TECHNISCHE UNIVERSITÄT
CHEMNITZ

Energy –Efficient Solar Model Improvement Using Motor Calibration Preference

Master Thesis

For

The fulfillment of the academic degree

M.Sc. in Automotive Software Engineering

Faculty of Computer Science

Professorship of Computer Engineering

July 2015

Submitted by: Abhishek Sahni, Matr. Nr: 307077

Supervisors: Prof. Dr. Wolfram Hardt
Dipl.-Ing. Daniel Reissner

Abhishek Sahni (abhishek.sahni@s2012. tu-chemnitz.de)
Energy –Efficient Solar Model Improvement Using Motor Calibration Preference

Master Thesis, Technische Universität Chemnitz, July 2015

Acknowledgment

This Master thesis would not exist without the extensive support and encouragement of many people. I express my cordial gratitude to my thesis supervisor **Dipl.-Ing. Daniel Reißner** for his useful ideas, suggestions and contribution, without him the research wouldn't have completed on time. Special thanks go to **Prof. Dr. Wolfram Hardt** for his guidance and providing me an opportunity to accomplish my research work under his professorship. In addition to these and all other people at the Technische Universität Chemnitz I might not forget my family that tolerated my absence in several activities in the family life. I would like to thank my friends for their encouragement and also for reviewing my document. The last but not the least I would like to thank all my friends for asking me for the progress of this work and thus providing a kind of staying power.

Contents

List of Figures

Chapter 1

Introduction

1.1 Motivation

The amount of force or power when applied can move one object from one position to another or the capacity of a system to do work is called energy. It exists in everybody whether they are human beings or animals or non-living things.

There are many forms of energy such as: kinetic, potential, light, sound, gravitational, elastic, electromagnetic or nuclear. According to the law of conservation of energy, any form of energy can be converted into another form and the total energy will remain the same. Energy can be broadly classified into two main groups' i.e. renewable and non-renewable resources. Many of the renewable energy a technology have been around for years, and as the time go by, are increasing in efficiency.

1.2 Resources of Energy

Renewable Energy

Renewable energy is the energy which is generated from natural sources i.e. sun, wind, rain, tides and can be generated again and again as and when required. They are available in plenty and by far the cleanest sources of energy available on this planet. For example, the energy that received from the sun can be used to generate electricity. Similarly, energy from wind, geothermal, biomass from plants, tides can be used to fulfill our daily energy demands.

Figure 1.1: Renewable resouces of Energy

1.3 Non-Renewable Energy

Non-Renewable energy is the energy which is taken from the sources that are available on the earth in limited quantity and will vanish fifty-sixty years from now. Non-renewable sources are not environmental friendly and can have serious effect on our health. They are called non-renewable because they cannot be re-generated within a short span of time. Non-renewable sources exist in the form of fossil fuels, natural gas, oil and coal.

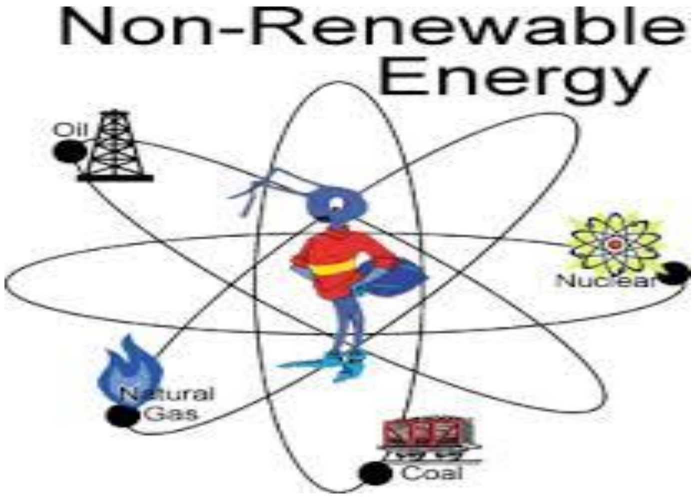


Figure 1.2: Non-Renewable resouces of Energy

Why Should we Conserve Energy?

Energy needs to be conserved to protect our environment from drastic changes, to save the depleting resources for our future generations. The rate at which the energy is being produced and consumed can damage our world in many ways. In other words, it helps us to save the environment. We can reduce those impacts by consuming less energy. The cost of energy is rising every year. It is important for us to realize how energy is useful to us and how can we avoid it getting wasted.

To start saving energy is not a big thing at all. We can start saving the energy from our home itself, just by turning off the lights during day hours, washing clothes in cold water or using public transport instead of using our own vehicle and later can implement these things on much wider scale at society level, then at city level then district level and finally at country level. With so many alternatives and so many techniques about there, if millions of people like us start doing these things, it will help us to save much more money and also help the environment.

1.4 Solar Energy

Solar energy refers to the sun's light or radiated energy that has been transformed to electrical power and is a very clean form of energy that doesn't pollute the environment as most other sources of energy do. Solar energy is categorized into direct or indirect as well as passive or active. It can also be classified according to the mode of harnessing it and these are "Solar Photovoltaic", "Solar Thermal and heat exchange". Since most renewable energy is ultimately “SOLAR ENERGY” because it has an endless resource of energy which can be utilized for useful work that is directly collected from sunlight. Energy is being released by the sun as electromagnetic waves. The energy which reaches the earth’s atmosphere consists of about 8% UV radiation, 46% visible light and 46% infrared radiations.

History of Solar Energy

It all started when everyone started sending satellites. Many countries were sending satellites into the atmosphere. These satellites used to have arrays of solar panels to generate power to them. So in early days lots of money was invested into making solar panels durable and reliable. But replacing them was very difficult. Once the space race ended, investment in solar technologies slowed down. Solar panels were least positioned in the race of alternate source of energy. They were too expensive for the main household stream marketplace, and there were pressured to make them more affordable.

Then global warming and climate change began to emerge. The oil crisis of the early 70’s, the war in the Middle East, pollution, acid rain, the melting glaciers, the formed hole in the ozone and endangered species getting decreased. Suddenly, there was a need for a non-damaging, reliable energy producing technology. We are now in a very interesting time to both for solar energy and for our rest of the world. The Kyoto protocol has been ratified by 174 countries and the government has invested large amounts to encourage solar energy adoption. And solar manufacturers have begun their own solar race to see who can be the first to make solar cheaper than coal. Solar energy has been evolving steadily over the last few decades. We are now in a situation where the demand for solar energy is bigger than the required supply. This puts the solar energy industry in a very interesting and important position.

How Solar Energy Works

There are several processes that are involved in the conversion of the sun's radiation into solar energy and then to electrical energy that is useful for household or business. These processes make use of solar panels and although one of them focuses on the heat from the sun, whereas the other focuses on the light from the sun. An efficient solar panel focuses on both the process that focuses on the sun’s heat is called solar thermal and the solar energy works here by harnessing the heat. These systems used to convert this heat by making use of mirrors or reflectors to concentrate it to very intense heat in a similar way that a magnifying glass is used to start a fire. The heat is concentrated to a liquid in a container mostly water or other liquids that retain heat longer than water. Once these liquids are heated to the boiling point they start producing steam and it is this steam that is used to turn turbines, as a result the turning motion of the turbines is used to generate electricity. This motion creates electricity in a similar way as setting up a coiled wire and rotating it between two magnets to generate an electric current. The second process that focuses on the sun's light is called photovoltaic process and makes use of photovoltaic cells to capture light and convert it to direct current. This is done by excitation of electrons, so that as they flow and a form of current is generated. The principal components of a photovoltaic cell are semiconductors made of silicon crystals that have been doped with other elements such as Phosphorus or Boron The bottom layer is doped with Boron and is termed as the p-type semiconductor while the upper layer is doped with Phosphorus and is termed as the n-type conductor and the space between them is called the P-N junction.

Once the sun's light enters the PV cells, its energy is transferred to electrons that are then knocked loose in both semiconductors and they are attracted to the p-type semiconductor however, the electric field at the junction makes this difficult. When you connect to an external circuit you create a path for the flow of electrons which is actually the current necessary for electricity. The current generated here is Direct and needs to be converted to a usable form and this conversion is done by use of a device referred to as an inverter although this leads to some loss of energy.

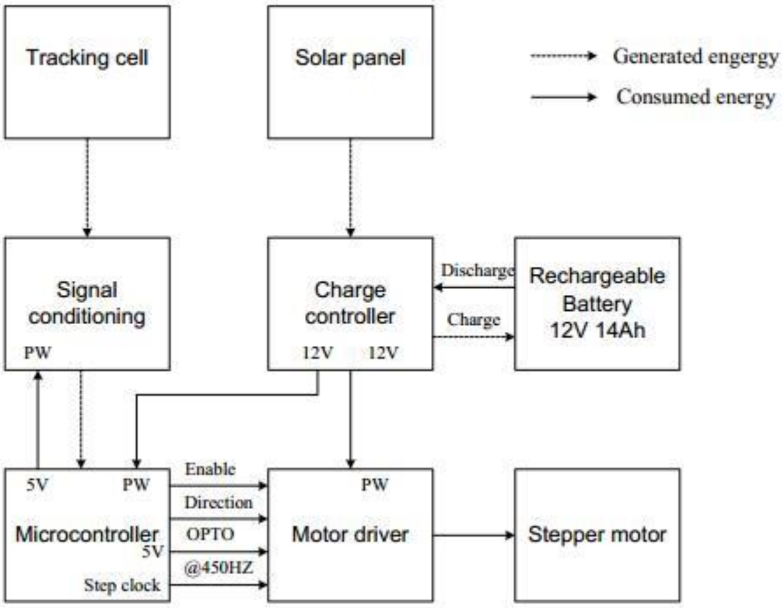


Figure 1.3: System Block Diagram

1.5 Project Information

To use solar energy instead of fossil fuel is one of the best options. But on the other hand, installation of solar panels is costly in comparison to the energy they produce. One of the reasons is they are aligned in one direction only. While the sun moves from east to west, solar panel cannot absorb full energy just because sun rays are diagonal to solar panel and not straight. If we can rotate the solar panel according to the sun's direction, we can make solar panel more efficient.

This project can overcome this problem. For this idea we need to track sun's position. We are using a smartphone because of several reasons for this purpose. It can find the highest luminance by light sensor. Find the coordinates of this orientation using gyroscope sensor and save this data to a remote database for further use to rotate the solar panel in the sun ray's direction. This document concentrates on explaining how an Android based smartphone can be used as various sensors and gives all necessary information to rotate the solar panel in the right direction.

Fossil fuel goes down day by day. This is not the only disadvantage of fossil fuel. It produces a lot of pollution, which is responsible for global warming. We must find some alternative ways to overcome contamination and perishable sources. One of the best alternatives of this problem is to use the sun as an energy source, because it gives a lot of energy without any cost. Solar panel (contains silicon cells) is a device which converts light into electric energy (photovoltaic effect). At some point we are using solar panels, but the solar panels which are currently available are not 100% efficient.

One of the reasons is that they are fitted in a fixed direction (orientation).On the other hand, sunlight is not easily available, especially in the regions which are far away from the equator. Also sun's position would change over the season and time. Because of these around some percent of energy can be lost. In addition, the solar panel is a bit costly and covers much area compare in energy it produces. Because of all these reasons, it is quite better if we make solar panel as much efficient as we can. When the sun moves from east to west, sunlight rays become diagonally. Because of this sunlight reduces and solar panel can be less efficient.

To overcome this problem we could develop a system which can automatically rotate the solar panel in the direction of the sun. If we do so, we can make solar panel 10% (in winter) to 40% (in summer) more efficient. To implement this project we need to put some sensors (i.e. Light sensor, gyroscope) on the solar panel. Along with this we also need to save sensor's data (values) to some database, in order to use further. This could be tricky and time consuming. So to use a smartphone, which is already having all these sensors and also can save data easily is the best option. The choice of smartphone is also important because we have to make our program according to our requirements.

The hardware design and implementation of a system that will ensure a proper profile of the solar photovoltaic panels with respect to the sun in order to gain maximum luminance can be gained on the panels. Renewable energy is rapidly gaining importance as an energy resource as fossil fuel prices fluctuate and may be scarce for the future generations. The unique feature of the proposed system is that instead of taking the earth as its reference, it takes the sun as a reference path. GPS constantly monitors the sunlight and rotates the panel towards the direction where the intensity of sunlight is maximized so that solar panels can get the maximum luminance. The GPS perform the task of sensing the changes in the position of the sun, which is dealing with the respective change in the solar panel's position by switching on and off the motor and the control circuit does the job of getting the input from the sensor. GPS data gives information to the motor to run in a specific direction to observe the change in the position of the sun and get the maximum luminance out of that data.

In every area the sun is a cheap source of electricity because instead of hydraulic generators it uses solar cells to produce electricity. The output of solar cells depends on the intensity of sunlight and the angle of incidence. To get maximum efficiency; the solar panels must remain in front of the sun during the whole day. But due to the rotation of the earth, those panels can't maintain their position always in front of the sun. This problem results in a decrease of their efficiency. So to get constant output intensity, an automatic system is required which should be able to constantly rotate the solar panels.
The Automatic Solar Tracking System (ASTS) was made as a prototype system to solve the problems, mentioned above. It is completely automatic and keeps the panel in front of the sun until the sunlight is visible. Here we also take up the task which will not allow the solar panels to orient in the wrong direction. This clearly states that it should only move from East to West direction.

The unique feature of the tracking system is that instead of take the earth as in its reference and guiding source, it takes the sun as its reference. We place some Programmable Logic Controller (PLC) sensors which will constantly look out for the sunlight and rotate the panel towards the direction where the intensity of sunlight is higher. In case the sun gets invisible, for instance, in cloudy weather, then without tracking the sun the solar tracker keeps rotating the solar panel in the opposite direction to the rotation of earth. But its speed of rotation will be related to that of earth.

In this documentation we are going to access data from websites which are having data related to sun's trajectory path values those are azimuth elevation angle with respect to local time of that location as well as sun's risen fall time and also with coordinates of that location (Longitude and Latitude) so now we are mapping this data values to locally associated database server. With the help of these data from data server solar panels are oriented according to the angles defined by web server. So therefore we get accuracy in tracking sun's path which is the main principle of solar tracking. In this paper we proposed a prediction model in order to get efficient power by tracking sun for mapping.

1.6 Document layout

This document is divided into several chapters, which handle different topics. Chapter 1 introduces the topic and requirement of this task. Chapter 2 discusses the backgrounds of solar panel focusing, android required for this thesis, the available technology for motor control preference and an algorithm for evaluating max luminance position. This is followed by chapter 3 about the developed concept for maximum luminance tracker. This chapter has discussed the selection of parameters for evaluating the position and hardware-software architecture for implementation. The chapter 4 provides implementation details on android studio, arduino server and NetBeans platform. This chapter starts with the programming of a servo motor using the arduino server and follows the implementation steps. The software implementation using the android studio for developing an android application has been realized and the details have been discussed in this chapter. The movement of solar panel using the small energy efficient motor has also been discussed. Finally the result analysis for comparison of the existing and the current model with conclusion ends this document.

Chapter 2

State of the art

This chapter discusses about the overview of the related backgrounds and methods available for the evaluation of chain elongation. In order to understand the technical details it is important to have an overview of its background.

2.1 Working of Solar Panel and Stand Alone System

The system consists of control circuits which is supplied with the output of light sensors and based upon these inputs it controls the operation of the geared motor. Also the circuits consume power implemented with electronic components (4).

A photovoltaic module or photovoltaic panel is a packaged interconnected assembly of photovoltaic cells, also known as solar cells. A typical silicon PV cell is composed of a thin wafer consisting of an ultra-thin layer of phosphorus-doped (N-type) silicon on top of a thicker layer of boron-doped (P type) silicon Regardless of size, a typical silicon PV cell produces about 0.5 – 0.6 volt DC under open-circuit and no-load conditions. The current (and power) output of a PV cell depends on its efficiency and size (surface area), and is Proportional to the intensity of sunlight striking the surface of the cell. The photovoltaic module, known more commonly as the solar panel, uses light energy (photons) from the sun to generate electricity through the photovoltaic effect.

Figure 2.1: Hardware model of stand alone system

A Proximity sensor can detect objects without physical contact. A proximity sensor often emits an electromagnetic field or beam and look for changes in the field. The object being sensed is often referred to as the proximity sensor's target. Different proximity sensor targets demand different sensors. For example, a capacitive or photoelectric sensor might be suitable for a plastic target; an inductive proximity sensor requires a metal target.

