Development of Solar Tracking System for Domestic Application

By

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CERTIFICATION OF APPROVAL

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Electrical & Electronics Engineering Programme
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TRONOH, PERAK

May 2011

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 have not been undertaken or done by unspecified sources or persons.

Mohamad Shawari Bin Abu Bakar

ABSTRACT

The highly volatile prices fossil fuel currently creates an opportunity for the development of alternative approaches in electricity generation. Comprehensive and concerted efforts are focused at developing SEGS (Solar Electricity Generation System). One of the challenges faced by SEGS is the apparent trajectory of the sun. Often, SEGS designers use standard testing condition, whereby the level of solar insolation is taken to be a constant value of $1000 W/m^2$. The fact remains that the only constant value of solar insolation occurs just outside the earth atmosphere, where the value of $1353 W/m^2$ is declared as solar constant. This value drops significantly as the solar radiation passes through the atmosphere, where the typical range is between 150 W/m^2 and $1000 W/m^2$. The aim of this project is to address the apparent trajectory of the sun. A novel design of the sun tracker has been tested and is able to do two-axis tracking for photovoltaic based SEGS.

ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1
INTRODUCTION

1.1 Background of Study

The highly volatile prices fossil fuel currently creates an opportunity for the development of alternative approaches in electricity generation. The Five-Fuel policy development under 8th Malaysia Plan is aimed at promoting the use of renewable energy especially for electricity generation [1]. This policy shows a concrete support from Malaysian government in realizing the objective of renewable energy.

Today, solar energy is increasingly becoming an important source of renewable energy. Comprehensive and concerted efforts are focused at developing solar Electricity Generation System (SEGS). Practically, solar energy is captured by solar collector through Photovoltaic effects. However, difficulty with solar collector is that they are static, while the sun is not. As the result, the sun does not always strike the solar collector in such a way as to maximize solar energy generation. This happens especially in the morning or late afternoon; when the sun's angle relative to earth decreases.

1.2 Problem Statement

The cost for developing and implementing SEGS is relatively on the higher side at the moment. Maximization for the energy generation by SEGS is important to gauge the system efficiency relative to it cost. The amount of energy generated by the SEGS depends upon the amount of solar radiation on the solar collector. In simple explanation, extra solar radiation on the solar collector means extra energy generation.

Apparent trajectory of sun daily change and different depend on the direction of the collector aimed, time of the year, position on the earth, altitude and the area of the collector set up. Due to the intermittent input of solar radiation, it is therefore necessary to optimize orientation and tilt of the solar collector towards the sun for optimum electrical power generation.

1.3 The Objectives

The objectives of this project are:

- To carry out a simulation study on solar geometry.
- To design a suitable and cost effective solar tracker for domestic use.

1.4 Scope of Study

Mainly, the project will be covering the SEGS system. However, as the problem is defined come from the input, the project will be focusing more on the input of SEGS system.

The study of this project covers the following:

- Analysis on Earth-Sun geometry at University Teknologi Petronas (UTP) for year 2011.
- Development of a suitable and cost effective solar tracker for domestic application.
- Design and Construction of cost effective solar tracker prototype.

CHAPTER 2
LITERATURE REVIEW

2.1 Energy from the Sun

Solar energy is the energy from the sun. The sun is a gigantic ball of hydrogen and helium gas. Extraordinary pressure inside the sun causes the core of two hydrogen atoms to fuse and producing a helium atom in a process called fusion. During fusion, nuclear energy is converted to thermal and radiation energy. Radiation energy is emitted from the sun in all directions and reaches earth [2].

Radiant energy is the energy in electromagnetic waves or radiation. Radiant energies are microwave, infrared, visible light, Ultraviolet, x-ray, gamma ray and others. These rays have different amounts of energy depends on their wavelength. A shorter wavelength radiant will contain more energy compared to a longer wavelength radiant [2].

With an average distance of 1.5×10^8 kilometers between the earth and the sun, solar radiation reaching the earth's atmosphere at a rate of 1353 Watt/square meter (W/m^2). About half of the energy from the sun is absorbed by water and land mass, while the rest is re-emitting back to the space. Earth receives sunlight in 174 PetaWatts on atmosphere at a particular time. Averagely, atmospheric conditions (clouds, dust and pollutant) will reduce the solar radiation. Total solar energy available to the earth in average is about 3850 ZettaJoules (ZJ) per year [2].

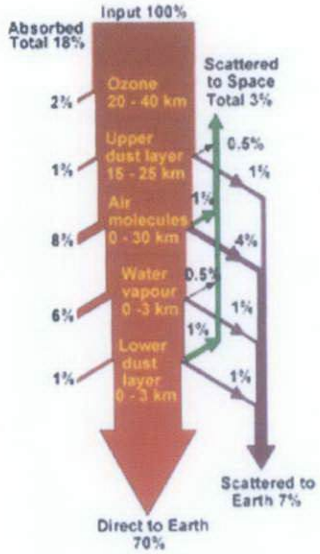

Figure 1: Breakdown of Solar Energy at Typical Clear Sky [2].

Total instantaneous solar radiation (global irradiance) on a horizontal surface consists of beam radiation and diffuse radiation. On a clear day, about 10% of the total incident solar radiation is diffuse [2].

$$I_G = I_{DIRECT} + I_{DIFFUSE} = 1.1 I_{DIRECT}$$

where,

The beam radiation is influenced by the altitude of the location, it can be found using the following formula [2]:

$$I_{DIRECT} = 1.353[(1 - 0.14h)0.7^{AM^{0.678}} + 0.14h]$$

'h' is the height above the sea level in kilometers.

The air mass can be found using the following formula:

$$AM = \frac{1}{\cos\theta + 0.50572(96.07995 - \theta)^{-1.6364}}$$

and 'θ' is the zenith angle (90° – Elevation angle)

In Malaysia, clouds are the main reason for lower input to the SEGS. The average diffuse radiation in Malaysia is about 40% of the direct component. Sunlight obstacle such as clouds, dusts and pollutants cannot be eliminated and the transient of global irradiance in Malaysia because of atmospheric conditions seem to be the biggest challenge for SEGS.

To prove that solar insolation is influenced by the atmospheric condition, the solar insolation data is taken for UTP on 5th January 2011. Full data analysis will be discussed in CHAPTER 4 under solar geometry analysis.

2.2 Solar Geometry

In order to track the sun throughout the day, there should be known geometric relationships between earth and sun. From a fixed location on earth, the sun appears to move at the sky. The apparent motion of the sun daily change and different by the rotation of the earth about its axis and it changes the angle at which the sunlight will strike the earth.

2.2.1 Earth Motions and Declination

Earth has two Principal Motions [3]:

- Rotation - each day the earth rotates on its own axis. This rotation gives us day and night which are 24 hour to complete a rotation.

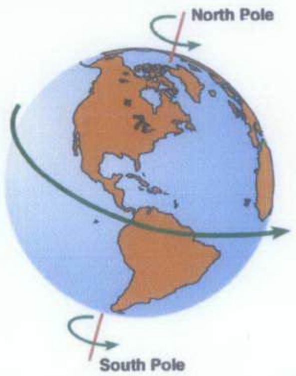

Figure 2: Earth Rotation [3].

- Revolution - As the earth rotates, it also revolves around the sun in an elliptical orbit in about 365¼ days (1 year) to complete an orbit.

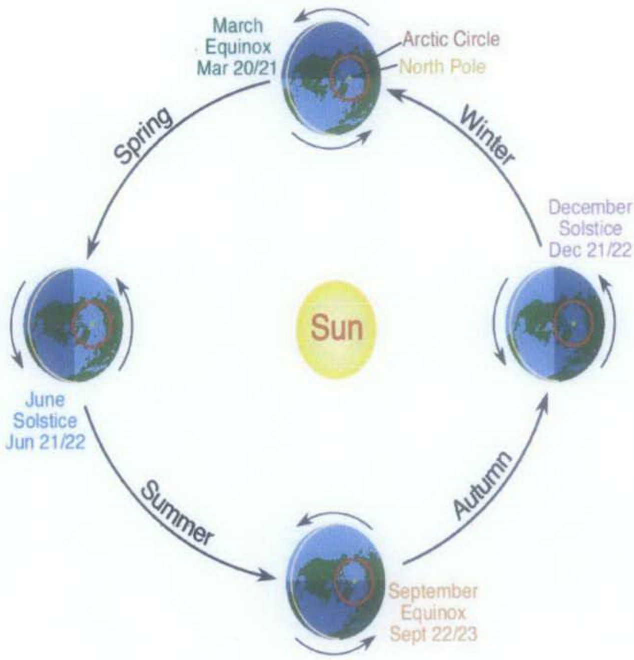

Figure 3: Earth Revolution [3].

During the motions, the earth also decline each day. Earth declination angle is measured from the slope perpendicular to the rays of the sun. This declination angle is 0° in March and September while it reach maximum in June (23.45°) and minimum in December (-23.45°) [3].

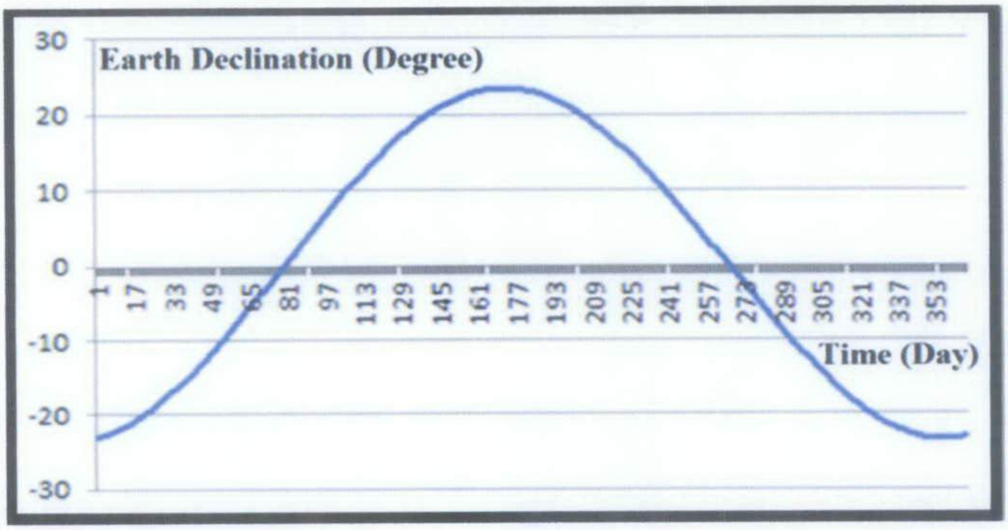

Figure 4: Earth Declination vs. Time.

The earth declination angle can be found using equation:

$$\delta = 23.45^\circ \sin[\frac{360}{365}(d + 284)]])$$

where, '*d*' is the day number counted as 1 = January 1, 2 = January 2 and so on.

2.2.2 Sun Position

The main idea of *Sun Position* is to determine the apparent position of the sun from the earth. For the apparent sun position here, calculation is required for Elevation angle and Azimuth angle.

