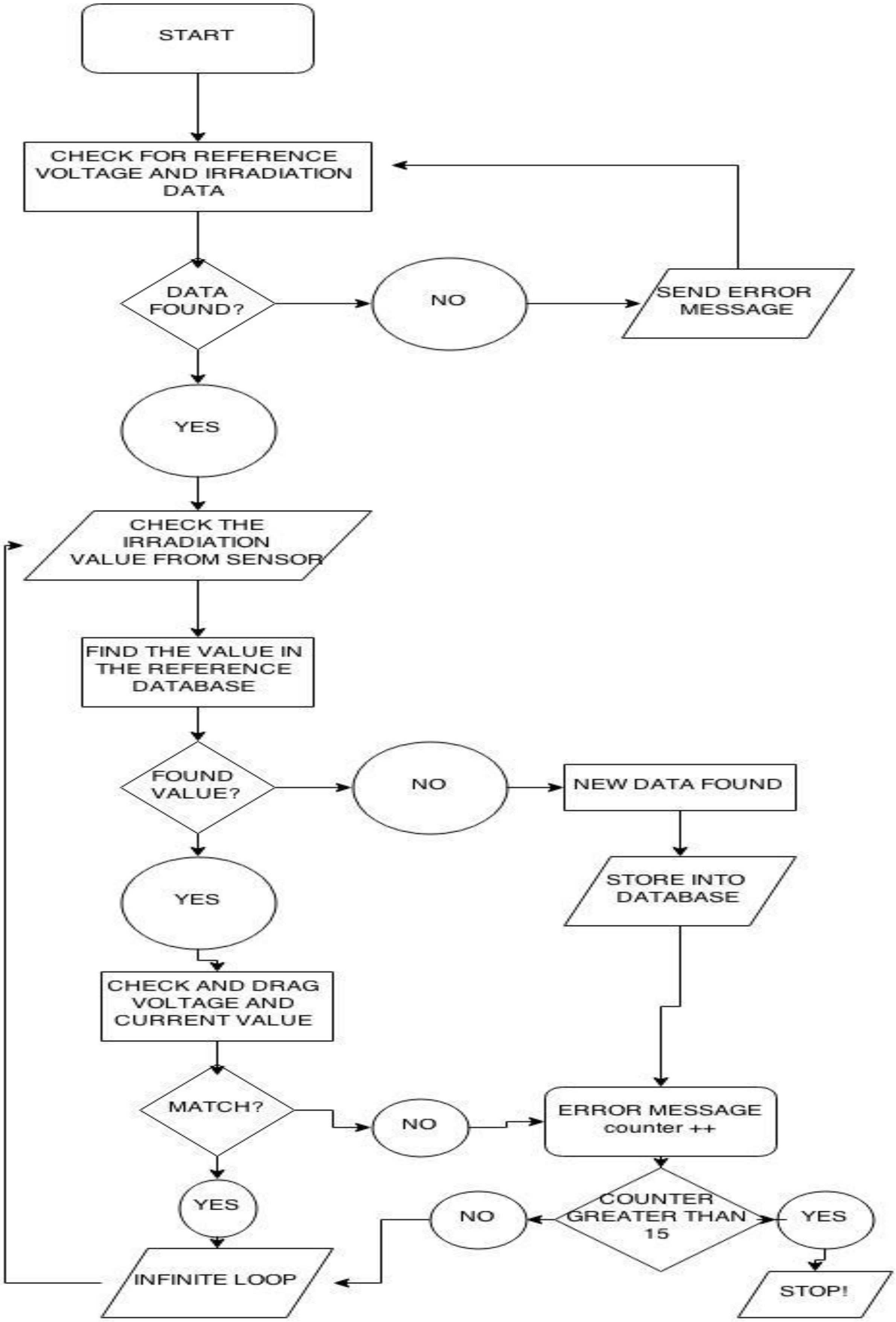
Appendix I



Appendix II


START
CHECK FOR REFERENCE VOLTAGE AND IRRADIATION DATA
DATA FOUND?
NO
SEND ERROR MESSAGE
YES
CHECK THE IRRADIATION VALUE FROM SENSOR
FIND THE VALUE IN THE REFERENCE DATABASE
FOUND VALUE?
NO
NEW DATA FOUND
STORE INTO DATABASE
YES
CHECK AND DRAG VOLTAGE AND CURRENT VALUE
MATCH?
NO
ERROR MESSAGE counter ++
YES
COUNTER GREATER THAN 15
NO
YES
INFINITE LOOP
STOP!