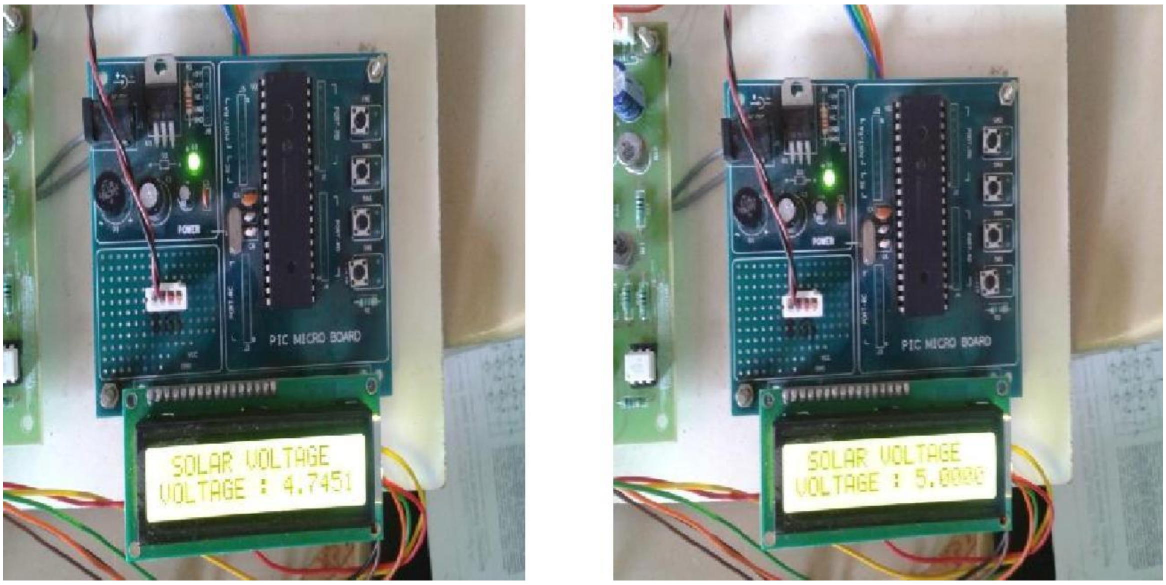


Figure 2.2: Result according to sun position

In the time period of Morning 8am to 12 pm the panel moves according to the sun direction. So the maximum value of the output is 4.7V. The panel moves according to the sun direction as per the solar panel parameters each cell giving maximum of 0.6v and minimum 0.2V.In the time period of afternoon 12 pm to 4pm the panel move according to the sun direction. so the maximum value of the output is 5.0000V. The panel moves according to the sun direction as per the solar panel parameters each cell giving maximum of 0.6v.

The hardware of an automatic solar energy tracking system designed and implemented which ensured 25 to 30% of more energy conversion than the existing static solar module system. Several tracker technologies currently are available on the market. However, the different tracker technologies come with different characteristics such as the additional cost of maintenance, added cost of solar power unit at installation, accuracies of tracking, reliability and effectiveness in improving efficiency. The designed system requires minimum maintenance with a practically good level of improvement of system efficiency for the comparative cost of acquisition of systems of similar output capacity.

2.2 Solar Irradiance Prediction System (SIPS)

There are many types of prediction models in existence but SIPS is a much productive option. The main role of the prediction system is to track the solar irradiation in order to get maximum efficiency. Using these types of systems accuracy in power generation compared to general state of the art models can be achieved.

Key features:

- Enable high-resolution solar irradiance forecast.
- Limiting the impact of fluctuations in power output.
- Better prediction for short period.
- Wireless sensor network is used.

Working Principle:

Initially the solar panel movement is based on Sun rise and fall time which is considered from the GPS values which are taken from the web server. The role of prediction model is to track the Sun in such a way that it should be able to get maximum luminance to generate power. In this model sun rise and fall time with luminance values in order to get maximum output are considered. By processing these two data values the new orientation of the solar panel is predicted which is determined by the controller using the motor drivers to rotate the panel towards the desired position respectively (7).

SIPS: Architecture

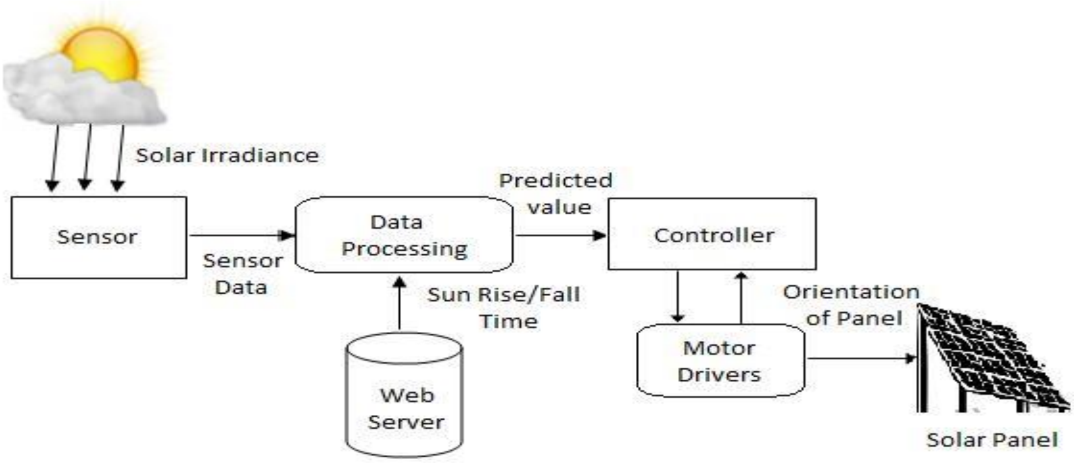


Figure 2.3: Architecture of Prediction system

Solar Tracking

Principle:

A good sun-tracking system must be reliable and able to track the sun at the right angle even in the periods of cloud cover. Over the past two decades, various types of sun-tracking mechanisms have been proposed to enhance the solar energy harnessing performance of solar collectors. Although the degree of accuracy required depends on the specific characteristics of the solar concentrating system being analyzed, generally the higher the system concentration the higher the tracking accuracy will be needed.

Types:

Taking into consideration of all the reviewed sun-tracking methods, sun trackers can be grouped into one-axis and two-axis tracking devices. Fig. 2.4 illustrates all the available types of sun trackers in the world. For one-axis sun tracker, the tracking system drives the collector about an axis of rotation until the sun central ray and the aperture normal are coplanar. Broadly speaking, there are three types of one-axis sun tracker:

1. **Horizontal-Axis Tracker** – The tracking axis is to remain parallel to the surface of the earth and it is always oriented along East-West or North-South direction.
2. **Tilted-Axis Tracker** – The tracking axis is tilted from the horizon by an angle oriented along North-South direction, e.g. Latitude-tilted-axis sun tracker.
3. **Vertical-Axis Tracker** – The tracking axis is collinear with the zenith axis and it is known as azimuth sun tracker.

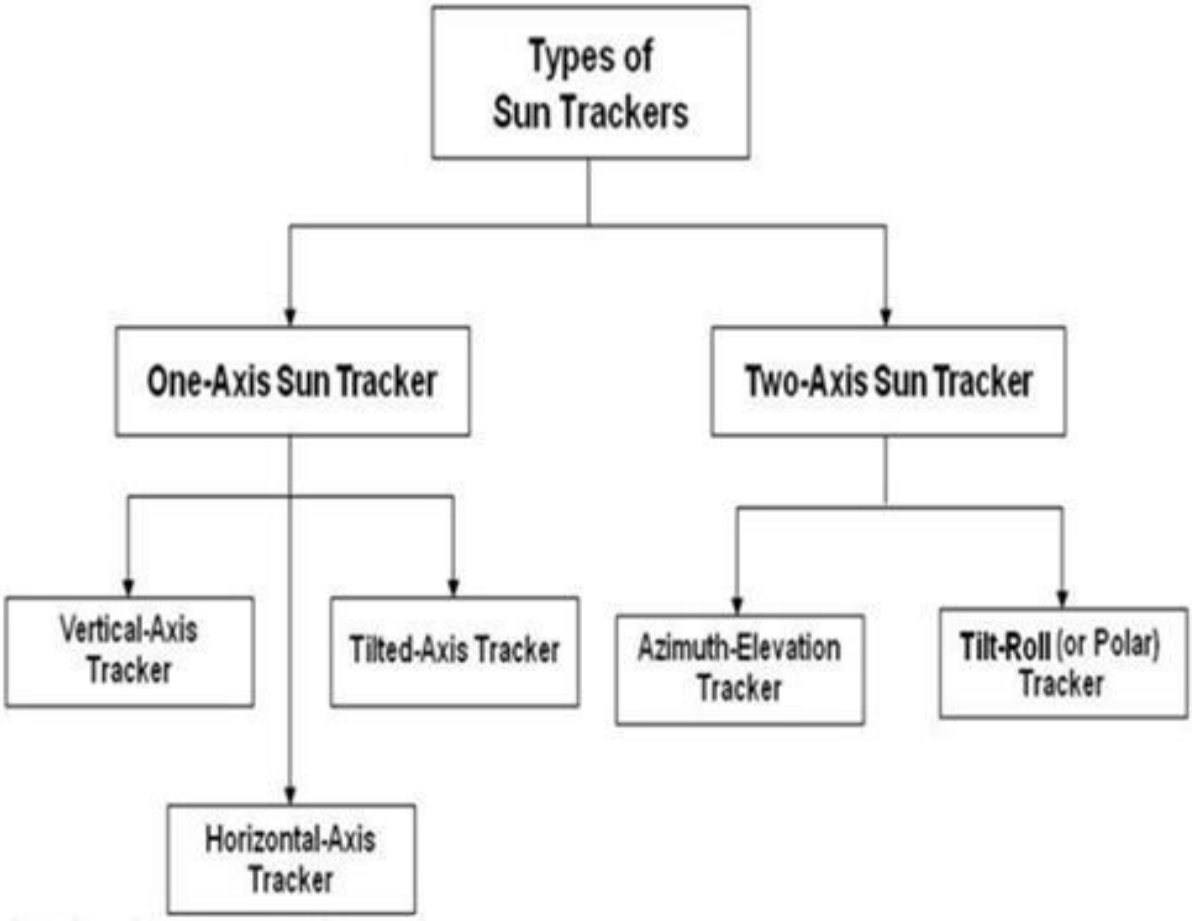


Figure 2.4: Types of Sun Trackers

There is no doubt that the dual axis solar tracker system increases the productivity by more than 40% but there are many factors which are affecting the performance of such systems. These factors include accuracy, reliability, tracking power, durability and cost. The proposed design discussed these factors from many practical viewpoints. The system has taken into account all the factors by calculating the sun location based on GPS data.

The main reason for the GPS data from external sources is to avoid the use of sensors to track the sun location. The critical assessments of the annual energy production of the system are also estimated.

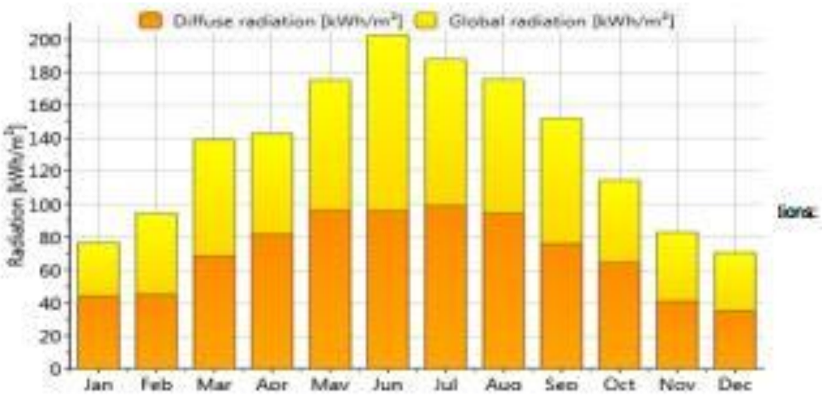


Figure 2.5: Solar Irradiation for test site

SIPS Comparison

The output generation graph with clouds as objecting the solar energy to fall on the photo voltaic panels and one with clear sky. From the below given figure we can easily trace out the inconsistency in the graph(7).

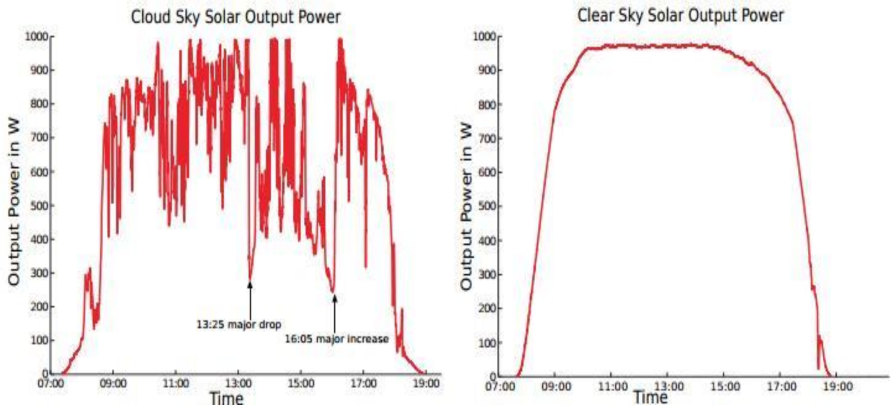


Figure 2.6: Solar power output for very cloudy day and clear sky conditions

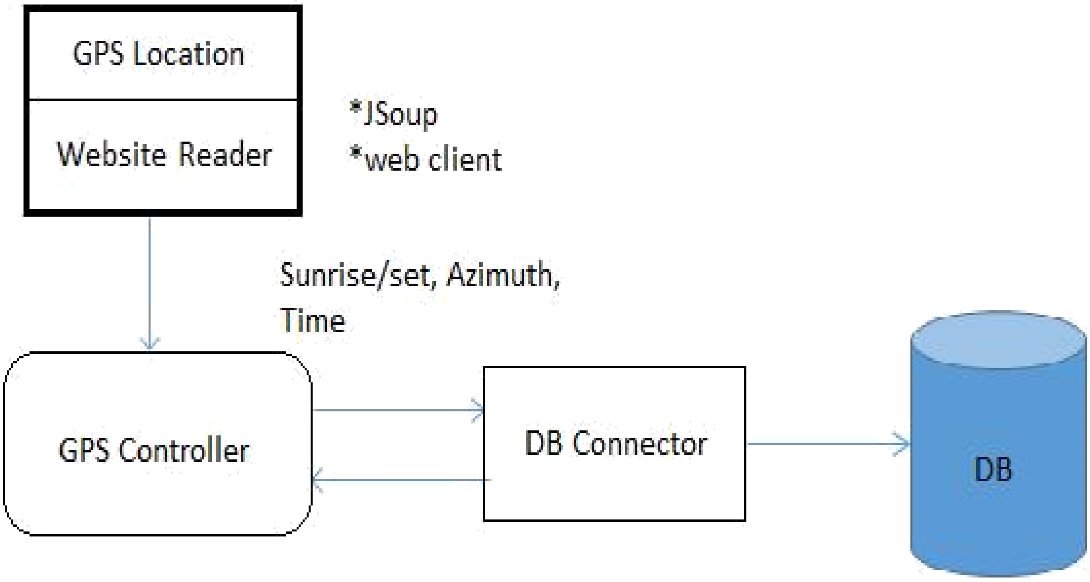


Figure 2.7: Block diagram of data storage system

This block diagram represents the storing the data values from website to local database through DB connector to DB. The main role of GPS controller use to define the values such as angles to solar panel so that solar panel oriented based on the given values and this GPS controller controls the rotation of solar panel. For this we develop a program with the help of NetBeans.

Solar Panel Angle Calculations

The solar panel should be perpendicular to the Sun. Sunlight direction changes regularly with changing seasons and weather.

Required Calculation:

SEASON	ANGLE / TILT CALCULATION
1) Winter	(Latitude*0.9) + 29 degrees
2) Summer	(Latitude*0.9) - 23.5 degrees
3) Spring & Fall	Latitude - 2.5 degrees

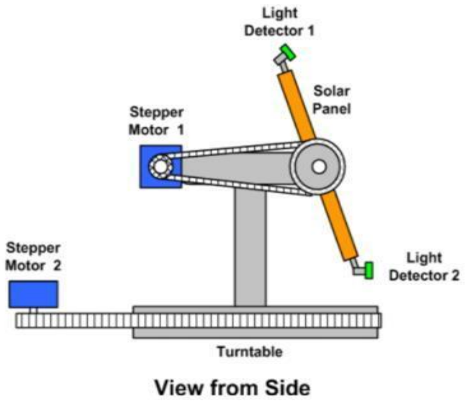


Figure 2.8: Solar Panel Setup

2.3 Motor Selection

There are many types of motor can be selected among. Currently, several types of motors being used in the area around the world are

- Step motor
- Servomotor
- AC asynchronous motor,
- Permanent magnetic DC servo motor,
- Permanent magnet brushless synchronous motor, etc.

Generally speaking, as the gear ratio is higher for the transmission system, motor control, precision has a very small impact to the tracking precision. For example, for a system with the gear ratio of 20000: 1, the tracker only covers an angle of 0.314mrad when a one complete circle is finished by the motor. Therefore, all kinds of the motor can satisfy the precision of the tracking system. However the future of each type of motor is different.

Figure 2.9: Stepper Motor

First of all, let’s take a look at the AC asynchronous motor. To use this motor, we need an encoder to locate the position of the tracker. AC asynchronous motor is in fewer prices. Even though it can achieve all the needed functions, AC asynchronous motor is too heavy, too large, and too low in efficiency to be installed. Also, for this type of motor, the torque at low speed is very small. In addition to these disadvantages, it needs the work frequency be above 5Hz to function properly. The possibility for us to use AC asynchronous motor in the future is eliminated.

Secondly, let's compare the features of DC Servomotor and AC Servomotor. There are two types of DC servomotor: motor with brush and motor without brush. A Motor with a brush is low in cost, simple in structure, and high in start torque. Also, it has a wide range of speed adjustment, is easy to control. Though it needs maintenance from time to time, it is very convenient to repair (replace the brush). However, it produces electromagnetic interfere.

Motor without brush is small in size, light in weight, high in output, fast in response, small in inertia, smooth in spinning, stable in output torque, low motor maintenance fee, high in efficiency, low in electromagnetic radiation, long life, and can be applied in different working environments.

However, it has a more complex control system. AC servomotor is also type of motor without brush. There are two types of AC servomotor: synchronous AC motor and asynchronous AC motor. Currently, synchronous AC motor is generally used in movement control.