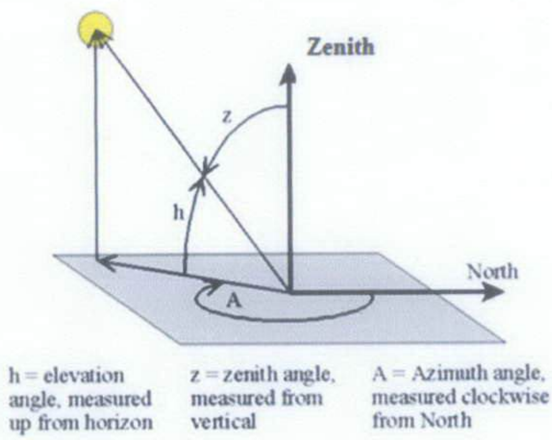

Figure 5: Sun Apparent Position

The Elevation angle (used interchangeably with altitude angle) is the angular height of the sun in the sky measured from the horizontal (zenith). The Azimuth angle is the compass direction from which the sunlight is coming [2].

The Elevation can be found using the following formula [2]:

$$Elevation, \alpha = \sin^{-1}[\sin\delta \sin\varphi + \cos\delta \cos\varphi \cos(HRA)]$$

and the Azimuth can be found using the following formula [2]:

$$Azimuth = \cos^{-1}[\frac{\sin\delta\cos\phi - \cos\delta\sin\phi\cos(HRA)}{\cos\alpha}]$$

where,

The declination angle, $\delta = 23.45°\sin[\frac{360}{365}(d+284)]))$

'd' is the day number counted as 1 = January 1, 2 = January 2 and so on.

'φ' or 'ø' is the position's latitude, it can be found using GPS device.

The hour angle, $HRA = 15°(LST - 12)$

The local solar time, $LST = LT + \frac{TC}{60}$

The 'LT' is position local time.

The time correction, $TC = 4(Longitude - LSTM) + EoT$

The position's longitude can be found using GPS device.

The local standard time meridian, $LSTM = 15°.\Delta T_{GMT}$

The ΔT_{GMT} is the difference of the local time (LT) from Greenwich Mean Time (GMT) in hours.

The equation of time, $EoT = 9.87\sin(2B) - 7.53\cos(B) - 1.5\sin(B)$

and 'B' (in degrees), $B = \frac{360}{365}(d - 81)$

Based on the equation defined, both calculation for Elevation and Azimuth need time and location (latitude and longitude) input. Different value for the time and the location will yield a different Elevation and Azimuth. Thus, the apparent position of the sun from the earth is discovered to be different at different time or at different position.

Next, using these equations, the analysis on Earth-Sun geometry at UTP for year 2011 will be done. The result is discussed in CHAPTER 4 and full simulation results are attached in **APPENDIX A** and **APPENDIX B**.

2.2.3 Solar Radiation on a Titled Surface

By using the Elevation angle and Azimuth angle from *Sun Position* calculation before; there is a relationship between the apparent sun position and power generation by the solar collector.

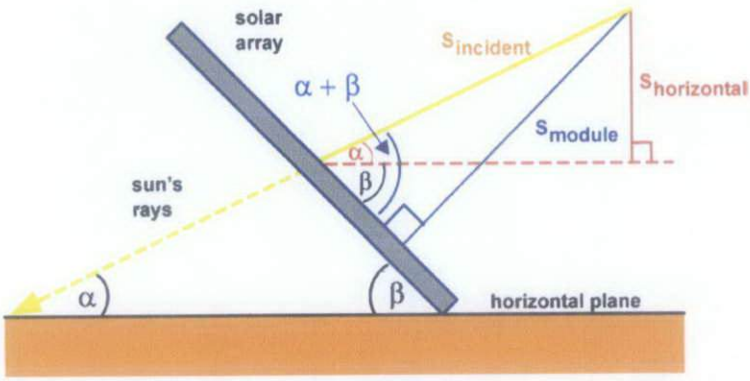

Figure 6: Solar Radiation on a Titled Surface [2].

The S_{module} is the maximum power the collector can get from the sunlight ($S_{incident}$), it can be found using the following formula [2]:

$$S_{module} = S_{incident} \sin(\alpha + \beta)$$

When to relate solar radiation on a tilt surface with solar Elevation and solar Azimuth, use [2]:

$$S_{module} = S_{incident}[\cos\alpha \sin\beta(\psi - \Theta) + \sin\alpha \cos\beta]$$

where, 'α' is the Elevation angle, 'Θ' is the Azimuth angle, 'β' is the module tilt angle and 'Ψ' = 0° at north hemisphere and in the northern hemisphere 'Ψ' = 180°.

Here, for maximum power generation, the collector has to be tilted at

$\alpha + \beta = 90^0$, to yield $S_{module} = S_{incident}$

From above relationship, the power receive by solar collector is directly related to the angle between the solar collector and the sunlight. As the apparent position of the sun from the earth is different for specific time and position, there should be a different tilt angle for the solar collector at specific time and position on earth too. This is the root solution to maximize the energy generated by SEGS by ensuring $S_{module} = S_{incident}$. To adjust tilt angle $\alpha + \beta = 90^0$ automatically, solar tracker implementation is needed.

2.3 Solar Collector

One more important factor that influences the efficiency of SEGS is type of photovoltaic (PV) cells used. Performance of PV cells depends on specific properties and chemical structure of the solar cells. In order to maximize the SEGS generation, high efficiency PV cells should be selected. However, for high efficiency PV cells, extra cost need to be invested. In this project, the cost of fabricating a particular solar cell structure must be taken into consideration to ensure a suitable and cost effective SEGS can be build.

2.3.1 Photovoltaic Effects - Method for Producing Electricity

Photovoltaic is known as a method for producing electricity using solar cells to convert solar energy into electrical power. PV effect refers to light photons knocking solar cell electrons into a higher state of energy to create electricity [2].

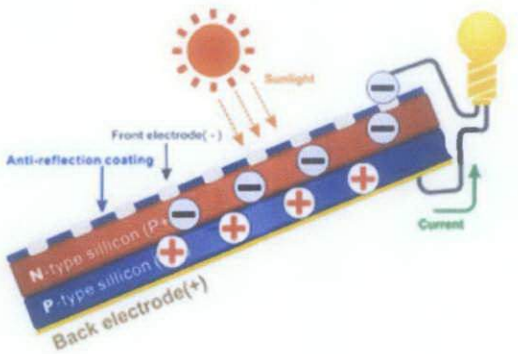

Figure 7: Photovoltaic Effect [4].

Sunlight composed packets of photons. This sunlight contains different amounts of energy in accordance with spectrum wavelengths of the sun. When photons strike on solar cells, they may be reflected or absorbed, or they may pass through. Absorbing photons produce electricity. PV generally consists of two areas that are thin, the n-type and p-type. Carrier collection of light emitted by PN junction causes the movement of electrons to the n-type side and holes into the side of p-junction [2].

As an open circuit, the carrier is prevented to leave the solar cell, the collection of carriers generated by sunlight cause an increase in the number of electrons in the n-type side and a similar increase of hole in the p-type side. Separation of charge causes the creation of electric field. In the short circuit, minority carrier concentrations on both sides increase drastically and so the drift current. The movement of electrons is a current which generate the voltage.

2.3.2 The Silicon Solar Cells

There are three types of silicon used in silicon solar cells based. Each of it has a specific properties and chemical structure [5].

Mono-crystalline Silicon: It is the most expensive solar cells; the ordered crystal structure which is obtained by a very slow growth of crystals. This solar cell's efficiency is high due to uniform orientation of the atoms [5].

Polycrystalline Silicon: It is the second most expensive solar cells; the ordered crystal structure which is obtained can grow faster than Mono-crystalline Silicon. This solar cell's efficiency is lower than Mono-crystalline Silicon due to random orientation of the atoms [5].

Amorphous Silicon: It is the cheap solar cells; the ordered crystal structure which is obtained can grow faster than Polycrystalline Silicon. This solar cell's efficiency is lower than Polycrystalline Silicon due to very random orientation of the atoms [5].

2.3.3 Dye-Sensitized Solar Cells

Dye-sensitized solar cells are innovative solar cell that mimics photosynthesis in plants. These cells have much potential because they can be made and produced with cheap materials. Unlike traditional solar cells, dye sensitive cells work effectively in low light conditions and less vulnerable to loss of energy to heat [5].

Based on four type PV cells discussed as above, the best solar collector to be used to maximize the SEGS generation is made from Mono-crystalline Silicon. Even though, the cell is costly, the efficiency should be considered first because SEGS is lack in efficiency.

2.4 Solar Trackers

A solar tracker is a generic term used to describe the various devices oriented towards the sun. In standard, solar tracking application is used to minimize the incidence angle between the sunlight and the solar collector. This will increase the amount of energy generated from the tracked solar collector compared to fix installed solar collector [6].

There are mainly two type of solar tracker:

Single Axis Trackers: Single axis tracker has one degree of freedom that act as the axis of spin [6]. Three common implementation of single axis tracking are Horizontal Single Axis Trackers, Vertical Single Axis Trackers and Tilted Single Axis Trackers [6]. Rated output energy generation is 20%-30% more than fixed solar collector [7].

Figure 8: 1-Axis Tracker [8].

Dual Axis Trackers: Dual axis tracker has two degree of freedom that act as the axis of spin [6]. This axis is normal to each other [6]. Two common implementations of dual axis trackers are Tip - Tilt trackers and Azimuth-Altitude trackers [6]. Rated output energy generation is 30%-40% more than fixed solar collector [7].

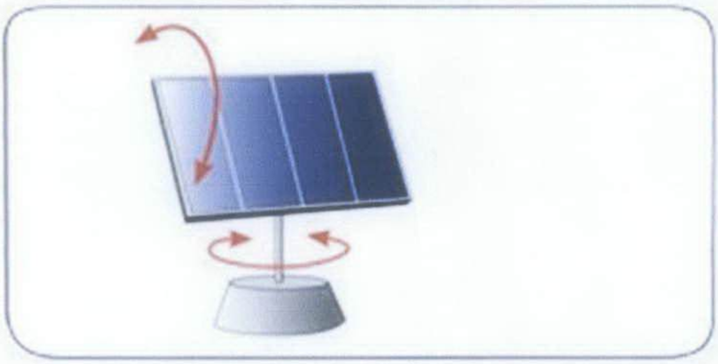

Figure 9: 2-Axis Tracker [8].

Common leading manufacture of solar tracker in the world is Array Technologies, Inc. from America. In residential category, their product include both single and dual axis tracker such as AZ-125 and AZ-225. Price for each tracker is $3385 for AZ-125 and $6250 for AZ-225. The design for both trackers is for low electricity generation, which is 1.8kW and 3kW [7].

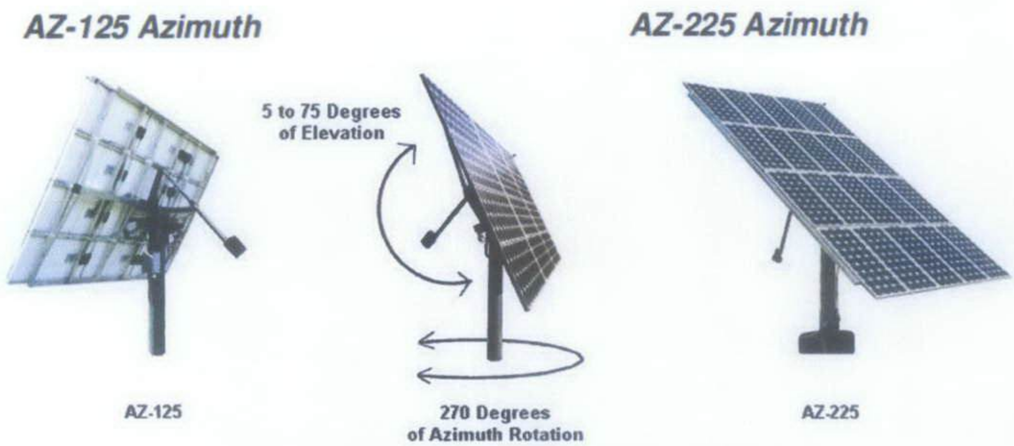

Figure 10: AZ-125 and AZ-225 Tracker [7].