2.4 Solar Trackers

It is a device for orienting a solar panel or concentrating a solar reflector or lens towards the sun. Photovoltaic cells, especially in solar cell applications, need very high degree of preciseness to ensure that the concentrated sunlight is directed exactly to the powered device. Precise tracking of the sun is observed through the systems with single or dual axis tracking.

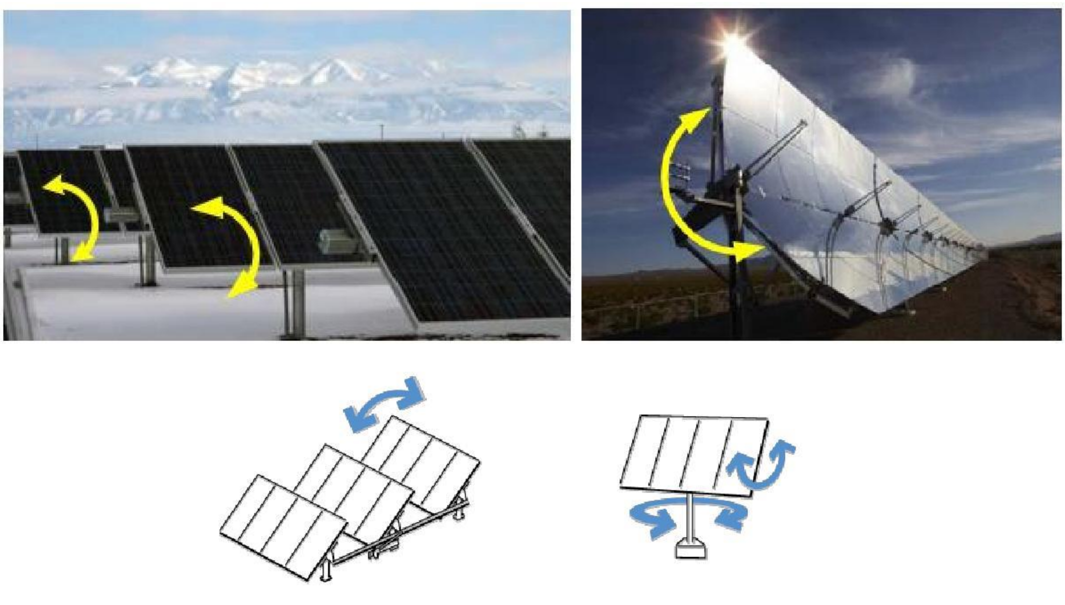


Figure 2.10: Single axis tracker and Dual axis tracker

Luminance controller

- Four direction changing luminance values
- Make model of unified circle angles for evaluation

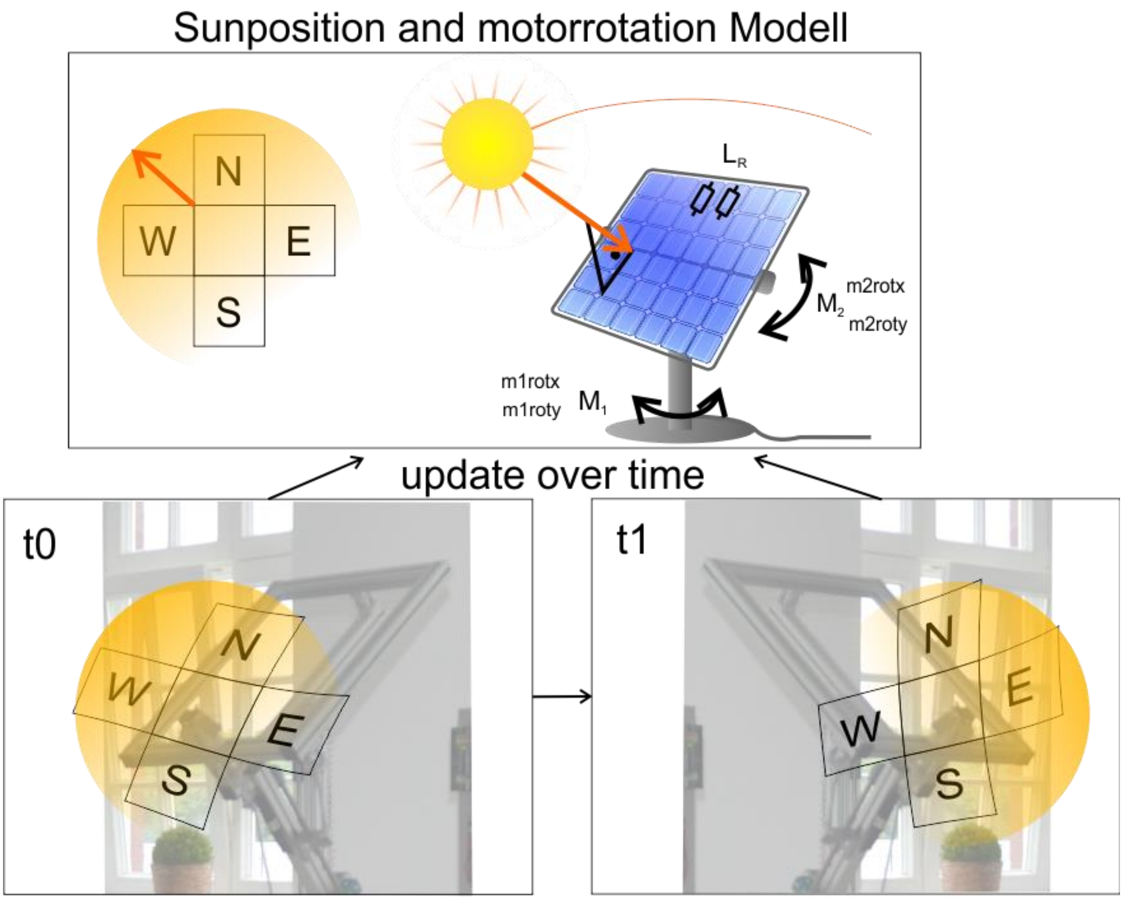


Figure 2.11: Sun position and motor rotation model

Parameters

- Detection rate
- Gradient forming
- Latency
- GPS

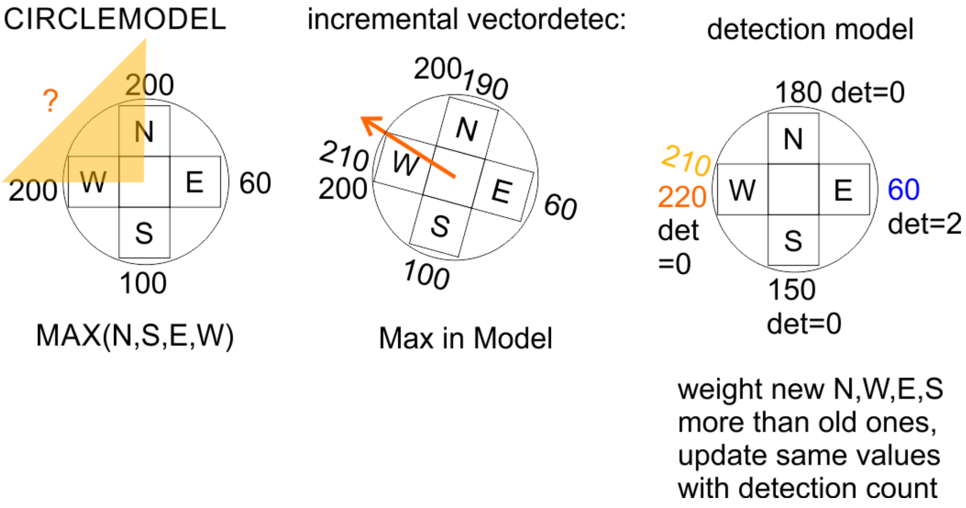


Figure 2.12: Parameters for circle model

Integrated Luminance

- Base band of gps
- height for much luminance
- low on tree/wall angle
- jitter from clouds

python program reading luminance values from database

spheral-luminance-preference

- construct model of homogen luminance intensities per angle
- allows for tracking, covering of areas for better results with tracing-smartphone-motor (detailing as needed)

- integrate all intensities gps, luminance and details in one sphere model
- choose ange with max radius to center

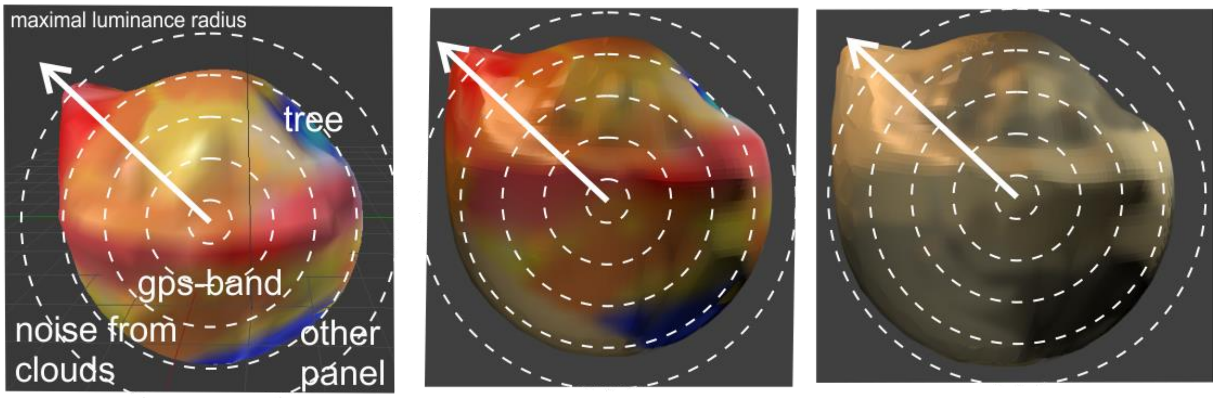


Figure 2.13: Integrated Luminance Model

Control of motor data and graphical evaluation

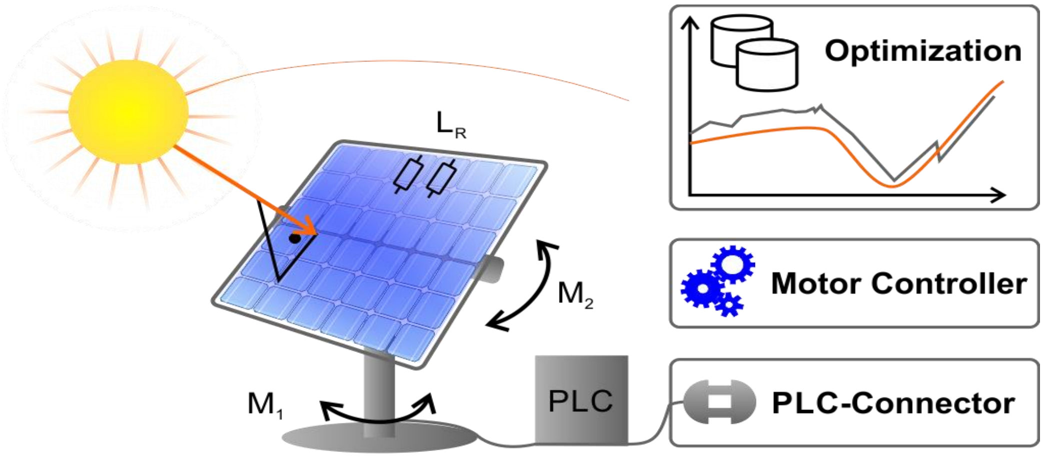


Figure 2.14: Motor Data control diagram

- Check relevant motor acceleration, energy-efficient intervals and avoid moving too much/ iterating.
- Consider weather prediction, too hot panel produces less power.
- GPS/Time Based rough realignment (evening->morning, place, season)
- Smartphone luminance sensor fine alignment
- Read Luminance, acc., GPS Sensors
- Transfer Data
- Local control evaluation

Motor movement minimization

In general rotation motor effort to high, robot based rotation of panels without motor
In case of cloud not moving to lightest point reasonable, iterating wasting motor energy
Solution orientation on gps, day time movement progress, and local light path conditions from diagram at morning, back rotation to track first sun rays.

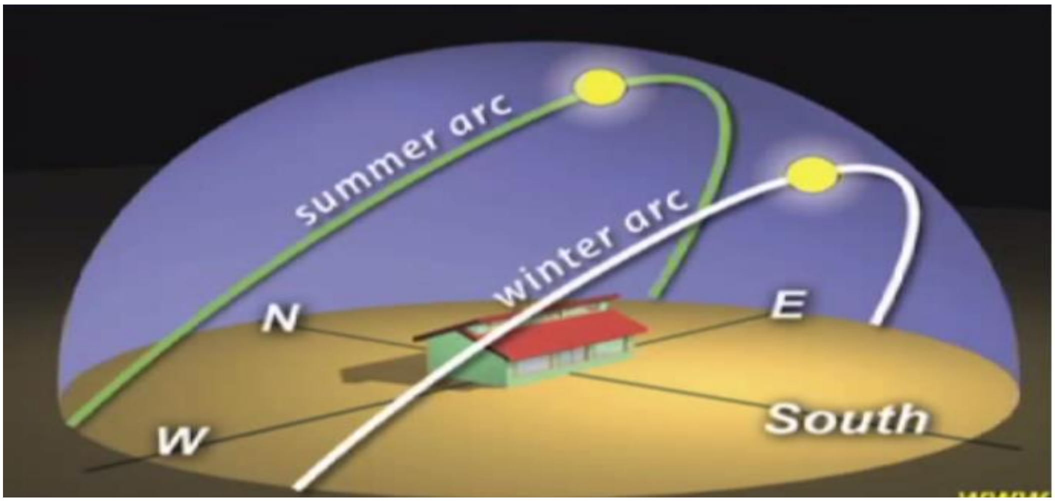


Figure 2.15: summer and winter arc diagram

Sun rise and fall times throughout the year

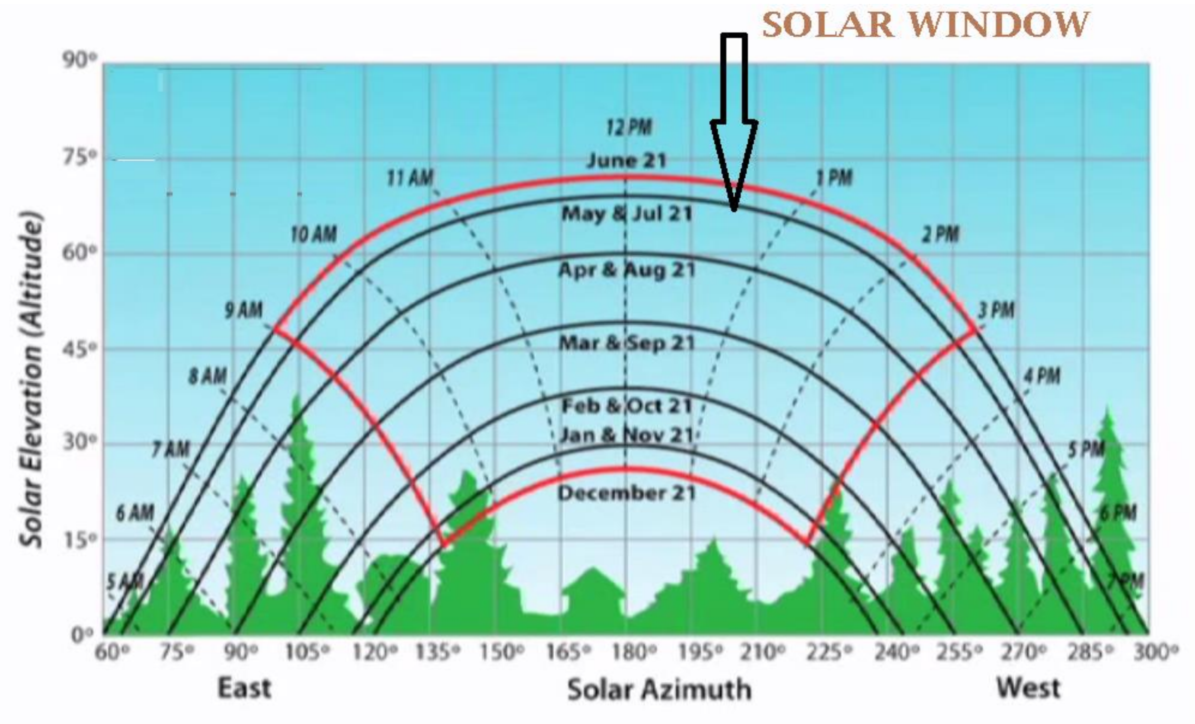


Figure 2.16: Sun rise and fall diagram

Solar Tracking

- Solar trackers are devices used to orient photovoltaic panels, reflectors, lenses or other optical devices toward the sun.
- Since the sun's position in the sky changes with the seasons and the time of day, trackers are used to align the collection system to maximize energy production.
- It is completely automatic and keeps the panel in front of sun until that is visible. The unique feature of this system is that instead of take the earth as in its reference, it takes the sun as a guiding source. Its active sensors constantly monitor the sunlight and rotate the panel towards the direction where the intensity of sunlight is maximized.