Based on the product data sheets, the movement of the solar collector is using low power motor to minimize power consumption during the system operation. Obviously, as the tracker being used for a remote home, they are using microcontroller to senses the environment by receiving input from a sensor and affects its surroundings by controlling the motor [7].

In considering for the project, the best tracker type to be selected is the two-axis tracker because it generates more energy compare to one-axis tracker and low power motor should be used to minimize the power consumption. Furthermore, for a remote home, tracking system using a sensor is relevance because it will be easier to set up at a different location.

CHAPTER 3

METHODOLOGY

3.1 Project Flow

Preliminary steps are carried before the construction of the prototype. The steps are illustrated in the flow chart in the following Figure and the project timeframe is attached on **APPENDIX E.**

Problem Identification

- Current SEGS output is low because of transient nature of solar insolation

Problem Cause

- Atmospheric conditions - clouds.
- Apparent trajectory of the sun daily change and different by the rotation and revolution of the Earth.

Problem Solution

- Extra energy input to solar collector will generate extra energy output.
- Need to maximise Input & Output.

Input & Output Maximization

- To maximize input, $S_{module} = S_{incident}$.
- To adjust till angle $\alpha + \beta = 90^{\circ}$: need solar tracker.
- To maximize output, choose high efficiency solar collector: Mono-crystalline Silicon.

Solar Tracker Selection

- 1-Axis or 2-Axis?
- Choose 2-axis: rated output energy generation is 30%-40% more than fixed solar collector.

Mechanical Design

- Tip-Tilt or Azimuth-Altitude Implementation?
- Choose Tip-Tilt: easier to construct the holding structure and low torque motor can be used.

Electrical & Electronic Design

- Sensor or Sensorless?
- Choose sensor: the system is for remote home - Easier to set up for different location.

Prototyping

Testing

Novel 2-Axis tracker system ready

START

FINISH

Figure 11: Project Flow Chart.

3.2 Design Approach

The design approach applied in this project is a problem-solving approach. The steps begin with recognizing the main objective that is to design a suitable and cost effective tracker for domestic use. The main objective will be used as a general guideline until the project complete.

Next, scientific prove is used to identify the real problems. As the problems are identified thoroughly, research on available product in the market is done to generate alternative solutions for the target problems. Next, selection for the best alternative solution is conducted. The selection will be gauge by the cost and the time limit. Finally, to evaluate the feasibility of the solution, prototype is tested for the efficiency.

3.3 Mechanical Design

Mechanical part in this project is important in order to construct the best structure for the prototype. Previously, selection is made for two-axis tracking system as it generates more energy compare to one-axis tracker. In implementation of two-axis tracker, there are two kind of design; Tip-Tilt and Azimuth-Altitude [11].

Figure 12: Tip-Tilt [11].

Figure 13: Azimuth-Altitude [11].

The selection of implementation will be considering the size of the motors that are needed to drive the solar collector at two-axis. In two-axis solar tracker, the design will need two different motor to drive the solar collector. As in Figure 12, the Tip-Tilt implementation may need two same size motor because both motor will drive the load of solar collector only.

However, in Figure 13, one motor has to drive the load for solar collector and one motor has to drive the load for the entire structure. If Azimuth-Altitude is selected, a big size of motor is needed as it drives a bigger load. This big motor will be costly and consume more energy.

Tip-Tilt implementation is selected and using the Google Sketch software, the mechanical structure is properly designed. The design is shown in the following figure.

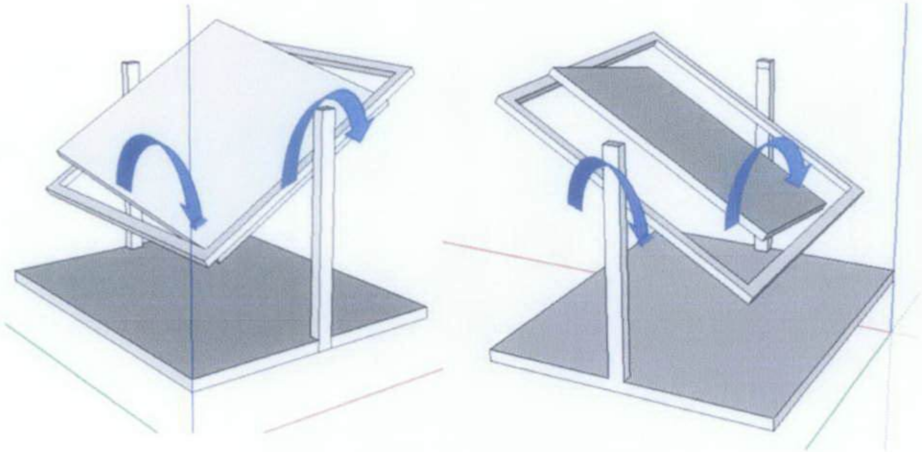

Figure 14: Mechanical Structure.

3.4 Electrical and Electronic Design

In order to align solar collector, electrical and electronic part is important to control the turning direction and position of the motor as it receives input from the sensors.

There are two types of electric motors; AC and DC motor. This project uses DC motor because solar collectors will generate DC voltage. It will be easier to power up and control the DC motor instead of AC motor. In addition, it is recommended to use DC compound motor as it gives good torque and stable speed.

3.4.1 Basic Control for Turning Direction and Position of DC Motor

To control the turning direction of DC motor, we can manually change the supply polarity to the motor. In industry, DC motors turning direction is controlled by using a transistor configuration called as 'H-bridge'.

The 'H-bridge' is useful to control the turning direction but not the speed. To control the turning direction of DC motor, the transistor pair in the circuit needs to be automatically switched 'ON' and 'OFF'. The automation is done using programmed microcontroller.

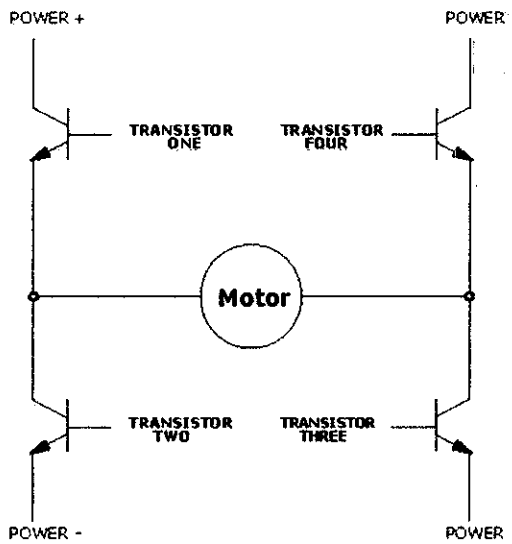

Figure 15: H-Bridge.

Next, for controlling the position of the motor, the system needs a FEEDBACK method. FEEDBACK will determine the present position of the motor. The motor can be adjusted to demand position by referring to present position of the motor.

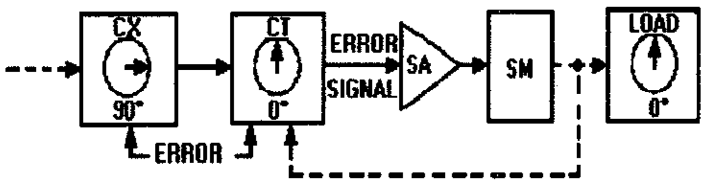

Figure 16: Controlling Motor Position using FEEDBACK Method [9].

Based on what has been review, to control the turning direction and the position of DC motor automatically, the system need:

- H-BRIDGE and Microcontroller – to control direction.
- FEEDBACK – to control position of DC motor.

3.4.2 Servo System -To Control Turning Direction and Position of DC Motor

A closed-loop control system is another name for a servo system. To be classified as a servo, a control system must be capable of the following:

- Accepting an order that defines the desired result.
- Determining the present conditions by some method of feedback
- Comparing the desired result with the present conditions and obtaining a difference or an error signal.
- Issuing a correcting order (the error signal) that will properly change the existing conditions to the desired result.
- Obeying the correcting order

In a dc position servo system, the amplitude and polarity of a dc error signal respectively are used to determine the amount and direction the load will be driven [9].

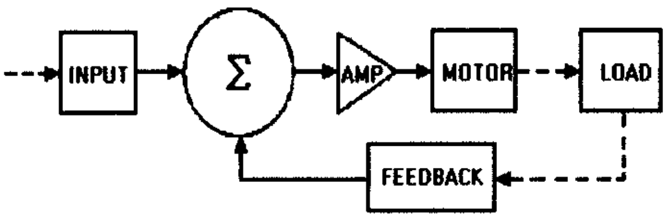

Figure 17: Block Diagram of Position Servo [9].

From Figure 17, sum point 'Σ' is where the input signal and the FEEDBACK signal are summed to produce the error signal. The control circuit for servo system includes H-bridge and the FEEDBACK.

3.4.3 Design a Servo System with Input from 555 Timer

To drive a different size of load, the system needs a common circuit that can be used to drive different DC motor size. Different DC motor sizes will need a different supply. Figure 18 is a practical circuit that can operate +5V to +7V DC motor without changing the circuit design.

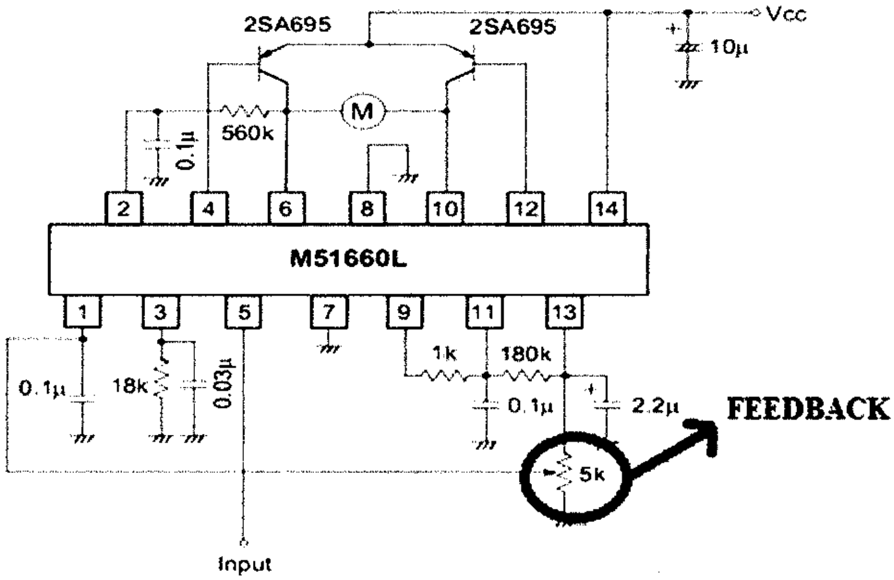

Figure 18: Servo System Control Circuit [10].