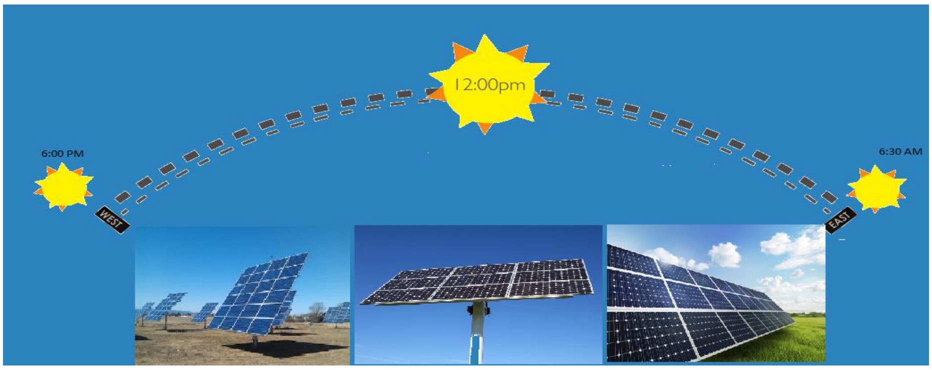


Figure 2.17: sun position at different time intervals

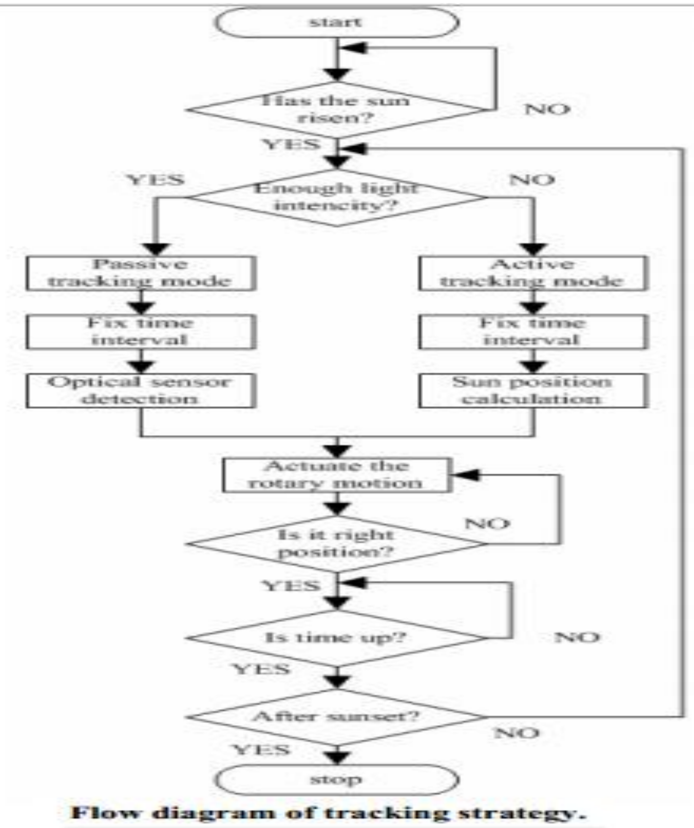


Figure 2.18: Flow diagram of tracking strategy

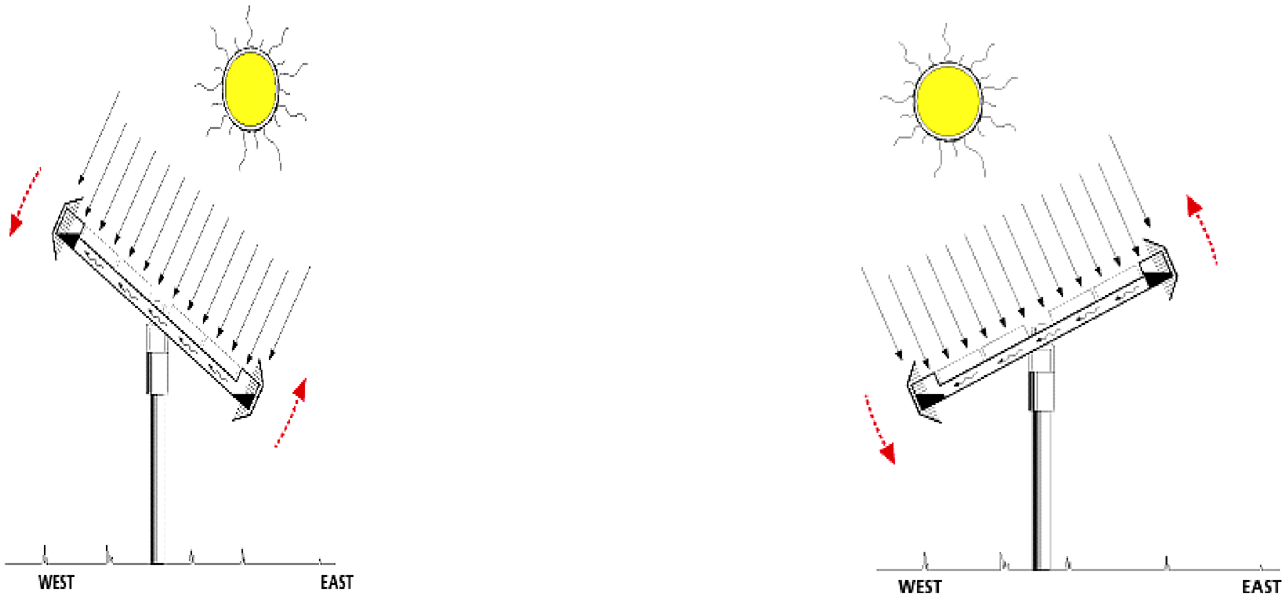


Figure 2.19: Pane movement from East to West

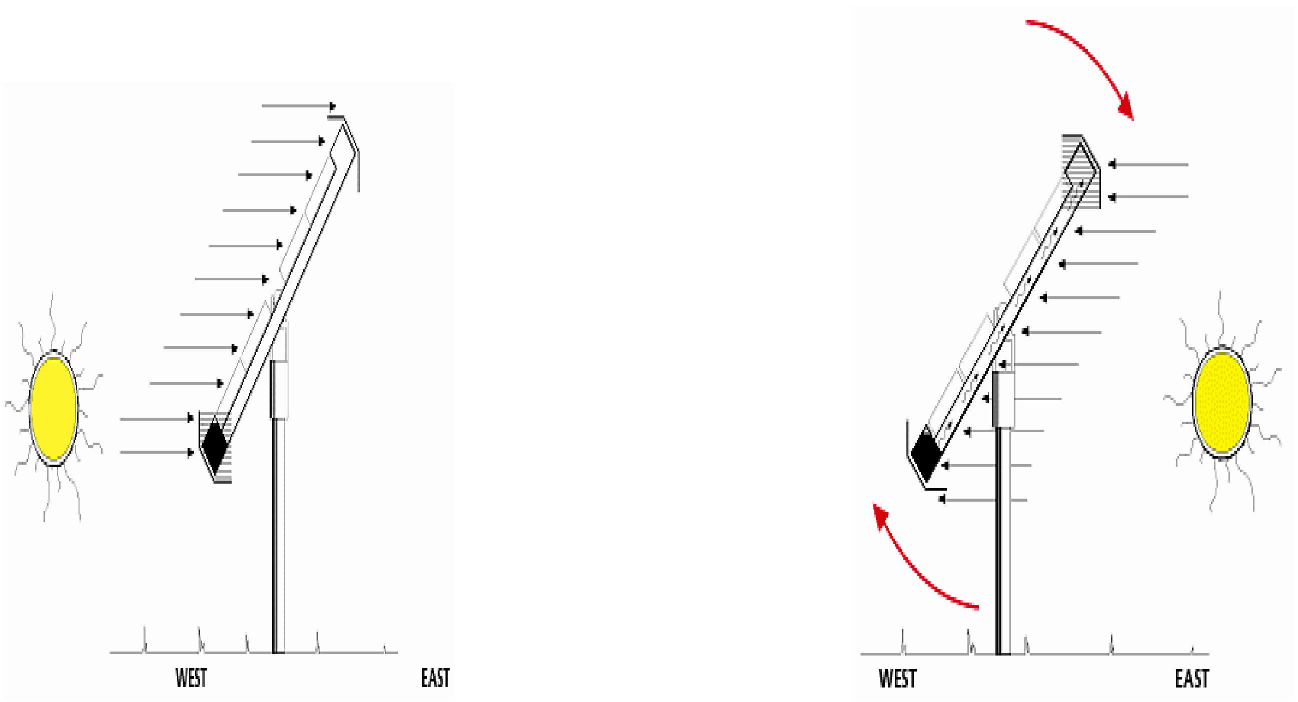


Figure 2.20: Panel Movement from West to East

Solar Tracker Structure

The adopted mechanical structure and the tracking technique are shown in the below given Figure. It is based on full tracking with tilt and angles. The system uses two actuators with built in PLC luminance sensors. The figure shows the design structure which can carry six solar panels (130 watts, 11 kg each) as a static load taking into consideration the dynamic loads such as wind and rain.

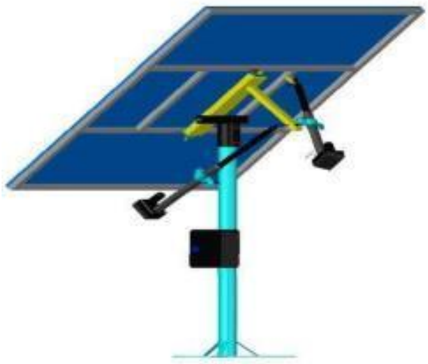


Figure 2.21: Structure of Solar Panel

Variation in Energy Generation

Here we can approximately find 40% improvement in solar energy generation using sun tracking method/System. By which we can gain much energy than what we obtain using stereotyped trackers. There will be constant power generation rather than fluctuation in the power gaining.

Fixed Solar Panel

Tracking Solar Panel

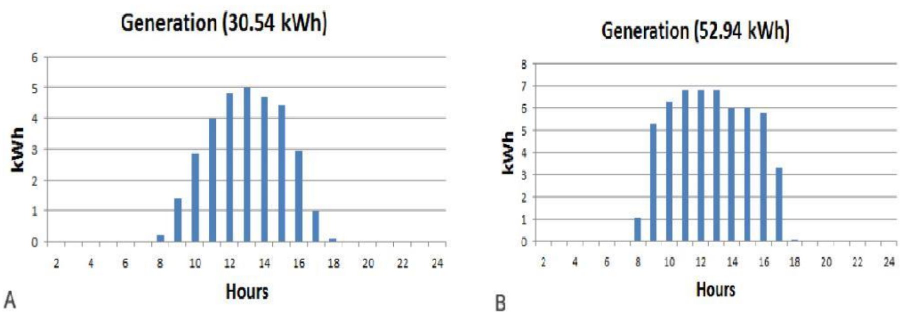


Figure 2.22: Output of without tracker and with Tracker

From the above figures (A and B) we can easily trace out the difference in their levels of productivity respectively. In the first figure we can see that the energy generation increases suddenly in the afternoon as there will be maximum luminance observed obviously. But in the second diagram above the output is based on the solar tracking panel. Where we can get maximum luminous on the panel from the early hours and also the productivity is constant unlike the one without a tracker

Optimum Tilt of Solar Panels

Adjusting the tilt twice a year gives you good observable results in energy gaining factor. Adjusting the tilt four times a year will vary only a little bit more in power gain, but could be important if you need to optimize the power production in the seasons spring and fall. You can shift into the best fixed tilt angle, or leave to the tilt variation on two seasons or four seasons adjusting accordingly so that we can gain maximum output.

The solar panel should be perpendicular to the Sun. Sunlight direction changes regularly with changing seasons and weather.

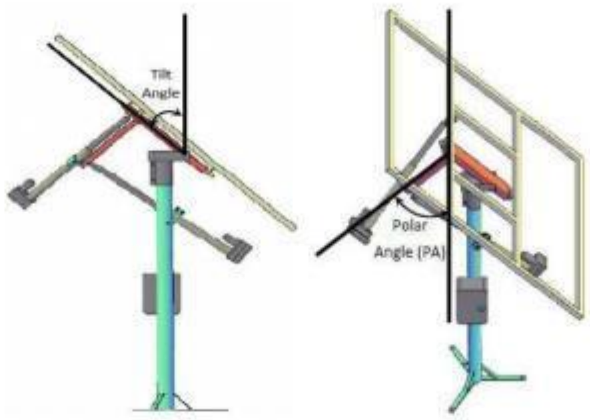


Figure 2.23: Tilt and polar angle representation

From the graph given below, we can observe the effect of adjusting the tilt. The blue line shows the amount of solar energy you would get each day if the panel is fixed at the full year angle.

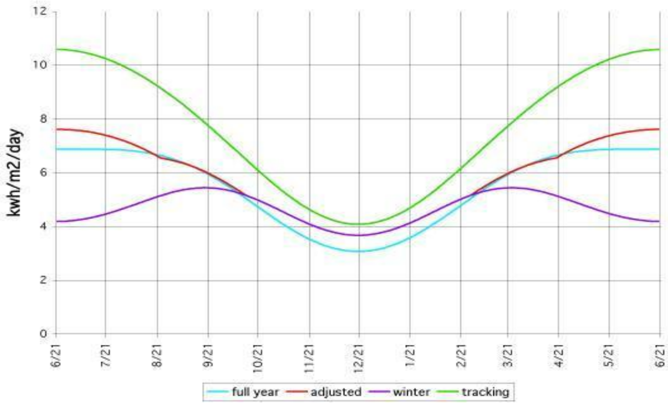


Figure 2.24: Graph of tilt, according to seasons.

From the above given graph red line shows how much you would get by adjusting the tilt four times a year as described below. For a small comparison of output we get according to the seasons, the green line shows the energy you would get from two axis tracking, which should always point the solar panel directly at the sunlight. (The violet line is the solar energy per day if the panel is fixed at the winter angle) These figures are calculated for 40° latitude.

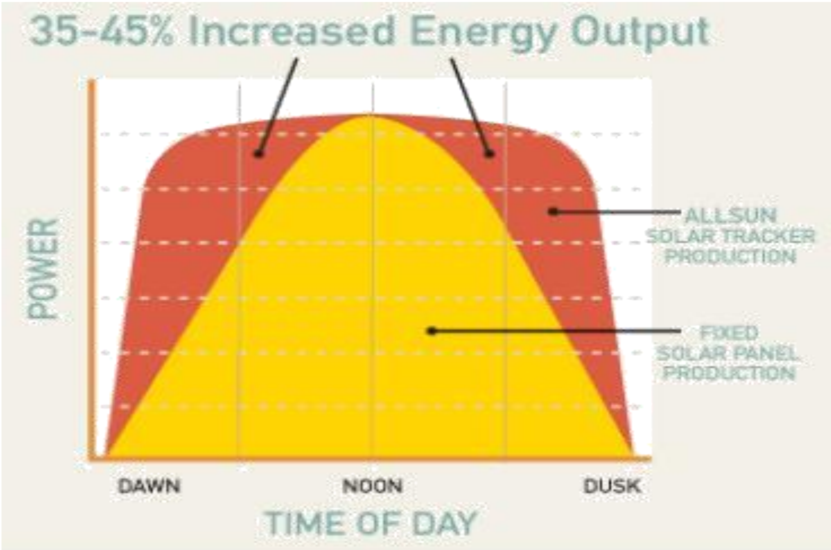


Figure 2.25: Observance of the maximum luminance using solar trackers.

2.5 Movement of panel by luminance values

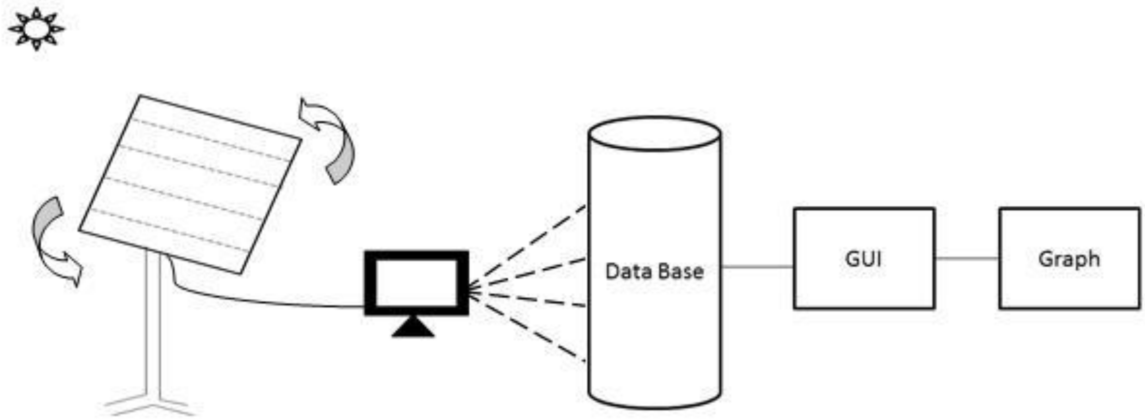


Figure 2.26: Block Diagram of Panel Movement System

- Changing the operating mode of CPU
- Monitoring and modifying PLC tags, date block tags, and I/O values.

- Downloading the data logs and updating the firmware.

With this application different data values from the solar panel are stored in the ConnectDB. In this project we designed ConnectDB to store values of date, time, luminance, rotation of X and Y axis. The database is present at TUChemnitz servers and data values are updated on real time basis.

The GUI block indicates the structural representation of the analyzed data from ConnectDB. The luminance values that are stored in the ConnectDB are from the four sensors that are placed on the top of the panel. Panel start moving with reference to these values, the code is written in such a way to plot a graph and depict how exactly panel will be moving in different patternsw.r.t to the luminance values. When these patterns are observed for the long time, we can get much detailed characteristic of the panel w.r.t to time, season and luminance value. This data can be further used in machine learning concepts to train the machine and to gain many feasible patterns. The design label of GUI shows the graph box and a J button.