Referring to Figure 18, the most important component to design the servo system is M51660L chip (servo motor control for radio-controlled). The datasheet for the chip M51660L is attached on the **APPENDIX D.**

In order to control the direction of the servo system, the system requires a PWM signal input. A short pulse (1ms-1.4ms) makes the servo drive to one direction and a long pulse (1.6ms-2.0ms) makes it drive to the other direction and at the medium pulse (1.5ms), the system is in a static condition. The working PWM signal for servo system is around 1ms to 2ms.

Today, there are several ways to generate PWM; most of it is using microcontroller. However, in order to minimize the cost and the complexity, the PWM will be generated by using 555 Timer (servo driver).

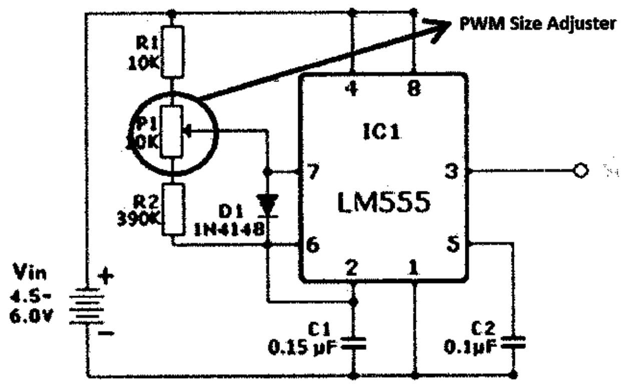

Figure 19: Servo Driver Circuit.

The equations for the 555 Timer are simple and easy to use. They are as follows:

$$T_{HIGH} = 0.693(R_1 + P_1)C$$

$$T_{LOW} = 0.693(R_2)C$$

Since P_1 is variable resistor, it varies from 0Ω to 10KΩ. At the same time, the signal varies from:

$$T_1 = 0.693(10K + 0)0.15e^{-6} = 1.039ms$$

$$T_2 = 0.693(10K + 10K)0.15e^{-6} = 2.079ms$$

To drive the DC motor, output signal from servo driver in Figure 19 is connected to input signal of servo system in Figure 18. For the purpose of explanation, assume 'FEEDBACK' potential resistor is fixed at the middle point. As the 'PWM Size Adjuster' potential resistor varies, the turning direction of the motor will also varies because the servo driver is generating a variable signal size.

Now, let fix the 'PWM Size Adjuster' potential resistor at the middle point. As the 'FEEDBACK' potential resistor varies, the turning direction of the motor will also varies because the servo system is feed backing a variable signal size.

From the two control theory above, there are two options in controlling the turning direction of the DC motor using servo system. First option is to vary the input signal while fixing the FEEDBACK signal and second option is vary the FEEDBACK signal while fixing the input signal.

3.4.4 Servo System with Input from 555 Timer and Sensor (LDRs)

Based on previous theory, to turn the motor, a manual operation is needed to vary the potential resistor value. From the main objective, the system should be operated by receiving input from a sensor (LDRs).

To perform an automatic operation for varying the potential resistor value at 'FEEDBACK' or at 'PWM Size Adjuster', the system needs to parallel the LDRs as in Figure 20 and Figure 21.

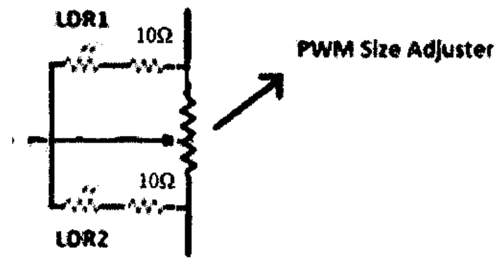

Figure 20: Parallel LDRs to 'PWM Size Adjuster' Potential Resistor.

Refer to Figure 20, the aim is to vary the input signal while fixing the FEEDBACK signal. Here, the both potential resistor is set somewhere in the middle to ensure that the servo motor is static. Next, we parallel LDRs with the 'PWM Size Adjuster' potential resistor. Right now, the input signal will be automatically adjusted by the LDRs.

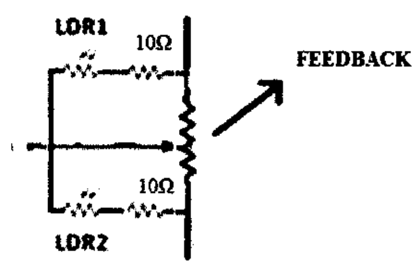

Figure 21: Parallel LDRs to 'FEEDBACK' Potential Resistor.

Refer to Figure 21, the aim is to fix the input signal while vary the FEEDBACK signal. Here, the both potential resistor is set somewhere in the middle to ensure that the servo motor is static. Next, we parallel LDRs with the

'FEEDBACK' potential resistor. Right now, the FEEDBACK signal will be automatically adjusted by the LDRs.

As both potential resistors is set somewhere in the middle, the total resistance depends on the LDRs, where:

$$R_L = \frac{(R_{LDR1} + 10)R_{potentialL}}{R_{LDR1} + 10 + R_{potentialL}}$$

and

$$R_R = \frac{(R_{LDR2} + 10)R_{potentialR}}{R_{LDR2} + 10 + R_{potentialR}}$$

Where,

R_L	=	Left total resistance	R_{LDR2}	=	Right LDR resistance
R_R	=	Right total resistance	$R_{potentialL}$	=	Left potential resistance
R_{LDR1}	=	Left LDR Resistance	$R_{potentialR}$	=	Right potential resistance

As there are invariance on R_L and R_R, there are also invariance on left voltage (V_L) and right voltage (V_R). So, the servo motor turning direction now depends on the LDRs instead of potential resistor. The mechanism of motor turning direction is simplified by the following figure.

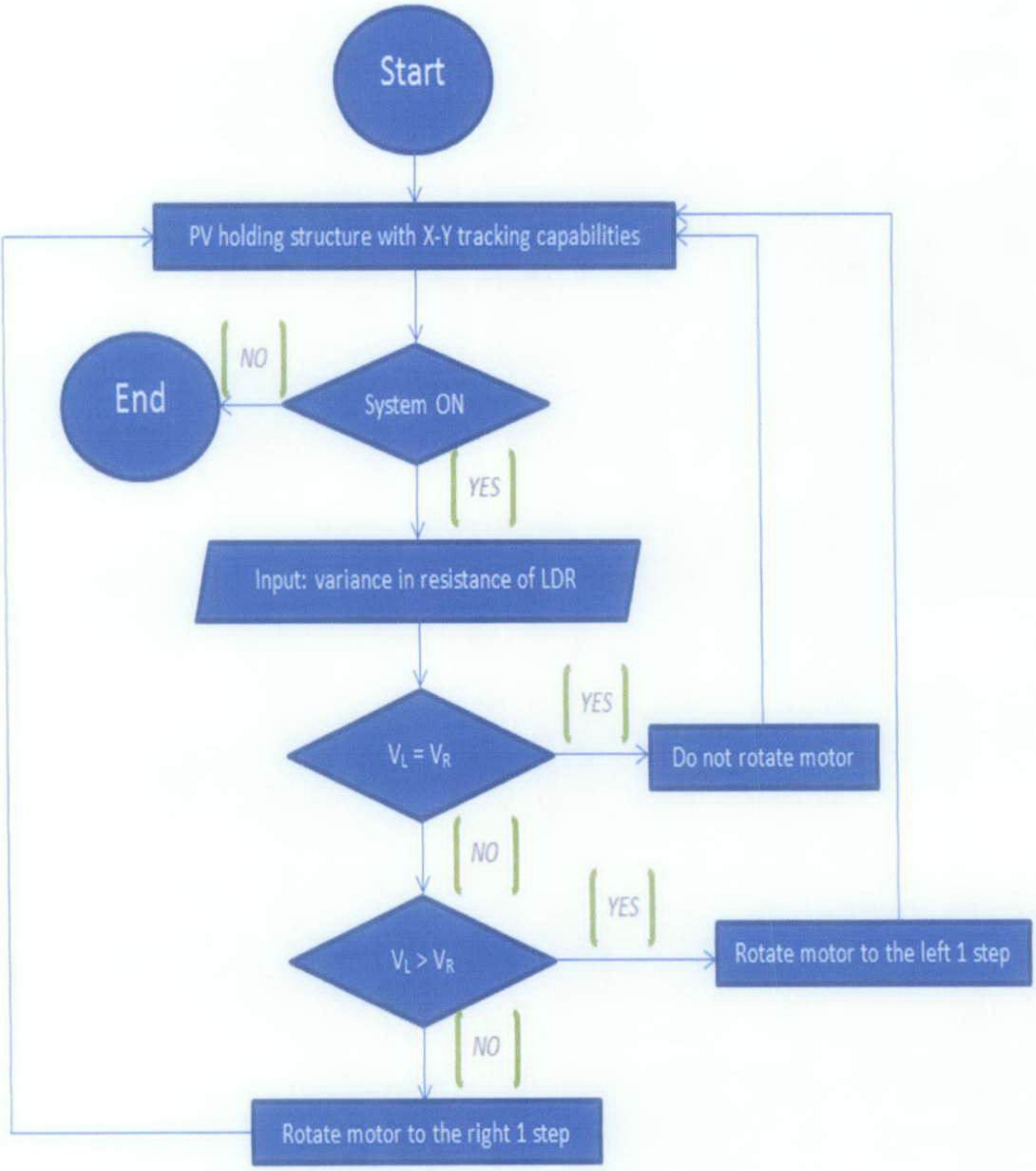

Figure 22: Motor Control Flow Chart.

3.5 Tool/Equipment Requirements

3.5.1 Sensors - Light Dependent Resistor

Light Dependent Resistor (LDR) is very useful, especially in the light / dark sensor circuit. If the light falling on the LDR, photon is absorbed by the semiconductor give outer bound electrons enough energy to jump into the conduction band. Free electrons are generated (and the hole pairs) and LDR start conducting as the light reduce the resistance [11].

Figure 23: Light Dependent Resistor.

3.5.2 Actuator – Servo Motor

Servos is a small DC motor which has gearbox and some control circuitry. Servo motors have three wires: V_{cc}, ground, and signal. The power wire is red, and connected to the +5V-+7V of supply. The ground wire is black or brown and connected to a ground. The signal wire is typically yellow, orange or white and connected to PWM (signal) source. Important design for servo is, no external motor drivers required to operate it. A short pulse of signal makes the servo drive to one direction and a long pulse makes it drive to the other direction, and at the medium pulse (around 1.5ms pulse), puts it in static condition.

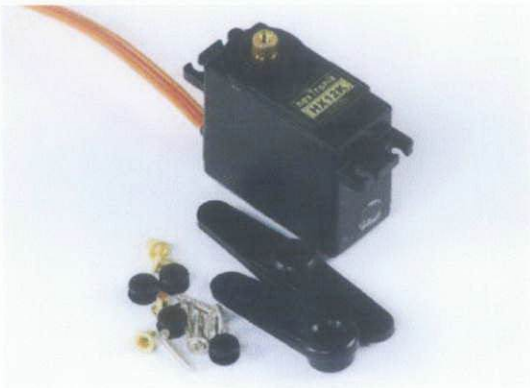

Figure 24: Servo Motor.

3.5.3 Servo Driver - ESKY EK2-0907

ESKY EK2-0907 can connect two sets of servo and control it with good stability and high precision. It is very practical for testing the performance the motor and there is no need to connect transmitter and receiver, which is equal to the function of "manually operation receiver", can imitate receiver operating the servo by turning the knob.

Figure 25: Servo Driver.

3.6 Software Requirements

3.6.1 Microsoft Excel

Microsoft Excel is user friendly software that very useful for complex equation calculation. This is useful for simulation study of solar geometry.

3.6.2 Google SketchUp

Google SketchUp is a free and easy to learn which allowing anyone to model in 3D quickly and accurately. This is useful for 3D structure design for the tracker.

3.7 Prototyping

Before the construction of the prototype executed, the design should be considering the size of solar collector that relevance for domestic application. 10Watts (SPM010-M) solar collector with dimensions 40cm x 30cm x 3cm from SC Origin (M) Sdn. Bhd. is suitable for the prototype [12]. By referring on the dimensions, the prototype will be designed and constructed for 10Watts solar tracker.

During the buying process of the equipment, survey on the market is made to select affordable and reasonable price. Cost for the prototype is shown in following table.

Table 1: Cost Breakdown.

No.	Tool/Equipment	Price (RM)
1	2 DF15SR 360 Degree Rotation servo (15kg)	140.00
2	1 E-Sky Servo Driver - EK2-090	60.00
3	4 LDRs	5.00
4	6 Volts Battery	10.00
5	Structure Steel with Nut and Bolt	50.00
	Total	RM 265.00

The cost for this project is RM 265.00. However, the solar collector is replaced by polystyrene as the dummy because the price is very expensive.

After all required equipment is gathered, the construction of prototype is executed. The prototype design is for two-axis tracker that has two degree of freedom which acts as the axis of spin. The axis is normal to each other based on Tip-Tilt implementation. To drive the 2-Axis Tilt, each axis will be rotate using a different servo motor and for controlling the rotation of each axis, two LDRs will be used as the sensor.

The prototype and the circuit diagram are in the following figure.

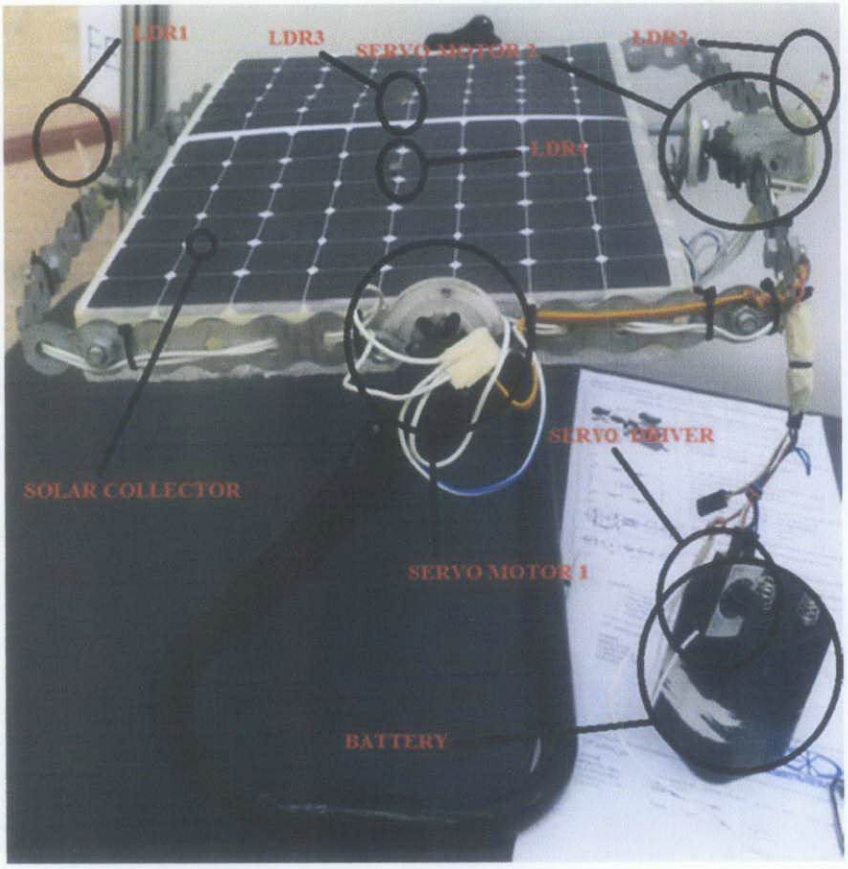

Figure 26: Prototype.

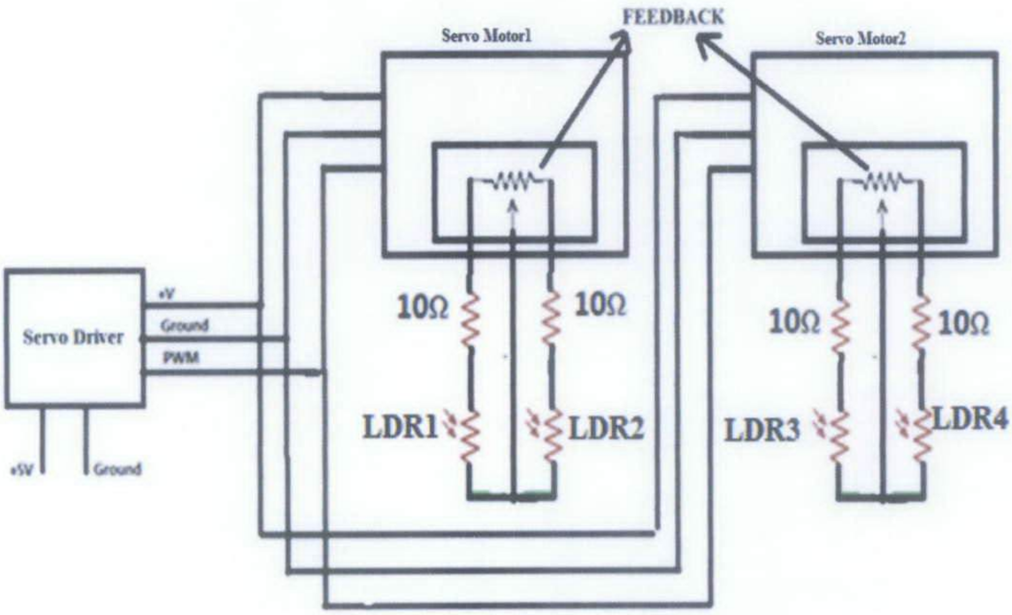

Figure 27: Prototype Circuit Diagram.

From Figure 27, the prototype is controlled by fixing the input signal while varying the FEEDBACK signal. The recommended idea is to use different servo driver for each motor to reduce the complexity and it will be easier to repair if one system broken-down. Yet, as the E-Sky Servo Driver is very costly, the design joins both servo motor to the same servo driver.

After the construction of the prototype finished, it was tested under the real condition. The prototype use light tracking method. Theoretically, it should align the solar collector toward high intensity light source. The test done by using torch light, as the light move to one position, the system constantly follows the light source.

The tracking result was very efficient. The Elevation servo and the Azimuth servo manage to move the solar collector toward the sunlight effectively. However, adjustment can be made at the sensor (LDRs) to increase the precision of solar collector alignment.

The prototype had achieved project objective as solar tracking system. Furthermore, the project successful eliminates the need of microcontroller to control the servo motor. The best way to define the benefit of this system is to compare it with current tracking system. The comparison is between the common tracker (using microcontroller) and the project tracker (not using microcontroller). Full comparison is in the following table.

Table 2: Tracker Comparison.

Comparison	Common tracker	Designed tracker
Complexity	Need microcontroller to control system.	System directly controlled by LDRs.
	One microcontroller is used to control all the motor. • Use complex algorithm.	Each motor is controlled using separate servo driver. • control system is different for each motor
	1 option in controlling the turning direction of the motor. • Vary the input signal while fixing the FEEDBACK signal.	2 options in controlling the turning direction of the DC motor using servo system.

		• Vary the input signal while fixing the FEEDBACK signal. • Vary the FEEDBACK signal while fixing the input signal.
Efficiency	Depends on the sensor type. • Optimise sensor for better accuracy.	Depends on the sensor type. • Optimise sensor for better accuracy.
	To microcontroller, analog input from sensor is chunky. • To reads voltage between 0 to 5 volts with resolution of 10-bit (1024 values). • 5/1024 = 4.8 mV is the smallest voltage change it can measure. • Control system not triggered as if voltage change below 4.8mV.	System triggered as if there are different voltage between LDRs pair.
Maintenance Requirement	Entire system affected, if control system broke down.	Each motor is controlled using separate servo driver. • 2 control system in 1 tracker. • If 1 control system broke down, 1 control system still can operate.
Cost	Control system consists of Microcontroller and electronic components - Expensive.	Control system consists of electronics components - Cheap.

CHAPTER 4
RESULT AND DISCUSSION

4.1 Analysis on Earth-Sun Geometry at UTP for Year 2011

Solar geometry simulation was done by using Microsoft Excel. The data input is UTP location and this simulation is just for year 2011. The equation for the simulation is from solar geometry Literature review in CHAPTER 2.

The latitude for UTP is +4.386 and the longitude is +100.979. The time zone for Malaysia is UTC+8 hours. By using this input data, calculation can be made for Elevation angle, Azimuth angle, sunlight duration, earth declination, sunrise and sunset.

4.1.1 Solar Insolation at Universiti Teknologi Petronas

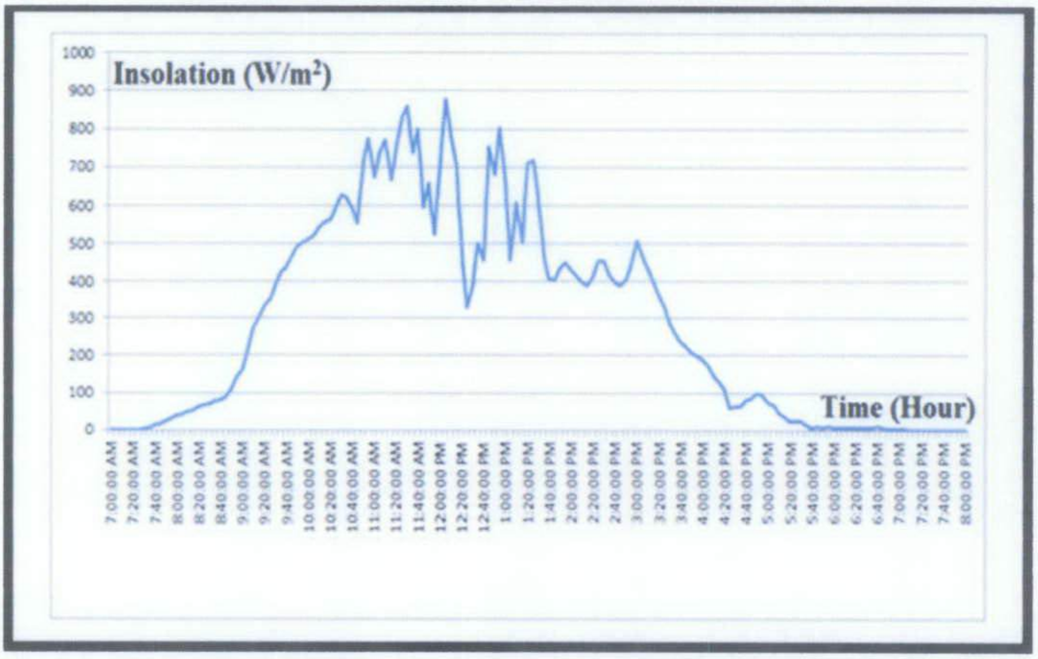

Figure 28: Solar Insolation vs. Time.