The output of the connect DB and GUI is displayed in this graph. Different parameters that are stored in the ConnectDB can be used to plot the graph; analysis between different parameters can be performed to get the most precise data optimization. In this project we optimized the data to plot a graph for panel rotation with reference to the luminance values. We can also use other parameters to find the patters and data optimization.

Panel patterns with SVM

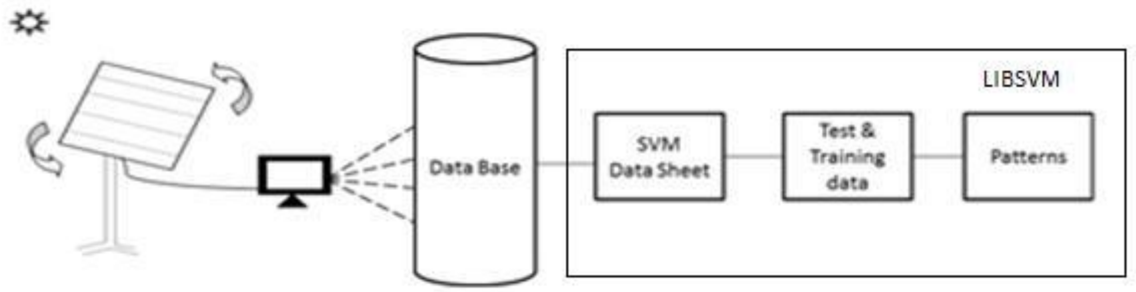


Figure 2.27: Block Diagram of Panel Movement by SVM

Above block diagram Fig [10], show the data flow to generating patterns from obtained data values of DB connector. LIBSVM software is used to generate these patterns. The below steps are followed to generate patters using LIBSVM:

LIBSVM

LIBSVM is a library for Support vector Machines (SVMs). It is integrated software for support vector classification (C-SVC, nu-SVC) regression (epsilon-SVR, nu-SVR) and distribution estimation (one-class SVM). It supports multi-class classification. LIBSVM provides an easy interface where users can easily link it with their own programs. The goal is to help users to easily apply SVM to their applications. The basic implementation of LIBSVM involves two steps: first, a model to be obtained by training a dataset and second, using the model to predict information of a testing dataset. LIBSVM can also output probability estimates for SVC and SVR.

The LIBSVM package is structured as follows

1. Main directory: core C/C++ programs and sample data. In general, the training and testing algorithms are implemented by svm.cpp
2. The tool subdirectory: Tools for checking data format and for selecting SVM parameters are included in this subdirectory.
3. Other subdirectories include prebuilt binary files and interfaces to other software/languages.

The principal features of LIBSVM include:

- Formulations for different SVM
- Cross validation for model selection
- Weighted SVM for unbalanced data
- Efficient multi class classification
- Various kernels
- Estimation of probability
- Automatic model selection which can produce contour of cross validation accuracy
- SVM classification and regression are demonstrated in GUI
- Python, Matlab, Perl, Ruby, Weka, Haskell, PHP interfaces, C# .NET code and CUDA extension is available. It's also included in some data mining environments such as PCP, Rapid Miner and LION solver

We used the version of Libsvm-3.19 in this project. A python interface has been included in Libsvm since version 2.33

- Create a datasheet with training data and test data for the sample set of parameters
- Set the border values (starting and ending point) of each parameter such that the values of the respective parameter should lie in that particular range.
- Generate the training data for parameters based on the border values. Consider the example set of data for each parameter should be 100.
- Train the Libsvm with the set of training data.
- The Libsvm will learn based on the training data without being explicitly programmed. Whenever a new set of data enters into the parameters it checks whether the newly arrived values are classified according to its border values.
- Create a test data (input) based on the training data. The test data is used for cross verifying the training data that is learned by the Libsvm.
- Check with the Libsvm whether the test data is linearly classified based on the

border values of train data.

- The easy script (easy.py) makes everything automatic from data scaling to parameter selection. To use this tool we need to install python and gnu plot
- Check with the contour of cross validation accuracy.
- If the accuracy of Libsvm is greater than 83%, then the test data is well classified.

Seasons as per months:

As per the geometrical location, there will different climatic condition existing so, when we plan to place a panel we do consider the geometrical location of the installation point and its climatically conditions, these values can be taken from the GPS from different websites and database is designed to store this parameters and use them when required in analysis part.

Seasons	Months	Sun rise and fall time
Summer	March – June	5.30 to 19.30
Winter	July – Otober	8.00 to 16.00
Rainy	November – Feburary	7.00 to 18.00

Seasons, months and respective sun rise and fall time.

As mentioned in the above table [1], panel rotation will completely depend on the sun rise and fall time with respective to the seasons with respective months they fall. If we consider the summer season from March to June the sunrise will be early and last for a very long time of the day and maximum solar energy can be obtained,
Whereas in winter and rainy sunrise will be a bit late and falls bit early. The panel is set to be in its initial position and the final position as per the sun rise and fall time.

To generate a Fixed Reference Pattern i.e.; the pattern can be followed by the panel such that there will be a possibility of obtaining maximum luminance and output power. This pattern is chosen by considering two main panel movements.

1. Panel Rotation
2. Panel Tilt

Panel Rotation:

The basic movement of panel should be from east to west that follows the sun movement. As the panel is fixed at a point by using some strong base stand such that panel can only rotate up to 180°. So we divided this 180° of panel free rotation into eight panel rotation positions. These eight positions are considered with reference to the sun movement and time stamp changes from season to season as shown in table.

For example, if we consider the timestamp of summer the table is described with respect to the panel rotation, time stamp and panel rotation position. As the start time

is from the early morning 5.30 am panel will be set to the position 0 and then it keeps on moving with the time slot as shown in the below table. Once the end time is reached by sunset time to the position 7, panel is reset to initial position 0.

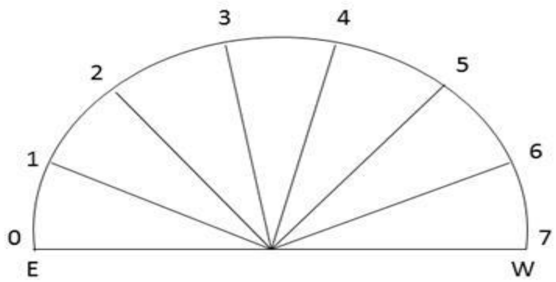


Figure 2.28: Panel Position Parameters from East to West

Position Parameter	Time Slot
0	05.30 – 06.30
1	06.30 – 08.00
2	08.00 – 09.30
3	09.30 – 12.00
4	12.00 – 14.00
5	14.00 – 15.30
6	15.30 – 17.30
7	17.30 – 19.30

Time Slots for Panel Position Parameters

Panel Tilt:

In panel tilt movement, we divided the panel into coordinates as shown below. This is to observe the region on the panel where we can observe the maximum luminance at a particular timestamp. As the luminous value shifts to the new coordinates there is a choice of tilting the panel to that position. This tilting will again coordinated with the panel rotation movement.

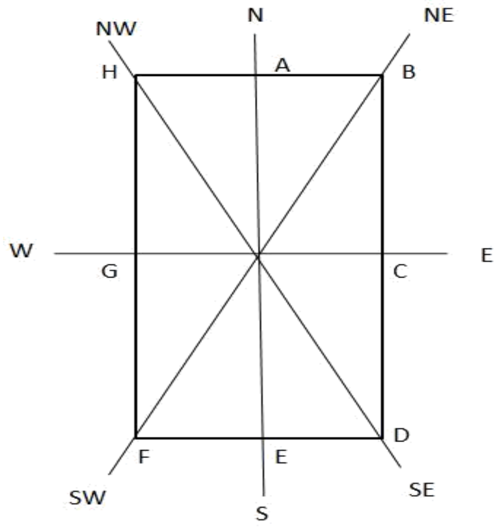


Figure 2.29: Division of Panel Co-ordinates

Position Parameter	**Co-ordinates of panel**
0	C
1	BCD
2	ABED
3	AE
4	AHEF
5	HGF
6	G
7	RESET

Co-ordinates with respect to Panel Position

The above table shows the expected coordinates of the maximum luminance at panel positions. Both the movements of the panel and panel tilt are synchronized together to obtain the fixed reference pattern. The panel in the real time scenario is made to follow this pattern so that we can reduce the unnecessary movements of the panel and also reduces the power consumption for these movements.

We introduced the term Bonus. These bonus points are used to make the panel to be in a fixed pattern. If there are more number of patterns generated by the SVM then these patterns will be compared with the fixed rotation pattern and the one very close to it is followed. So that the pattern close to the fixed pattern is given more bonus points.

2.6 Qbotix

- 10% winter to 40% summer energy loss by not aligning solar panels to sun
- Overhead of adjusting mobile robots
  - requires navigation helps
  - Markings, lane infrastructure overhead (Qbotix)
- With one sensing element could calibrate motors of homogeneous sensor field

Robotic Tracking System (RTS)

The Robotic Tracking System (RTS) is a sophisticated and rugged dual-axis tracking system that utilizes a pair of autonomous robots to optimally control up to 378 kW per block with high accuracy and reliability. Comprised of up to 225 trackers of ~1.5 kW each and only two robots per block, the RTS uses a complete systems approach that enables a truly optimized solar power plant. Each block or loop can be configured to accommodate any field design challenges while ensuring maximum energy production. The increased energy yields of up to 15% over single-axis tracking and up to 40% over fixed-tilt systems results in up to 20% improvements in project Leveled Cost of Energy, Internal Rate of Return, and Net Present Value.

Figure 2.30: Qbotix Setup

Tracker

The trackers are purely mechanical systems without any failure-prone motors or electronic components. They come pre-assembled for fast installation and are engineered to withstand high wind-loads. They are universally compatible with all types of PV panels, inverters, and foundations providing design flexibility.

Solbot

Solbot is an autonomous, rugged and mobile robot that can manage up to up to 378 kW PV array. It automatically travels to each tracker, returning in regular 40 minutes intervals to make precise adjustments. Solbot is intelligent, providing real-time information to optimize your solar array and maximize system availability. Certified waterproof and dustproof through IP-65 rating, and designed to operate in extreme conditions, each Solbot is quality-manufactured in the United States for outstanding durability.

Chapter 3

Concept

A working model saves up to 50% by aligning solar panels to the sun. Movement with limited amount of sensors may result in swings or pendling of the panel. In order to deal with these issues the model of the sky should be updated by a small tracking motor .A Luminance gain has to be given for collected path luminance. A resulting small motor calibration preference allows for movement preference also for fields of big panels based on collected model data.

A continuous research was done on servo control motors, arduino server, android studio programming. Apply preference for weighting of position or orientation and luminance information under changing motor swings and setting up voltage conditions. Finally, defining an algorithm for regulating motor movement to maximize luminance gain for the luminance model.

3.1 Global Positioning System

GPS controllers are extremely cheap and eliminate potentially costly human error. For large scale solar farms (1MW or above) the cost of a GPS system is so low that they completely disappear in the economic analysis. On the other hand, an error in configuration would reduce the power output of the entire farm and therefore reduce the revenue of the project. Because of natural day to day variability this might not be immediately noticed resulting in lost revenues. With small systems (10100kW) expertise might be costly. The advantage of having a plug and play self-calibrating system that doesn't rely on human calibration is that it just works. Equipment cost could potentially be saved by removing the GPS at the expense of additional calibration steps by the installer, but the cost saving is such a tiny amount compared to other costs that it is almost not worth worrying about. GPS can determine the user's position and display it as latitude and longitude. This is used to calculate the coordinates of the Sun with respect to the location, using this data solar panel are placed perpendicular to the Sun.

3.2 Android

"Android is an open-source software stack for a wide range of mobile devices and a corresponding open-source project led by Google" .The Android operating system (OS) is based on the open Linux kernel. Unlike iPhone operating system (iOS), Android is an open source, meaning developers can modify and customize the operating system according to their requirements for each phone. Therefore, different Android-based phones may have different GUIs (graphical user interfaces) even though they use the same OS. Android phones typically come with several built-in applications and also support third-party programs. Developers can create programs for Android using the free Android SDK (Software Developer Kit). Android programs are written in Java and run through Google's "Davlik" virtual machine, which is optimized for mobile devices. Users can download Android applications from the online Android Market. Now, after deciding to choose an Android based smartphone, we must know how to use miscellaneous sensors provided. We are using mainly three sensors for this project. Because android provide so many features it is better to use android based smartphone for this project. As Android is an open source, we can make applications according to our use.

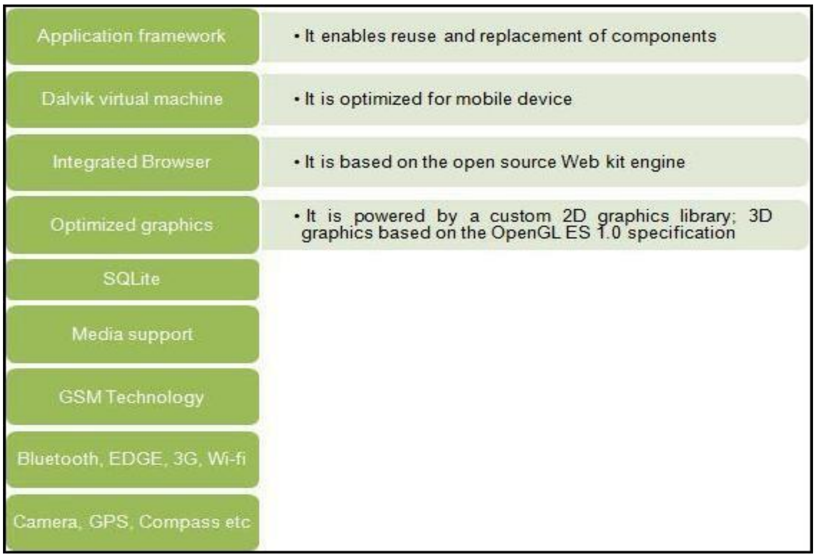


Figure 3.1: Android functionality

3.3 Smartphone

“A smartphone is a cellular telephone with an integrated computer and other features not originally associated with telephones, such as an operating system, Web browsing and the ability to run software applications“. The first smartphone was built by IBM (IBM's Simon), which was presented as a concept device at the 1992 COMDEX computer industry trade show. After that lot of company jumped in this trade to make various smartphones. We can say today’s available smartphone is equally functional to a computer. Since a smartphone is having so many features we can use it to fulfill our purpose. For example Wi-Fi/mobile data to connect to the internet, a light sensor to detect light intensity, GPS to find the exact location if solar panel, gyro sensor to find the orientation of the device, etc. As a reason that a smartphone hold all these facilities we need, it is the best option to use to detect and change solar panel direction. But we have to choose very precisely which operating system of smartphone is more useful to us, because we have to build a custom application. We are having a choice between Apple’s iOS, Google’s Android, Blackberry OS, Microsoft’s Windows OS for smartphone, etc.

Figure 3.2: Basic smartphone features

3.4 Sensor

“A sensor is a device that detects and responds to some type of input from the physical environment”. Input from a sensor could be light, heat, moisture, pressure, etc. Generally the output of any sensor is a human readable signal, which could transmit over network for reading or further process. Nowadays a smartphone consist many of these sensors. Normally a fully equipped smartphone has almost all those sensors that a normal person knows.

Figure 3.3: Smartphone sensors

A. Light sensor

Ambient light sensor gives reading of the light detected by the device’s light sensor. As the light level changes, the sensor readings change. They contain photo diodes which are sensitive to different spectrums of light and combined mathematical effect adjusting the gain and output changes of the light intensity on the screen. In our case we are only using light sensor not proximity sensor. And for convenient we are taking light sensor value in the unit “lux”.

- Ambient light sensor senses light based on principle of "superposition".
- They contain photo diodes which are sensitive to different spectrum of light.

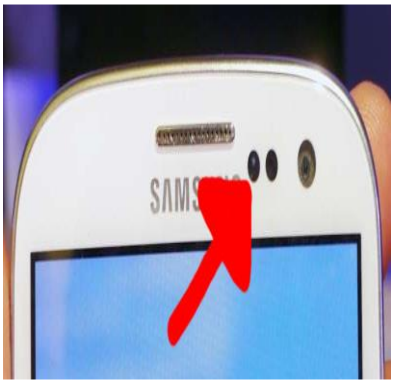


Figure 3.4: Ambient light sensor (along with proximity sensor)

B. GPS

GPS: The Global Positioning System is a space-based satellite navigation system that provides location and time information in all weather conditions, anywhere on or near the Earth where there is an unobstructed line of sight to four or more GPS satellites. By the use of GPS we can access the global positioning of our device and we can continuously get latitude and longitude, which is enough to know the exact position of the device on the earth. In our case the values of GPS is not that much useful, we are attaching our device with solar panel, which is static. But if we are using the concept for any moving object (i.e. steamer) GPS values (latitude & longitude) are important too.

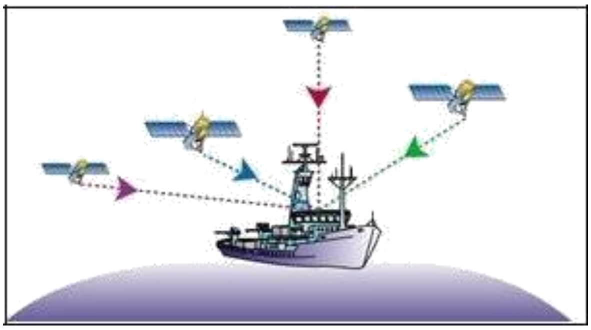
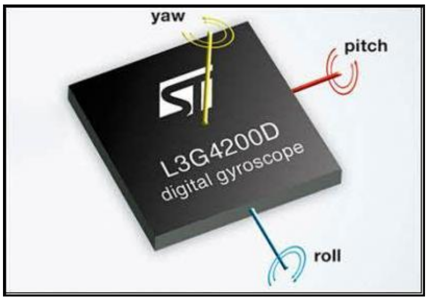


Figure 3.5: GPS navigation for moving object

C. Gyroscope

A gyroscope is a device for measuring or maintaining orientation, based on the principles of angular momentum. This device gives values as the device rotates. The values would be in the form of X, Y & Z axis.