The insolation data was collected on 5th January 2011 at block P in UTP using CMP 11 pyranometer. The full result of analysis is on **APPENDIX A.** The total insolation for 5th January 2011 is 45597.97W/m^2. Referring to Figure 28, the quantity of solar insolation reaching UTP surface in a day is known to be influenced by the sunlight duration of the day. However, atmospheric conditions as cloud cause a variation in the quantity of solar radiation.

Atmospheric conditions create a big problem in power generation for SEGS but this problem cannot be eliminated because it is a nature form. However, by using solar tracker, this problem can be minimised to produce extra energy generation.

Referring to the solar tracker review in CHAPTER 1, 30% - 40% energy could be produce for a single day. Theoretically, if the pyranometer is attached to 2-axis solar tracker, 37% more solar insolation will be collected. High solar insolation will maximize the SEGS energy generation throughout the day.

4.1.2 Solar Calculations for 1 Day at Universiti Teknologi Petronas

Here, solar calculation is for 5th January 2011.The full result of analysis is on **APPENDIX B.**

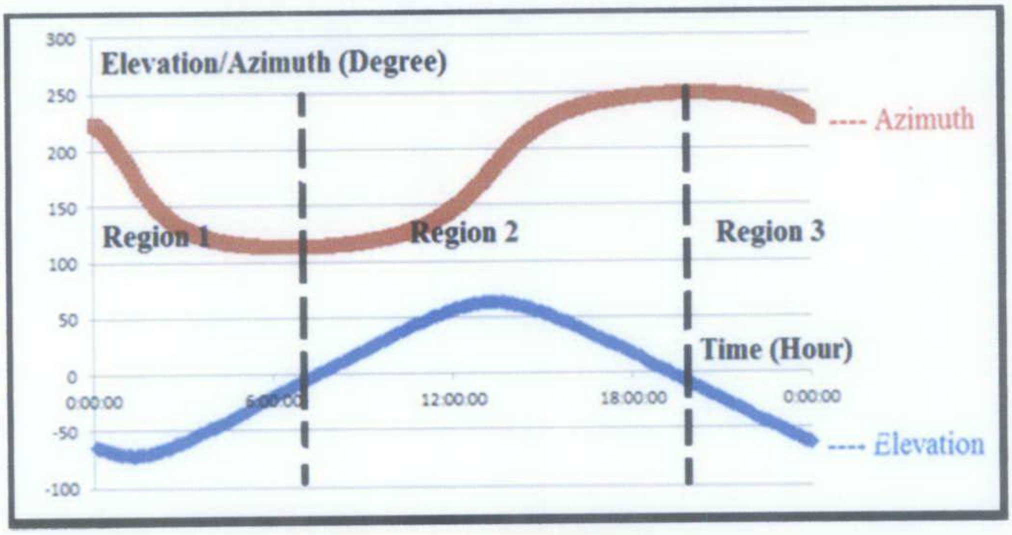

Figure 29: Elevation/Azimuth vs. Time.

Referring to the Figure 29, there are three different regions that have to be known. Region 1 and Region 3 is the time where UTP experience night. On the other hand, Region 2 is the time where UTP experience day. Day or night is determined by the polarity of Elevation angle. If Elevation angle is positive, UTP experience day because UTP receive sunlight but if it negative UTP experience night.

From the graph, as the Elevation angle varies throughout the day, Azimuth angle also varies. In considering the day time for UTP in Region 2, the sun seem moving from East to West. Further analysis show that the speed of sun movement is about 1° shifting for every four minutes.

Relating to the project, the Elevation and Azimuth angle need to be tracked by the two-axis tracker instead of one-axis tracker because there two different angle that change as the time shift. Furthermore, the tracking system does not need a very fast motor because the sun moves very slowly.

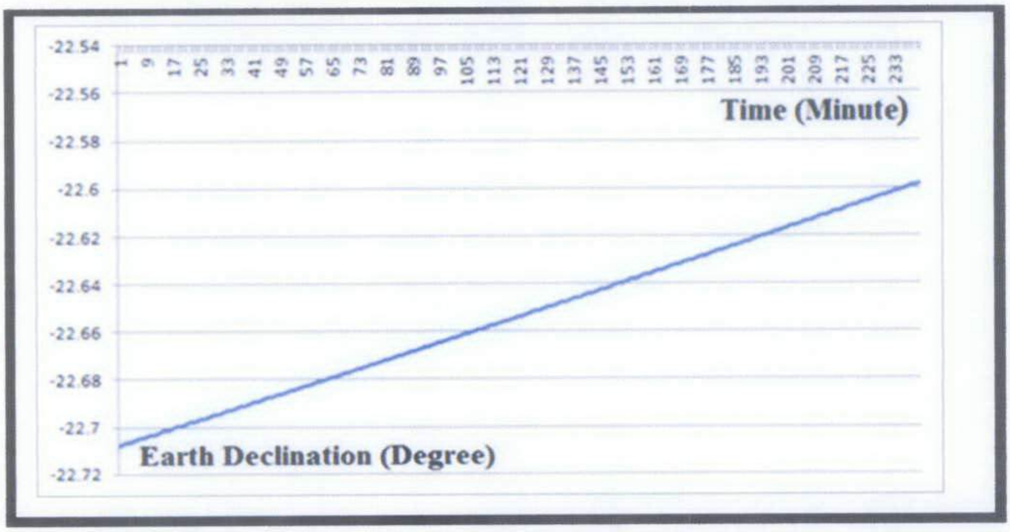

Figure 30: Earth Declination vs. Time.

Referring to the Figure 30, earth declination varies from -15.7° to -16.0°; the value of variation is less than 1° which is too small for the entire day. Further analysis shows that, the path of sun movement will almost be the same for a week.

4.1.3 Solar Calculations for 1 Year at Universiti Teknologi Petronas

Here, solar calculation is for year **2011.** The full result of analysis is on **APPENDIX C.**

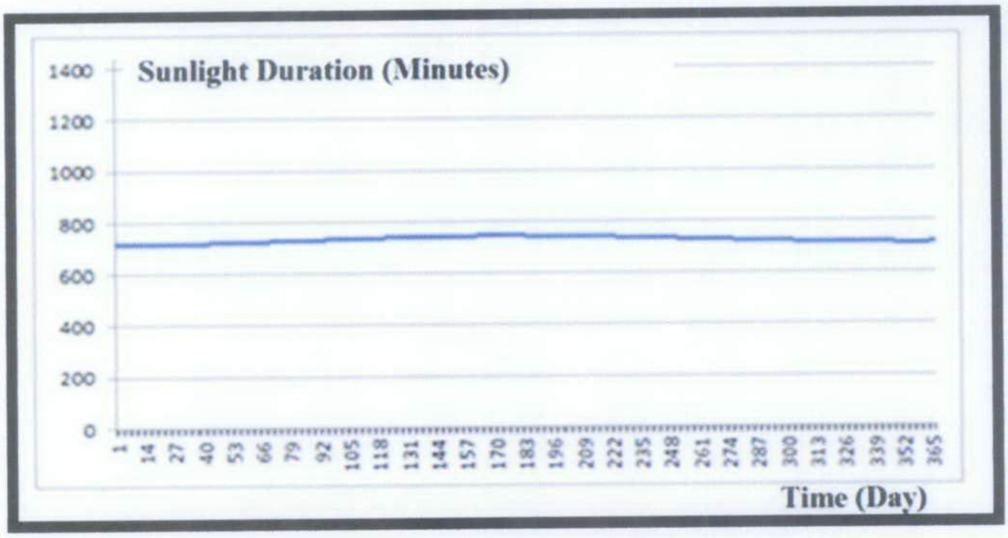

Figure 31: Sunlight Duration vs. Time.

Referring to the Figure 31, it shows that UTP receive sunlight approximately about 700 to 750 minutes for a single day. The sunlight period is relatively high which make this location suit for installation of SEGS.

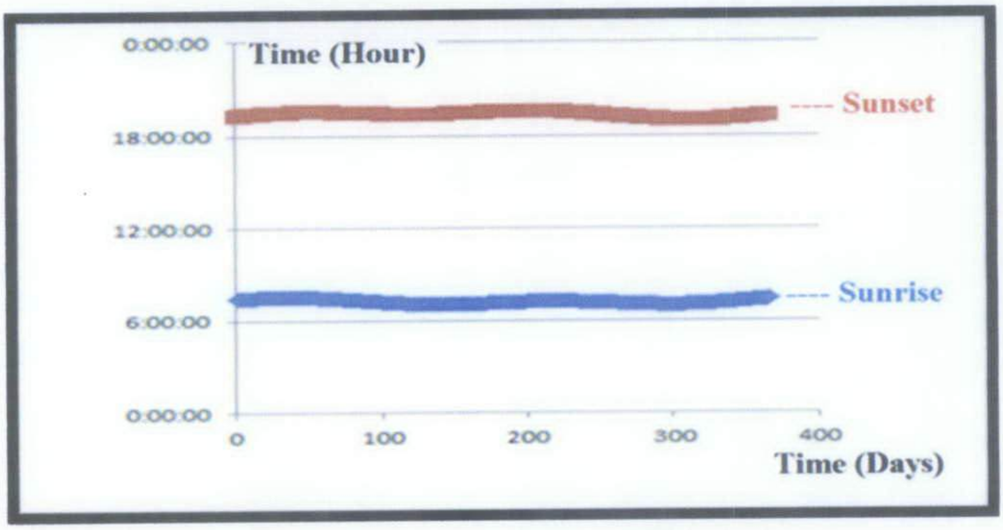

Figure 32: Sunrise and Sunset.

Referring to the Figure 32, for the entire year the sunrise is approximately at 7 a.m and the sunset is approximately at 7 p.m. from this result, the of solar tracker should be turn 'ON' slightly before the sunrise to ensure it ready to track the sun. Next, the tracker must be turned 'OFF' after 7 p.m as there is no sunlight for energy generation and operating the tracker during night is a energy waste because motor consume energy.

4.2 Achievements

a. There are two options in controlling the turning direction of the DC motor using servo system:
   - Vary the input signal while fixing the FEEDBACK signal.
   - Vary the FEEDBACK signal while fixing the input signal.

b. The project successful eliminates the need of microcontroller to control the servo motor.

c. The project uses the light tracking method to align the solar collector toward the sunlight by using four LDRs as the sensor of the light source.

d. The Elevation servo and the Azimuth servo manage to move the solar collector toward the sunlight effectively.

e. There is one way to optimize the alignment of solar collector toward the sunlight :
   - Optimize the sensor (LDRs).

f. The prototype has achieved project objective as solar tracking system.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Solar geometry is the factors that determine the potential penetration of solar energy throughout the day. The knowledge gain produces many methods and solutions in designing the solar tracking system. Among the available methods, best alternative had been chosen to be the final design.

Finally, this project presents a simple and effective way in controlling a sun tracking system without microprocessor system. The prototype demonstrates a working solution to maximize the output of SEGS with perfect position for solar collector at the point of maximum light intensity. All the objectives are achieved.