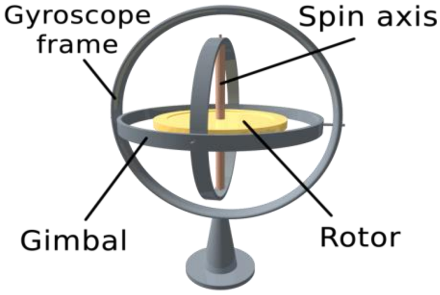


Figure 3.6: Gyroscope chip

- Geomagnetic field sensor in combination with a device's accelerometer.
- Azimuth(degrees of rotation around the z axis)
- Pitch(degrees of rotation around the x axis)
- Roll(degrees of rotation around the y axis)
- Coordinate system (relative to a device) used by the Sensor API

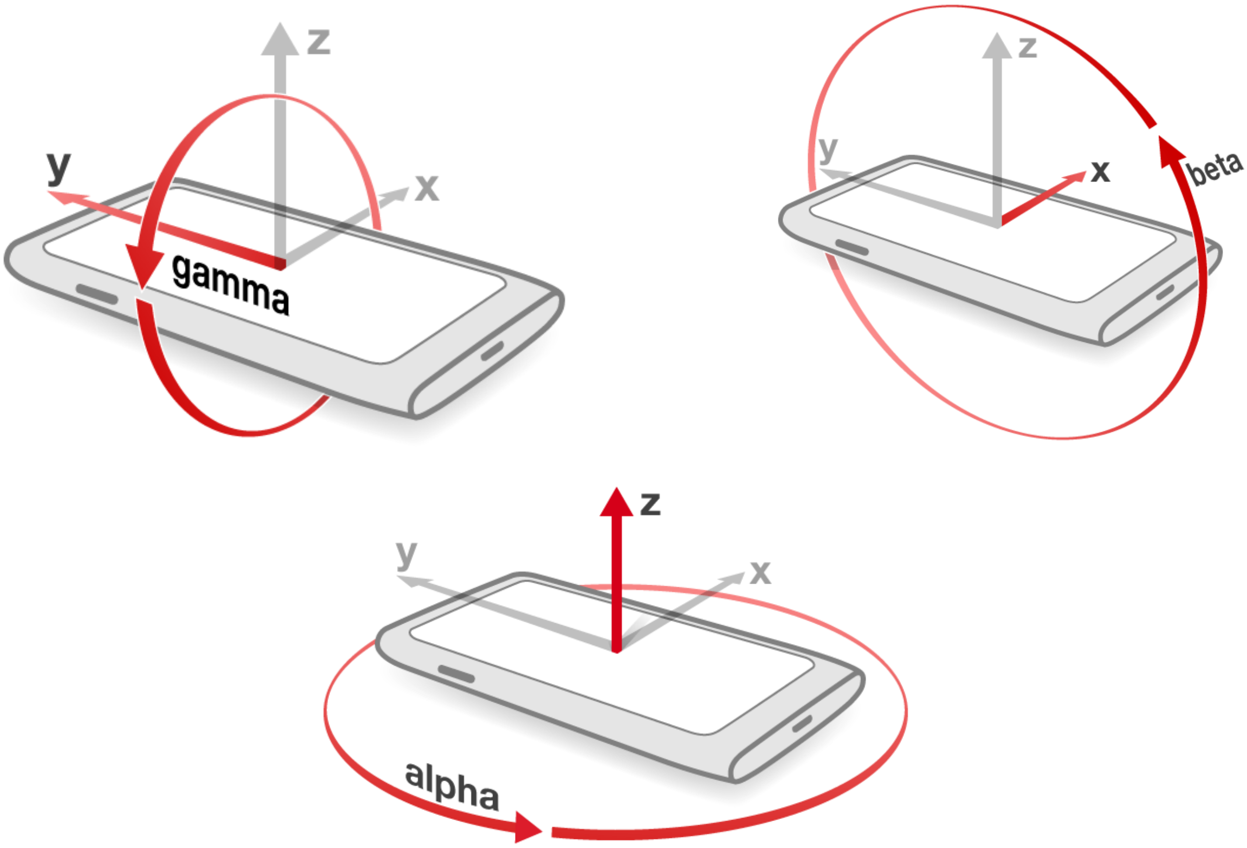


Figure 3.7: Coordinate system (relative to a device) that's used by the Sensor API

Once, after deciding which components we are going to use, we have to program them according to the project requirements.

1. **Light sensor**

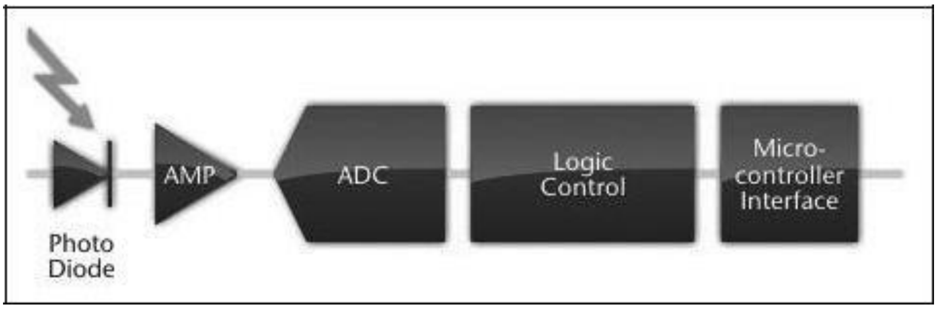


Figure 3.8: Block diagram of light sensor in a smartphone

This figure gives shows how a light sensor works in a smartphone. Normally we use a light sensor to automatically increase or decrease brightness of screens in our smartphones.

Below is an android application code for the light sensor.

```
SensorEventListener lightSensorEventListener = new SensorEventListener() {

    @Override
    public void onAccuracyChanged(Sensor sensor, int accuracy) {
        // TODO Auto-generated method stub

    }

    @Override
    public void onSensorChanged(SensorEvent event) {
        // TODO Auto-generated method stub
        if (event.sensor.getType() == Sensor.TYPE_LIGHT) {
            final float currentReading = event.values[0];

            luminance_read.setText(" " + String.valueOf(currentReading));

        }
    }
};
```

Figure 3.9: Code snippet of light sensor

2. **Gyroscope**

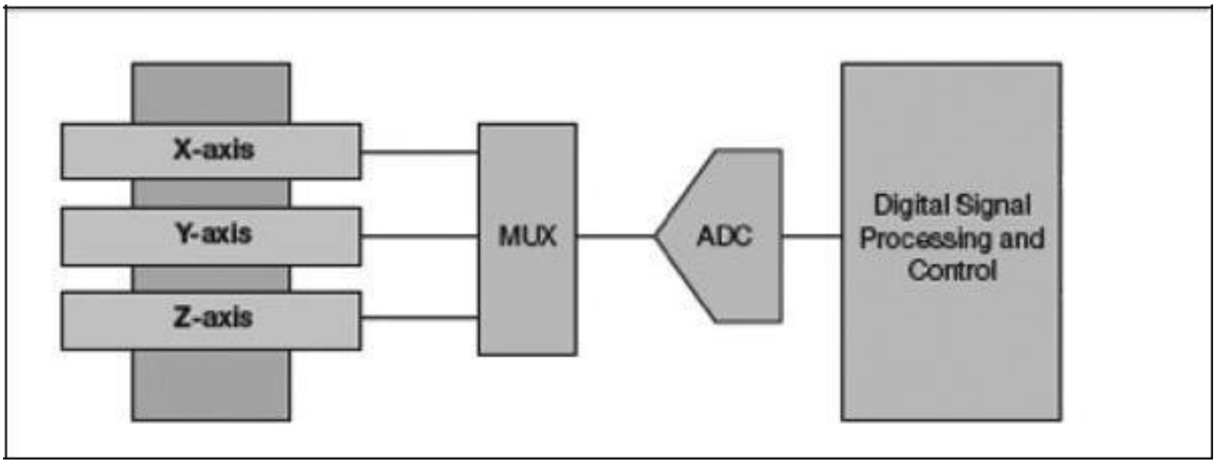


Figure 3.10: Block diagram of gyroscope in a smartphone

Use of gyroscope in a smartphone is for tilting. So many games and apps are based on this sensor. For example tilt, NOVA, star walk, nearest tube, etc.

Below is an android application code for the gyroscope.

```
@Override
public void onSensorChanged(SensorEvent event) {
    // TODO Auto-generated method stub
    if (event.accuracy == SensorManager.SENSOR_STATUS_UNRELIABLE) {
        return;
    }

    // else it will output the Roll, Pitch and Yawn values
    gayro_x.setText("" + Float.toString((int) event.values[2]));
    gayro_y.setText("" + Float.toString((int) event.values[1]));
    gayro_z.setText("" + Float.toString((int) event.values[0]));
}
```

Figure 3.11: Code snippet of gyroscope

3. **GPS**

Normally the use of GPS in a smartphone is to track the location of the device. We can also get the location by cellular ID if SIM card is inserted. But that could be provided by the cellular company only. So it’s a better idea to use GPS in our project.

4. Connectivity

In order to store values from all these sensors, we must ensure that our smartphone is connected to the internet connection. It doesn't matter whether it is Wi-Fi connection or cellular provided internet service. Connection should be fast is the only requirement. We can store data in various platforms (i.e. shared preference, internal storage, external storage, SQLite database, network connection). I chose MySQL in our case. I am storing data on TU-Chemnitz database (a remote database), and shared with team members, involved in this project (https://login.tu-chemnitz.de/phpmyadmin/). Application is made in such a way that it will store all important data in database periodically.
Unlike location we also have to get permission to access internet.

- **Wi-Fi:** Wi-Fi is a local are wireless technology that allows an electronic device to exchange data or connect to the internet using radio waves.

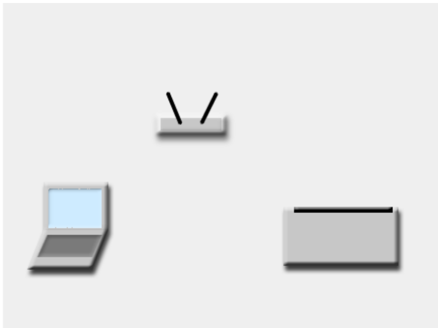


Figure 3.12: Wi-Fi connectivity

<uses-permission android:name="android.permission.ACCESS_WIFI_STATE"></uses-permission>
<uses-permission android:name="android.permission.UPDATE_DEVICE_STATS"></uses-permission>
<uses-permission android:name="android.permission.CHANGE_WIFI_STATE"></uses-permission>
<uses-permission android:name="android.permission.WAKE_LOCK"></uses-permission>

- **Cell ID:** A Cell ID is a number which is associated with a specific cell (the radio tower to which your handset is connected).It is not as accurate as GPS, though location via Cell ID still presents a very useful alternative.

<uses-permission android:name="android.permission.ACCESS_COARSE_LOCATION"/>
<uses-permission android:name="android.permission.ACCESS_FINE_LOCATION"/>

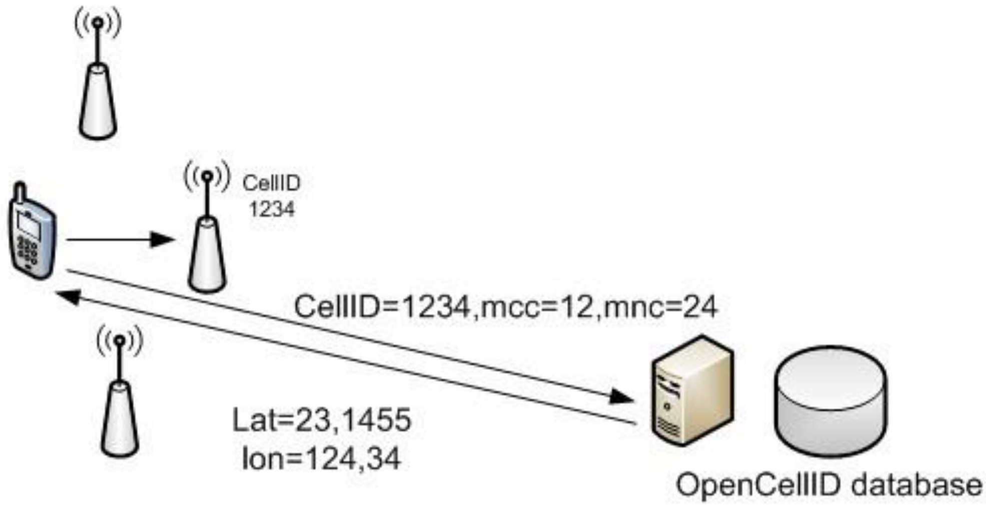


Figure 3.13: Cell ID

- Some network doesn't provide their data for several reasons.
- OpenCellID is the solution (opencellid.org)
- Get current readings of light intensity and get orientation of that position.
- Rotate device slowly and check the difference in reading.
- Get new orientation coordinates if better light intensity is found.

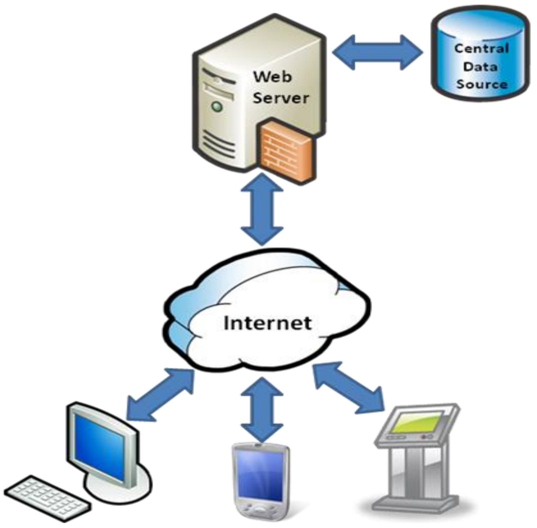


Figure 3.14: Cell ID connections

3.5 Solar Trackers

It is a device for orienting a solar panel or concentrating a solar reflector or lens towards the sun. Photovoltaic cells, especially in solar cell applications, need very high degree of preciseness to ensure that the concentrated sunlight is directed exactly to the powered device. Precise tracking of the sun is observed through the systems with single or dual axis tracking.
Fig [2]: Single axis tracker and Dual axis tracker

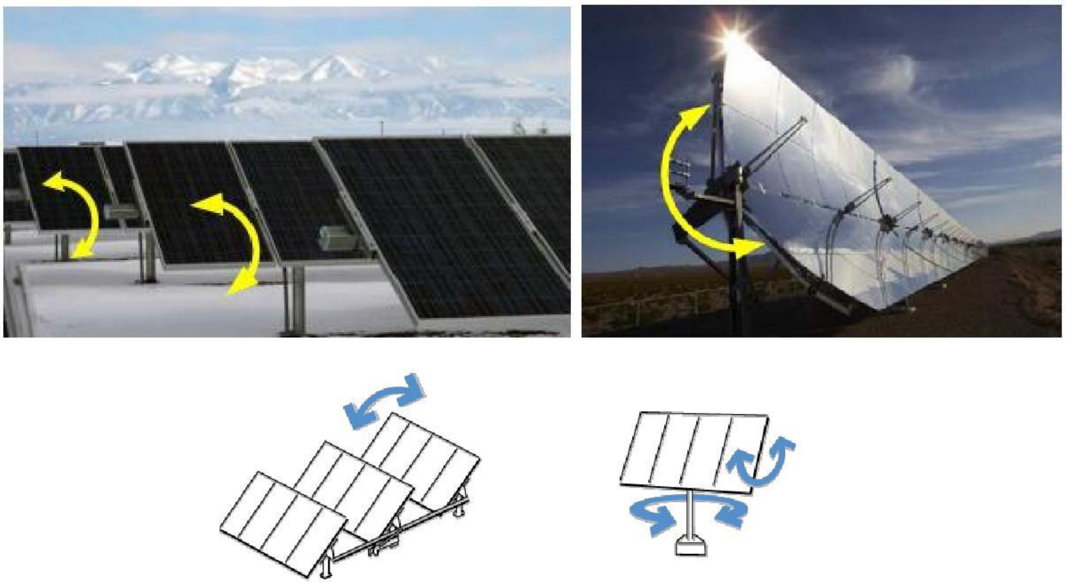


Figure 3.15: Single axis tracker and Dual axis tracker

Solar Tracking System

Solar trackers are devices used to orient solar panels, reflectors, lenses or other optical devices toward the sun.
Since the position of the sun changes in the sky with respect to the time of the day, seasons, trackers are used to maintain the solar panel system to maximize energy production using effective methods. The unique feature of the proposed system is that instead of taking the earth as its reference, it takes the sun as a reference path. Its PLC sensors constantly monitor the sunlight and rotate the panel towards the direction of maximum luminance.

Solar Tracking

Principle:

An efficient solar tracking system should be efficient enough and be able to track the sunlight at the correct angle, even though at the time of cloudy weather. Over the years, various kinds of solar tracking systems and mechanism are being proposed to improve and enhance the solar energy. Generally the accuracy required will depend on the specified characteristics of the solar photovoltaic systems that are being analyzed. Basically the higher the system will get the maximum luminance the more accurate the solar tracker will be indeed.

Types:

Taking into consideration of all the available solar tracking systems, solar trackers can be classified into one axis and two axis tracking devices. The figure given below explains all the available types of sun trackers in the world which are given just for our knowledge; there is no need to learn about all that stuff. For one axis solar tracking, the tracking system drives the panels about an axis of rotation until the sun ray and the aperture are normal.

Broadly speaking there are three types of one axis sun tracking systems available:

1. Horizontal Axis Tracker

The tracker axis will remain parallel to the earth's surface and it will always move along East to West or North to South in direction. These are mounted at a particular angle and elevation at the respective latitude. Comparative to vertical axis trackers these horizontal trackers will consume less space for installation.

2. Tilted Axis Tracker

The tracker axes are moving away from the horizon by an angular movement along North to South direction, for instance Latitude tilted axis solar tracking. These are prone to wind factors while tilting at some angles.

3. Vertical Axis Tracker

The tracking axis is linear with the zenith axis and it is called as azimuth solar tracking. These are optimal at high altitudes than horizontal trackers. The field layout should be aware of shading regions to avoid unnecessary loss of energy.

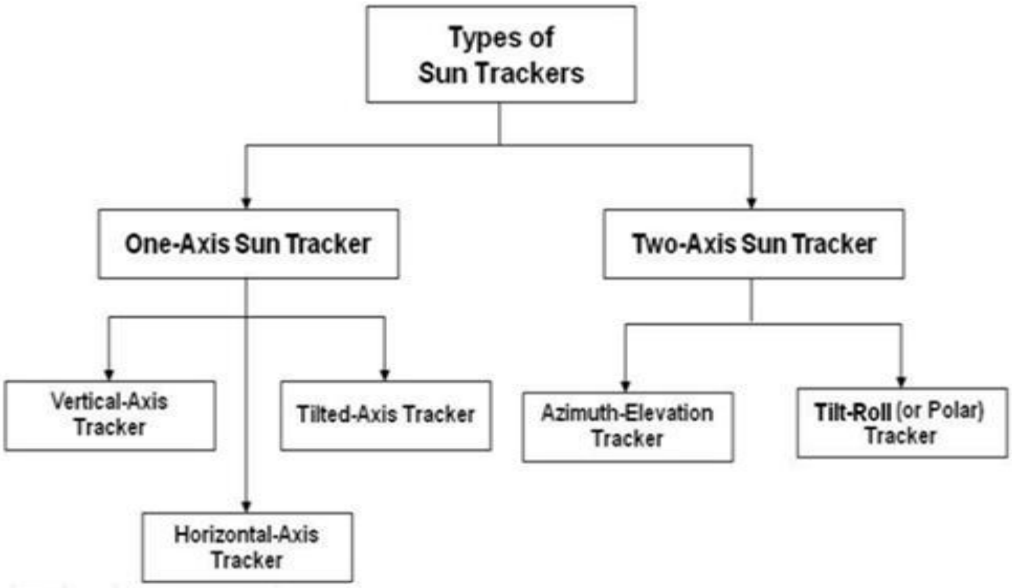


Figure 3.16: Represents Types of Sun Trackers

Using this method as the concept we are going to implement in such a way that we introduce another axis and thereby making it a three axis tracker. This procedure can be improved in many ways to make it more energy efficient. Firstly, using a smartphone in built with light sensor and gyroscope is the best way to proceed because the values can be transferred through wifi via the android device and no external source or assumption based on GPS has to be taken into account. Secondly, the motors used in this procedure are two heavy motors which would be replaced by a small calibration servo motor which can be configured to explore the entire sky and not restrict the positions thereby providing useful information to the database which in turn can help rotate the big panel which has limited sensors.

Due to this big panels can rotate taking the max luminance value obtained the small device and not just predict or assume the values. The procedure becomes faster and is way easier to calibrate because of the easy availability of the components and thus providing high efficiency and reliability compared to using heavy motors and wasting energy when the sky is cloudy or at night time. The circular model tracking luminance is way faster than the big panel rotation by itself. Hence, the process becomes faster and much more accurate than the existing one.

3.6 Challenges

There were various challenges faced during the above mentioned projects to track solar energy. The proposed method gives a much reliable output and is highly energy efficient. Thee drawbacks of the other models or in specific the model proposed by TU Chemnitz research internship group were that there were limited testing possibilities by slow big motor, availability, setup time, slow model update and low data amount. Energy efficient methodology needed for extension and integration of more sensor data, motors. No exploration of environment luminance was done.Heavy panel motor only gets reduced calibration results from limited sensors. In case of cloud not moving to lightest point reasonable, iterating wasting motor energy.

Chapter 4

Implementation

This chapter deals with the implementation of the developed concept for improvement of a solar panel model using the pan tilt mechanism. The first task is the hardware implementation of the pan tilt and connecting it with an arduino board which provides the necessary source to the pan tilt to move on both horizontal and vertical axis and follow the commands as provided. The construction is hassle free because of the time efficient assembly and easy connections which forms a major reason for the selection of an arduino board over the Nanettboard microcontroller and provides better connectivity and also provides us with an input voltage of 5V which is an advantage. The availability of the arduino board is not a big issue and being reliable and easy to handle is a plus point. Because of these beneficial functionalities arduino board suits our project and it can be further implemented using software programming after the hardware connections are tested. The next step is to program the arduino using the arduino server. A clock timer is set and the commands for the auto rotation of the pan tilt are provided. It can move in 180 axes horizontally and vertically.

The implementation starts with the basic understanding of the software platforms and servers working in tandem.

4.1 Arduino Server

Figure 4.1: Arduino Server

Arduino is an open-source computer hardware and software company, project and user community that designs and manufactures kits for building digital devices and interactive objects that can sense and control the physical world. It includes a 5 volt linear regulator and a 16 MHz crystal oscillator

Because of the high voltage of 5V we use this board over MSP430 Nanettboard microcontroller Based on the commands the given on the arduino server the Arduino motor can be controlled to rotate, move and detach both in horizontally and vertically.

Figure 4.2: Arduino Board

The Arduino is cheap enough that you can buy a few to mess around with. Alongside the flagship Arduino Uno, you have a ton of other variations of the arduino to choose from. The Arduino also consumes very little power, so it's perfect for projects that run all day long, or need to be powered with batteries. Most importantly, the Arduino is insanely popular, so it's easy to find support, tutorials, and projects. Finally, the Arduino is flexible and can interface with just about anything.

The Arduino is best suited for single-purpose projects. Say, a system where your dryer sends you a text message when your clothes are done or a video doorbell system. The Arduino is also really well suited for interacting with objects in the real world, so if you need to interface with something like window blinds or door lock the Arduino is a good place to start. So, if you're designing something simple like a control panel for a garden, an Arduino is perfect.

Below are the commands presented as given to the move the motor using the arduino server.

- (g) activate/attach motor1
- 30m, 150m rotate left right a little (also from start with timer)
- (d) deactivate/detach
- (f) attach motor2
- 60b, 120b (55-146 degree) rotate

- (e) detach motor2 (not for referencing)
- May init read from eprom tested
- Write server timing app for sending rotation, and stop command to rotate 30 degrees (exact if possible)
- Because continuous rotation servo must be stopped to not rotate all the time
  100c set period to stop; 1m start rotation
- Seems to get a new reference when over 180degree, may move on shortest way over 180degree mark back
- Current solution: **g**-reference then set counter **1000c** (20,100,1000) and move from ref count width **1m**

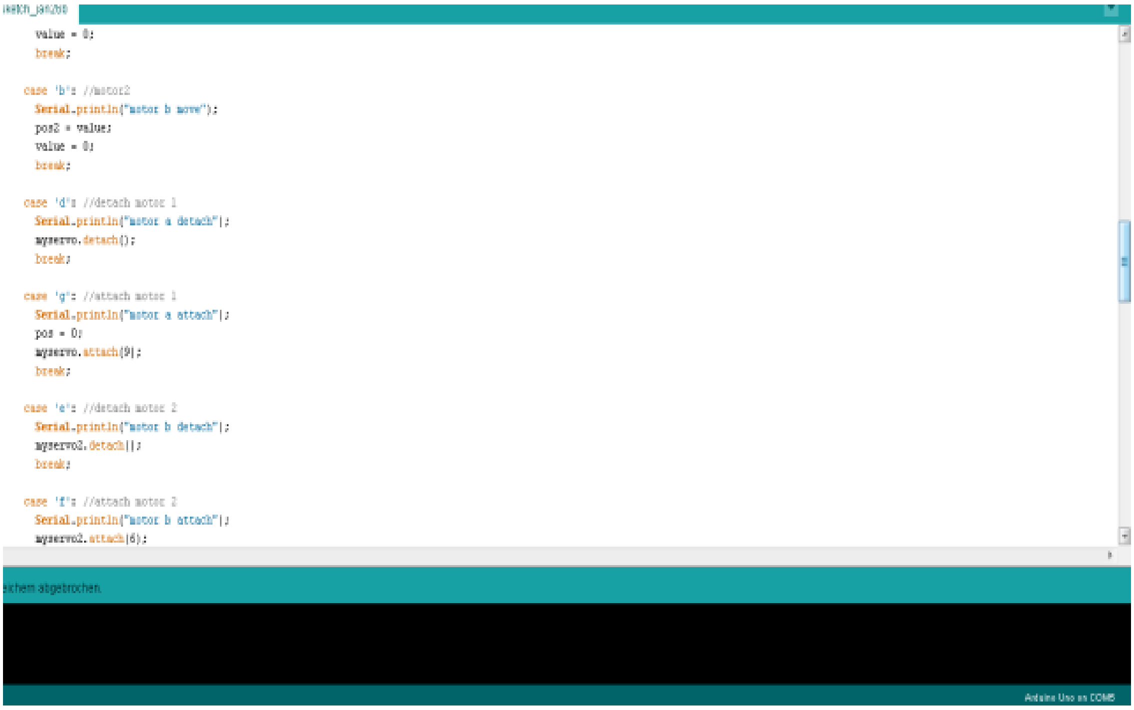


Figure 4.3: Code snippet of arduino program

```
case 'i':
     Serial.println("motor a idle");
     pos = 0;
     break;

   case 'm':
     Serial.println("move m1 from cur pos");
     myservo.attach(9);
     pos = value;
```

```
    value = 0;
    MsTimer2::start();
    break;



case 'c': //reset clock width
    Serial.println("reset timer width for m1");
    MsTimer2::set(value, timer2function);
    value = 0;
    break;

  case 'a': //motor1
    Serial.println("motor a move");
    pos = value;
    value = 0;
    break;

  case 'b': //motor2
    Serial.println("motor b move");
    pos2 = value;
    value = 0;
    break;

  case 'd': //detach motor 1
    Serial.println("motor a detach");
    myservo.detach();
    break;

  case 'g': //attach motor 1
    Serial.println("motor a attach");
    pos = 0;
    myservo.attach(9);
    break;

  case 'e': //detach motor 2
    Serial.println("motor b detach");
    myservo2.detach();
    break;

  case 'f': //attach motor 2
    Serial.println("motor b attach");
    myservo2.attach(6);
    break;
```

- M Version for timer usage
- G at end allowed for second recalibration G after start up swing

```
debug:
Stable Library
=========================================
Native lib Version = RXTX-2.1-7
Java lib Version   = RXTX-2.1-7
g
g

motor a attach
20c
20c

, 2, 20reset timer width for m1
1a
1a

, 1motor a move
motor a detach
motor a idle
g
g

motor a attach
10c
10c

, 1, 10reset timer width for m1
1a
1a

, 1motor a move
motor a detach
motor a idle
g
motor a attach
10c
10c

, 1, 10reset timer width for m1
1a
1a

, 1motor a move
motor a detach
motor a idle
g
g

motor a attach
10m
10m

, 1, 10move m1 from cur pos
g
g

motor a attach
100c
100c

, 1, 10, 100reset timer width for m1
1m
1m

, 1move m1 from cur pos
g
g
, 1, 10, 100reset timer width for m1
1m
1m

, 1move m1 from cur pos
g
g

motor a attach
180m
180m

, 1, 18, 180move m1 from cur pos
g
g

motor a attach
10c
10c

, 1, 10reset timer width for m1
g
g

motor a attach
180m
180m

, 1, 18, 180move m1 from cur pos
g
g

motor a attach
```

Figure 4.4: Commands for motor movement

4.2 Netbeans IDE

Figure 4.5: Netbeans IDE

NetBeans is a software development platform written in Java. The NetBeans Platform allows applications to be developed from a set of modular software components called modules. Applications based on the NetBeans Platform; including the NetBeans integrated development environment (IDE).Netbeans IDE provides connection with MySQL database. The NetBeans IDE is primarily intended for development in Java, but also supports other languages, in particular PHP, C/C++ and HTML5. NetBeans is cross-platform and runs on Microsoft Windows, Mac OS X, Linux, Solaris and other platforms supporting a compatible JVM.

It is a framework for simplifying the development of Java Swing desktop applications. The NetBeans IDE bundle for Java SE contains what is needed to start developing NetBeans plugins and NetBeans Platform based applications; no additional SDK is required.

Applications can install modules dynamically. Any application can include the Update Center module to allow users of the application to download digitally signed upgrades and new features directly into the running application. Reinstalling an upgrade or a new release does not force users to download the entire application again.

The platform offers reusable services common to desktop applications, allowing developers to focus on the logic specific to their application. Among the features of the platform are:

User interface management (e.g. menus and toolbars)

User settings management

Storage management (saving and loading any kind of data)

Window management

Wizard framework (supports step-by-step dialogs)

NetBeans Visual Library

Integrated development tools

NetBeans IDE is a free, open-source, cross-platform IDE with built-in-support for Java Programming Language.

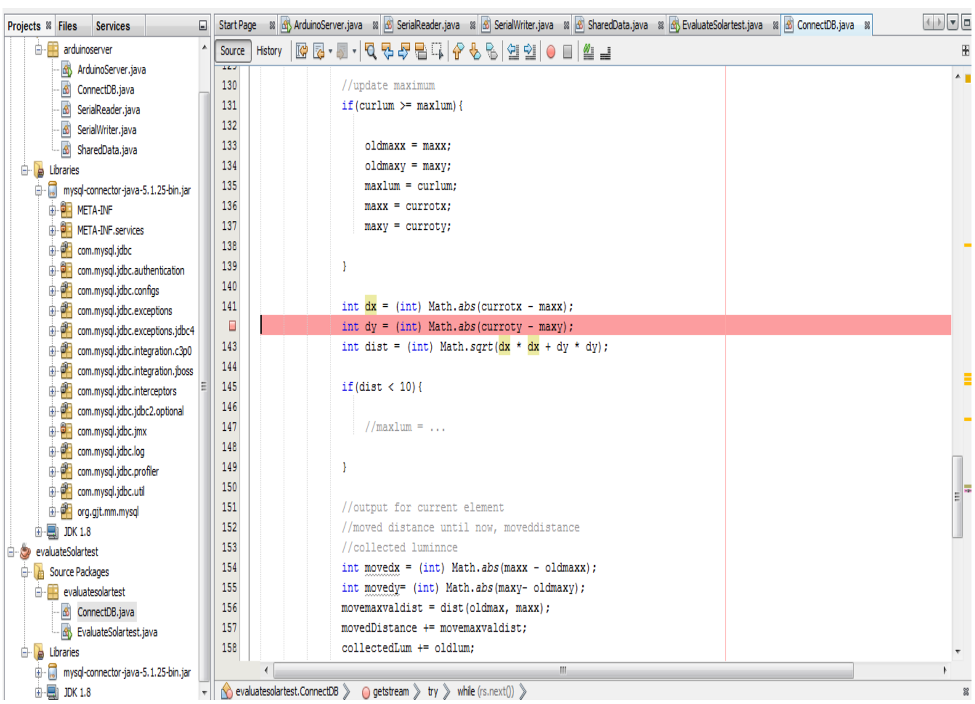


Figure4.6: Code Snippet of Netbeans program for maximum luminance

4.3 Android Studio

Figure 4.7: Android Studio

Android Studio is an integrated development environment (IDE) for developing on the Android Platform. Importing the project via usb to the smartphone using android studio will show changing values. The android application which could run in the smartphone and continuously detect changing values of luminance and also the changing rotation of axis has been developed using android studio. Though the entire process of building an app was time consuming but the results were very satisfying. Once the project was created it was imported to the smartphone as shown in the code snippet. The retrieved values are transferred to the database after enabling the wifi.