5.2 Recommendation

Based on the project, small servo motor was used with low torque capability. So, in larger scale utilization, there is a need to use larger motor to drive a bigger torque. However, selection of motor should be considering the operation cost in term of power consumption, there should be high energy generation compared to its consumption to define a good SEGS.

One of the best ways instead of using bigger motor is using gearing system. The advantage of gear system is to improve the ability of small motor to drive a big load. Furthermore, gearing system will not affect the efficiency of the tracker theoretically because this gear will decrease the motor speed which is not too important as sun move slowly

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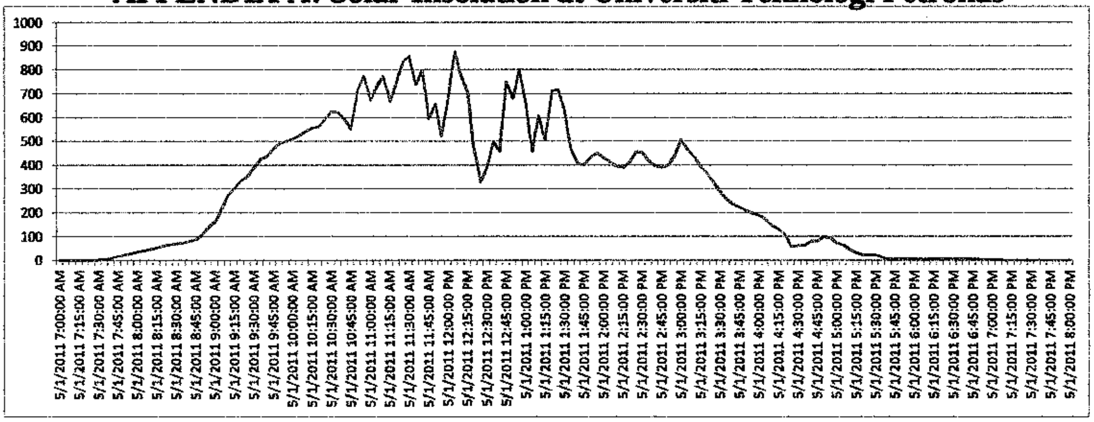
APPENDIX A: Solar Insolation at Universiti Teknologi Petronas



5/1/2011 7:00:00 AM	0
5/1/2011 7:05:00 AM	0.2
5/1/2011 7:10:00 AM	0
5/1/2011 7:15:00 AM	0
5/1/2011 7:20:00 AM	0
5/1/2011 7:25:00 AM	0.36
5/1/2011 7:30:00 AM	1.64
5/1/2011 7:35:00 AM	4.64
5/1/2011 7:40:00 AM	11.37
5/1/2011 7:45:00 AM	17.56
5/1/2011 7:50:00 AM	24.09
5/1/2011 7:55:00 AM	30.39
5/1/2011 8:00:00 AM	36.76
5/1/2011 8:05:00 AM	41.82
5/1/2011 8:10:00 AM	47.88
5/1/2011 8:15:00 AM	53.33
5/1/2011 8:20:00 AM	62.33
5/1/2011 8:25:00 AM	67.19
5/1/2011 8:30:00 AM	70.48
5/1/2011 8:35:00 AM	75.68
5/1/2011 8:40:00 AM	81.71
5/1/2011 8:45:00 AM	88.15
5/1/2011 8:50:00 AM	107.8
5/1/2011 8:55:00 AM	141.41
5/1/2011 9:00:00 AM	164.01
5/1/2011 9:05:00 AM	213.66
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5/1/2011 9:15:00 AM	303.46
5/1/2011 9:20:00 AM	334.66
5/1/2011 9:25:00 AM	352.66
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5/1/2011 10:40:00 AM	592.91
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5/1/2011 10:50:00 AM	718.18
5/1/2011 10:55:00 AM	773.83
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5/1/2011 11:20:00 AM	744.9
5/1/2011 11:25:00 AM	832.06
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5/1/2011 11:40:00 AM	797.3

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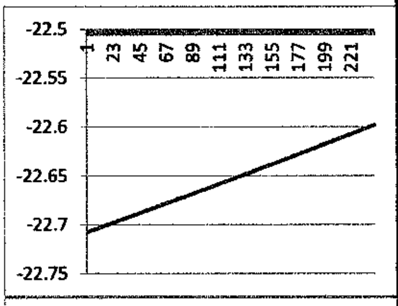
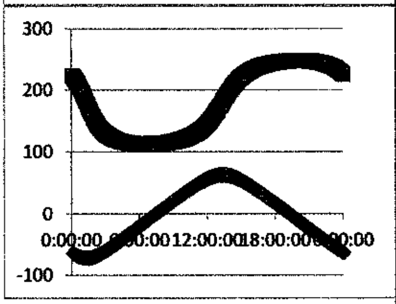
APPENDIX B: Solar Calculations for 1 Day at Universiti Teknologi Petronas

Latitude (+ to N)	4.386
Longitude (+ to E)	100.979
Time Zone (+ to E)	8
Date	1/5/2011





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APPENDIX C: Solar Calculations for 1 Year at Universiti Teknologi Petronas

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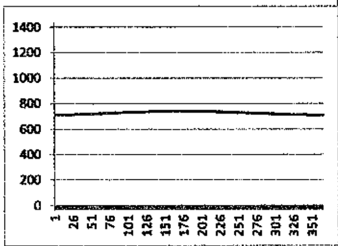
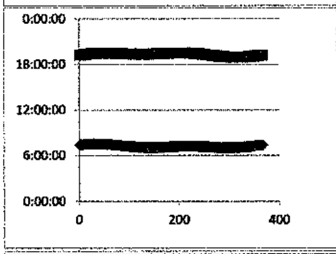
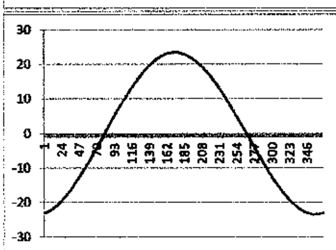
Time Zone (+ to E)	8
Local Time (hrs)	12:00:00
Year	2011







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1/3/2011	12:00:00	-22.85828946	7:24:05	19:16:31	712.4319571	56.44475527	145.1082277
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12/1/2011	12:00:00	-21.73531902	7:08:17	19:01:28	713.1789487	59.4383909	149.3260803
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12/3/2011	12:00:00	-22.03802171	7:09:09	19:02:08	712.9784979	59.08867736	149.3619105
12/4/2011	12:00:00	-22.17880259	7:09:36	19:02:29	712.8850487	58.92080682	149.3631674
12/5/2011	12:00:00	-22.31243885	7:10:03	19:02:50	712.7962089	58.75773446	149.3536259
12/6/2011	12:00:00	-22.43886099	7:10:30	19:03:13	712.7120442	58.59956084	149.3335071
12/7/2011	12:00:00	-22.55800265	7:10:58	19:03:36	712.6326179	58.44638254	149.3030249
12/8/2011	12:00:00	-22.66980069	7:11:26	19:03:59	712.5579908	58.29829223	149.262386
12/9/2011	12:00:00	-22.77419531	7:11:54	19:04:24	712.4882203	58.15537859	149.2117904
12/10/2011	12:00:00	-22.87113011	7:12:23	19:04:48	712.4233613	58.01772639	149.1514313
12/11/2011	12:00:00	-22.96055223	7:12:52	19:05:14	712.3634652	57.88541641	149.0814952
12/12/2011	12:00:00	-23.0424124	7:13:21	19:05:40	712.3085801	57.75852554	149.0021621
12/13/2011	12:00:00	-23.11666504	7:13:51	19:06:06	712.2587507	57.6371267	148.9136058
12/14/2011	12:00:00	-23.18326833	7:14:20	19:06:33	712.2140179	57.52128888	148.8159937
12/15/2011	12:00:00	-23.24218429	7:14:50	19:07:00	712.1744192	57.41107714	148.7094874
12/16/2011	12:00:00	-23.29337885	7:15:20	19:07:28	712.1399881	57.30655261	148.5942423
12/17/2011	12:00:00	-23.33682188	7:15:50	19:07:56	712.110754	57.2077725	148.4704083
12/18/2011	12:00:00	-23.37248729	7:16:20	19:08:25	712.0867424	57.1147901	148.3381292
12/19/2011	12:00:00	-23.40035303	7:16:50	19:08:54	712.067975	57.02765479	148.1975437
12/20/2011	12:00:00	-23.42040117	7:17:20	19:09:23	712.0544688	56.94641204	148.0487848
12/21/2011	12:00:00	-23.4326179	7:17:50	19:09:52	712.046237	56.87110344	147.8919801
12/22/2011	12:00:00	-23.43699359	7:18:19	19:10:22	712.0432883	56.80176667	147.7272521
12/23/2011	12:00:00	-23.43352277	7:18:49	19:10:52	712.0456272	56.73843557	147.5547181
12/24/2011	12:00:00	-23.42220418	7:19:19	19:11:22	712.053254	56.68114009	147.3744903
12/25/2011	12:00:00	-23.40304074	7:19:48	19:11:52	712.0661645	56.62990635	147.1866761
12/26/2011	12:00:00	-23.37603957	7:20:17	19:12:22	712.0843503	56.58475661	146.9913777
12/27/2011	12:00:00	-23.34121196	7:20:46	19:12:52	712.1077989	56.54570935	146.7886926
12/28/2011	12:00:00	-23.29857338	7:21:15	19:13:23	712.1364933	56.51277922	146.5787135
12/29/2011	12:00:00	-23.24814342	7:21:43	19:13:53	712.1704125	56.48597708	146.3615284
12/30/2011	12:00:00	-23.18994579	7:22:11	19:14:23	712.2095312	56.46531006	146.1372203
12/31/2011	12:00:00	-23.12400825	7:22:38	19:14:54	712.2538205	56.45078149	145.9058679
1/1/2012	12:00:00	-23.05036259	7:23:05	19:15:24	712.3032469	56.44239099	145.6675449

M51660L

APPENDIX D: M51660L

SERVO MOTOR CONTROL FOR RADIO CONTROL

ESCRIPTION

ıe M51660L is a semiconductor integrated circuit for use in servo ›tor control in radio control applications.
ıused in a 14-pin molded plastic zig-zag inline package (ZIP), the ;1660L contributes to the miniaturization of the set.
ıe built-in voltage regulating circuit, and the differential mparator used in the comparator circuit provide the M51660L th extremely stable power supply voltage fluctuation aracteristics and temperature change characteristics.

:ATURES

Small circuit current ······································· 3.5mA typ. (When output is off)
Excellent power supply and temperature stability
Simple setting of dead band
Includes protection circuit for continuous "H" level input

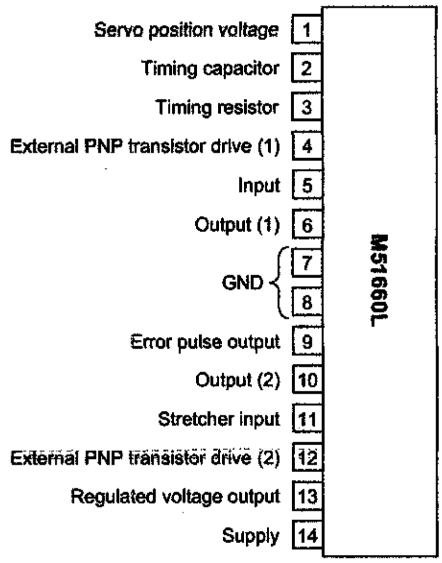
PPLICATION

gital proportional system for radio control, and servo motor ntrol circuit, etc.

ECOMMENDED OPERATING CONDITIONS

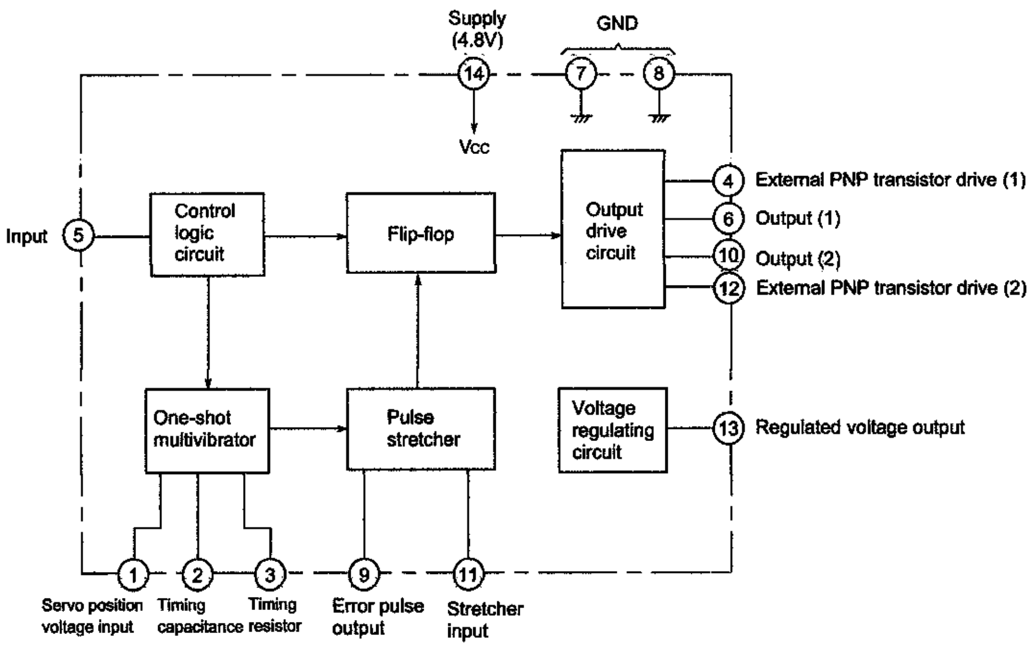
Supply voltage range ·····································3.5 – 7V
Rated supply voltage ·· 4.8V

PIN CONFIGURATION (TOP VIEW)



Outline 14P5A

3LOCK DIAGRAM



›SOLUTE MAXIMUM RATINGS (Ta = 25°C, unless otherwise noted)

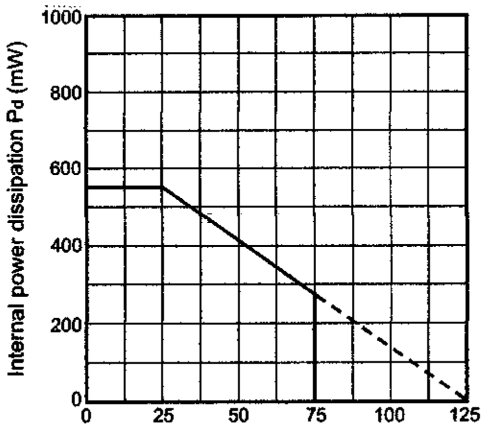
Symbol	Parameter	Conditions	Ratings	Unit
cc	Supply voltage		7.5	V
) SINK	Output sink current		500	mA
) SOURSE	Output source current		200	mA
d	Power dissipation		550	mW
θ	Thermal derating range	Ta ≥ 25°C	5.5	mW/°C
opr	Operating temperature		-20 – +75	°C
stg	Storage temperature range		-40 – +125	°C

.ECTRICAL CHARACTERISTICS (Ta = 25°C and Vcc = 4.8V, unless otherwise noted)

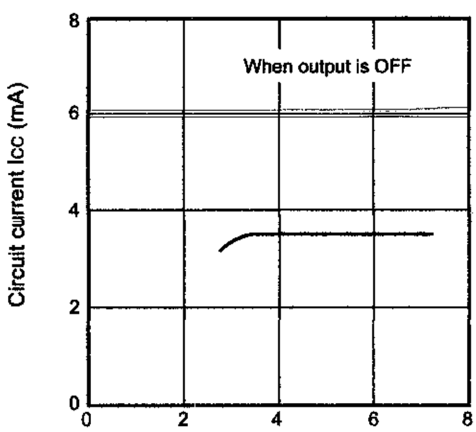
Symbol	Parameter	Test conditions	Limits			Unit
			Min.	Typ.	Max.	
cc	Circuit current	When output is OFF		3.5	5	mA
		When output is ON		20		
'OL	Output voltage "L"	Io SINK = 100mA		0.1	0.2	V
		Io SINK = 400mA		0.4	0.7	
'OH	Output voltage "H"	Io SOURCE = 100mA	3.4	3.8		V
'NP	External PNP transistor Drive current		30			mA
'Reg	Internal regulated supply voltage		2.3	2.45	2.6	V
Reg	Internal regulated supply output current				3.0	mA
'DB	Minimum dead band width	RDB = 510Ω, Cs = 0.1μF			1.5	μs

'PICAL CHARACTERISTICS (Ta = 25°C, unless otherwise noted)

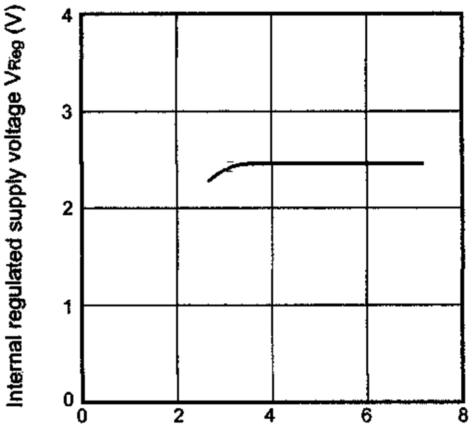
Thermal derating (maximum rating)



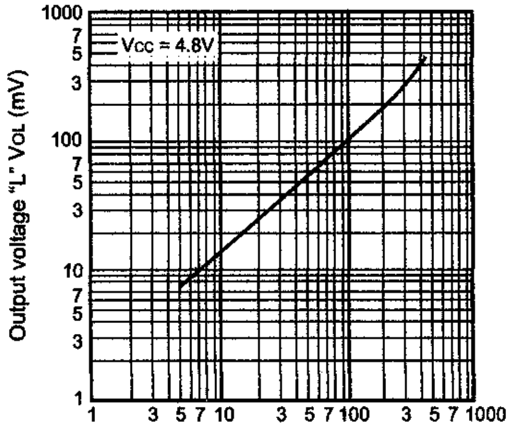
Circuit current vs. supply voltage



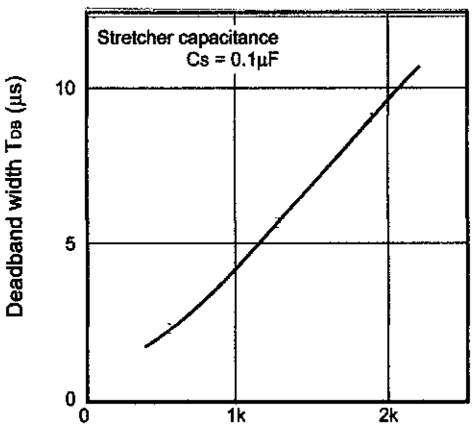
Internal regulated supply voltage vs. supply voltage



Output voltage "L" vs. output sink current

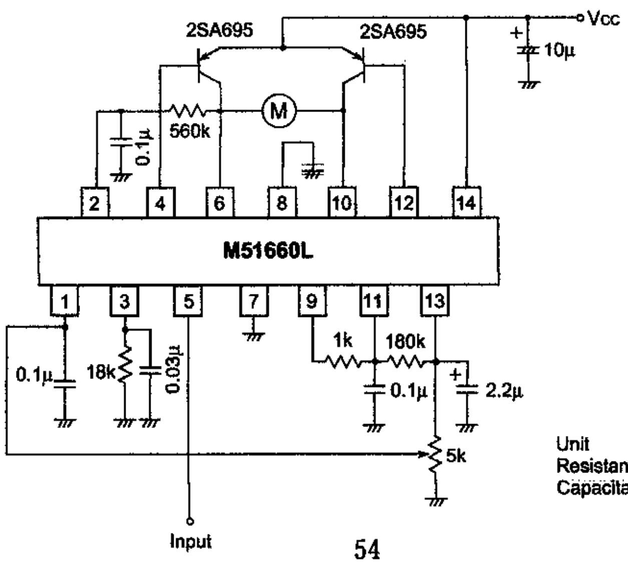


Deadband width vs. deadband resistance



PPLICATION EXAMPLE

Servo motor control circuit for radio-controlled



Unit
Resistance : Ω
Capacitance : F

:CHNICAL APPLICATION NOTES
N DESCRIPTION

Servo Position Voltage Input Pin (Pin ①)
Connect the potentiometer terminal for position detection that follows the output axis. Compare this voltage with the voltage of the triangular wave of pin ② and drive the motor. A capacitor of approximately 0.1μF should be connected for noise prevention.

Timing Capacitor Pin (Pin ②)
Connect a capacitor that will generate a triangular wave by constant current charging. A typical value is 0.1μF. Also connect a feedback resistor from the output here.

Timing Resistor (Pin ③)
Connect a resistor that will determine the value of the constant current of pin ②. A resistor of 18kΩ will yield a current of 1.0mA. A capacitor of approximately 0.03μF should be connected in parallel with the resistor to increase stability.

External PNP Transistor Drive ① (Pin ④)
Connect to the base of the external PNP transistor.

Input Pin (Pin ⑤)
Operate with a positive pulse of peak value 3V or greater.

Output ① Pin (Pin ⑥)
Connect a feedback resistor between this pin and pin ②.

Ground (pins ⑦ and ⑧)

Error Pulse Output pin (Pin ⑨)
Connect a resistor between this pin and pin ⑪. The dead band will change according to the value of this resistor.

Output ② pin (Pin ⑩)
This is the output ② pin.

. **Stretcher Input Pin (Pin ⑪)**
Connect the capacitor and resistor of the pulse stretcher section.

. **External PNP Transistor Drive ② (Pin ⑫)**
Connect to the base of the external PNP transistor.

. **Regulated Voltage Output Pin (Pin ⑬)**
This is the output of the internal regulated supply voltage. Make connections from this pin to a potentiometer or pulse stretcher resistor. Connect a capacitor of approximately 2.2μF for stability.

. **Supply Voltage (Pin ⑭)**
The supply voltage exhibits uniform characteristics from 3.5V to 7V. Connect a capacitor of approximately 10μF.

APPENDIX E: GANTT CHART

Activity/Week	Semester 1													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Topic Selection	■	■												
Preliminary Research			■											
Preliminary Report				■										
Seminar					■				■					
Project Work						■	■	■	■	■	■	■	■	■
Progress Report							■							
Interim Report													■	
Oral Presentation														■

Activity/Week	Semester 2															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Project Work	■	■	■	■	■	■	■	■	■	■	■	■				
Progress Report								■								
Draft Report													■			
Final Report (Soft)														■		
Technical Paper														■		
Viva															■	
Final Report															■	■