It has various features. Such as:

- Flexible Gradle-based build system
- Build variants and multiple apk file generation
- Code templates to help you build common app features
- Rich layout editor with support for drag and drop theme editing
- lint tools to catch performance, usability, version compatibility, and other problems
- ProGuard and app-signing capabilities
- Built-in support for Google Cloud Platform, making it easy to integrate Google Cloud Messaging and App Engine

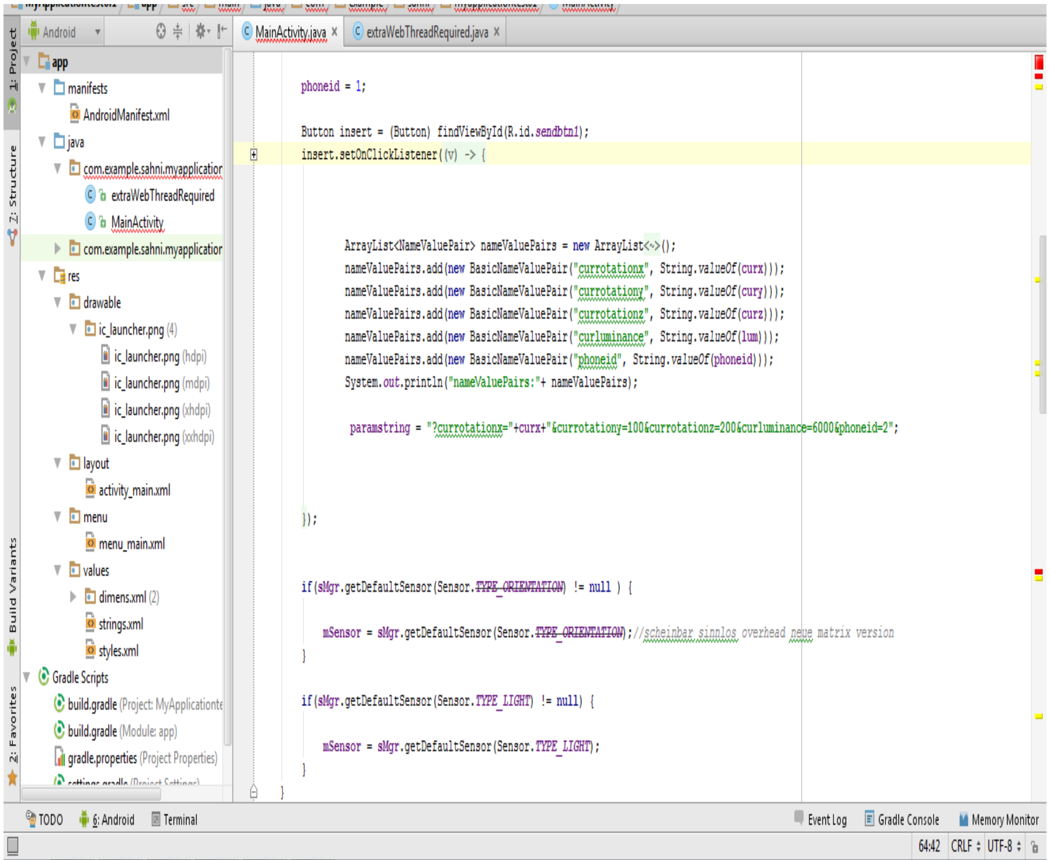


Figure 4.8: Code snippet for creating android app

4.4 Motor Control Preference

In order to organize weight updates (redetection importance, different sensor weighting) and allow extension as comparison indicator for fields of solar panels the preference approach was applied (1). Furthermore to organize motor update in an energy efficient way (updates of motor active state) and with short message format commands, the Preference concept was used to operate on group-value Format (2).The motor control preference is obtained by the movement of the small calibrated motor which is configured with various commands like attach, detach, setup counter etc. The calibration preference is achieved by attaching the motor then setting up a counter which can rotate with 20ms pulse and finally detaching the motor. The MMP (motor movement preference is explained below:

- MMP = f(state) = init : attach, init counter, setup pulse width
  stop: detach motor
  cont. rotation: set rotation speed
  look at: regulation of current position with target max luminance position using tolerance value

In order to deal with these issues the model of sky should be updated by small tracking motor which could explore the entire model of the sky and provide the required values at different positions using an android device i.e. the android smartphone. The android smartphone incorporated with light sensor and gyroscope updates the database upon receiving command from the server. Movement with limited amount of sensors may result in local swings or iterating between distant points. An algorithm has to be defined to regulate motor movement to maximum luminance gain for luminance model. Then motor movement preference on the device software architecture is required supporting continuous rotation and looking at a point has to be realized. Continuous rotation command has to be send from Arduino server via Motor Controller to the tracking device from small motor for field of big panels.

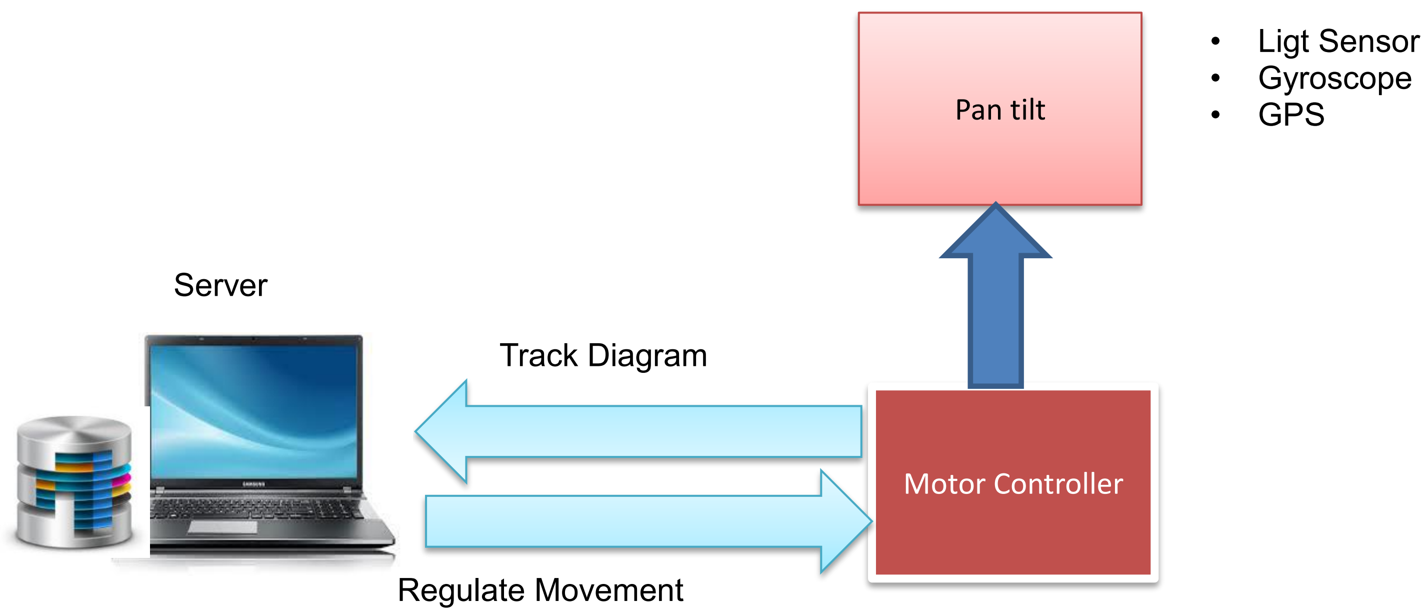


Figure 4.9: Motor Control Preference Diagram

4.5 Architecture

The architecture comprises of many aspects which have been briefly explained in the previous chapters. Firstly, the tracking device which is developed from a servo motor control which works on the pan tilt mechanism giving us the freedom to rotate it on both horizontal and vertical axis and thus providing with varied and good collection of values for testing and reaching to the maximum luminance value. This motor is further connected to the arduino board which provides the s the commands to the servo motor. The software implementation is done via arduino server which is a software platform for the functionality of arduino boards. The commands vary from the manual rotation on 180 degree axis to the auto rotation thus making a convenient circular model via usb connection with the PC.As the energy used is very less for the arduino to run it is very efficient and hence reliable. The clock timer is set and the rotation is dependent on the timer hence giving us values at particular intervals. All this can be achieved with the smartphone which is mounted on the pan tilt which has an in built light proximity sensor which detects the light source and thus helps in obtaining the values in the database via wifi.

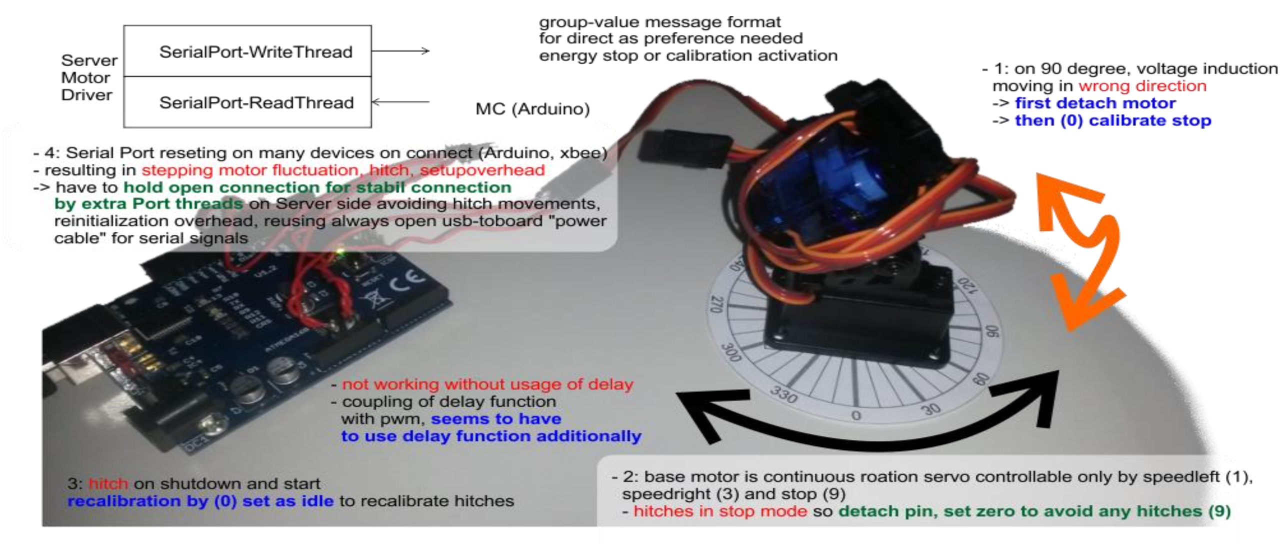


Figure 4.10: Architecture Overview

The smartphone also has a gyroscope which gives provides us with the X, Y; Z axis values. These values are dependent on the particular angle thus defining its orientation. This procedure helps us keeping the values updated in the database. Additionally

NetBeans platform is used to write a java code which helps us to register the values to the database and also retrieve them. A NetBeans IDE is a software platform where JDK is used to provide serial communication. Once the serial communication has been obtained the values can be easily transferred to phpMyAdmin that is the database. The maximum luminance gain is obtained depending on the received values which are integrated to get closer to the desired result. The path covered, distance and also the redetection factor along with maximum luminance considering all the parameters gives the preference for the movement for the big solar panels with the help of a small calibrated motor. A specific algorithm which leads to the final result has been explained in the next chapter which tells how the preference for weighing of position orientation and luminance information under changing motor swings and setup voltage conditions is carried out. The maximum luminance values are transferred through wifi and this serve as the input for the big panel, thus guiding them to move to the exact position than waste energy and detect wrong values. This is possible because we were able to explore the entire sky through exploration. The entire process of using a small motor was to minimize the energy losses which were happening due to the use of heavy motors which would give us random points in the sky assuming it to be the maximum luminance point based on the latitude and longitude values. But to neutralize the assumption exploration process helps to get accurate points thus saving energy and providing accurate results

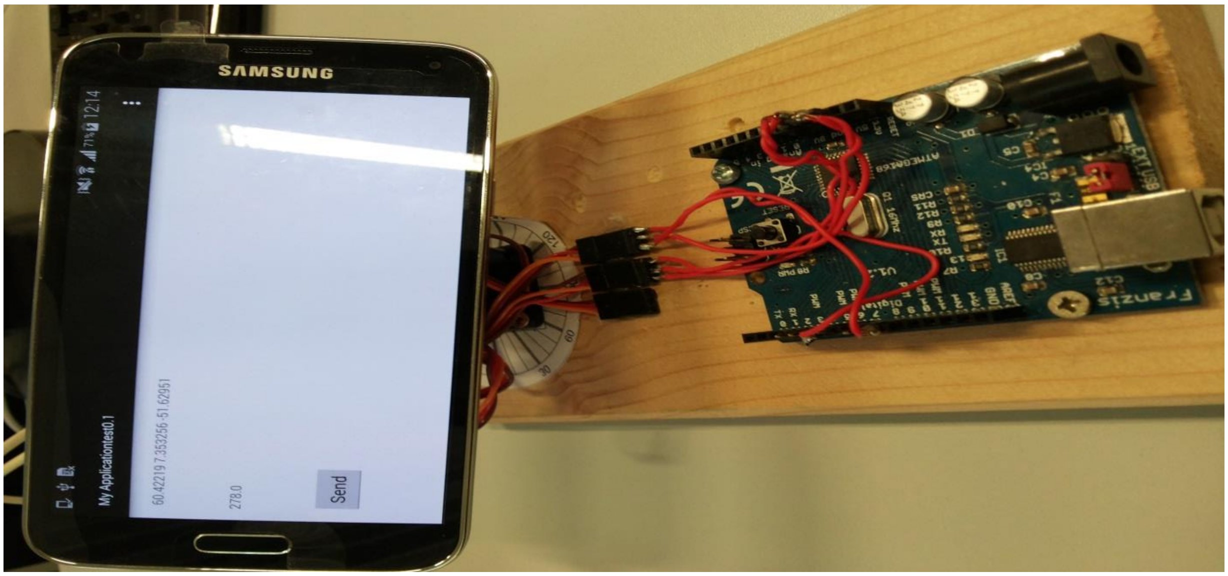


Figure4.11: Proposed Model Diagram

The maximum luminance values are transferred through wifi and this serve as the input for the big panel, thus guiding them to move to the exact position than waste energy and detect wrong values. This is possible because we were able to explore the entire sky through exploration. The entire process of using a small motor was to minimize the energy losses which were happening due to the use of heavy motors which would give us random points in the sky assuming it to be the maximum luminance point based on the latitude and longitude values. But to neutralize the assumption exploration process helps to get accurate points thus saving energy and providing accurate results.

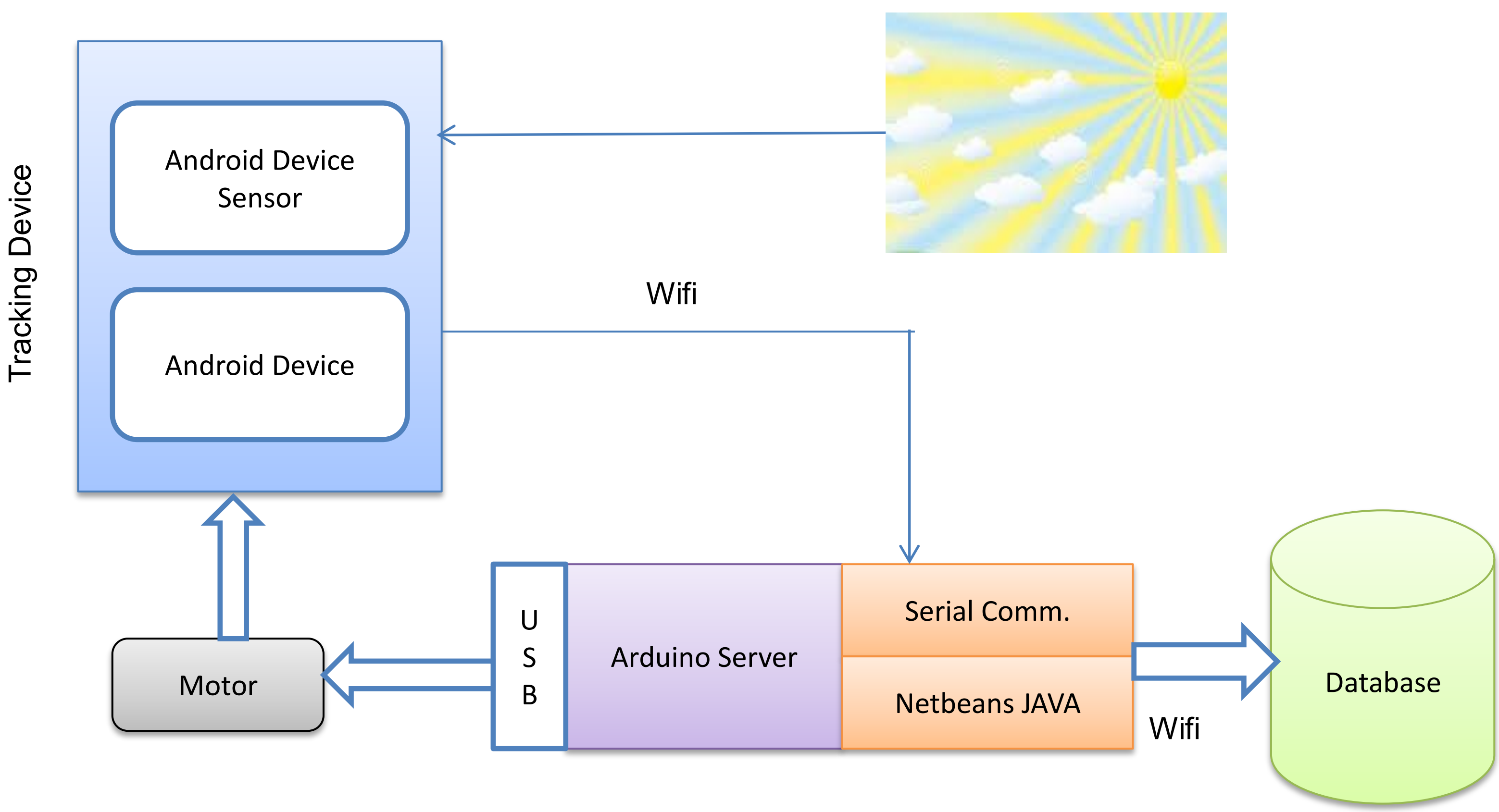


Figure4.12: Architecture Block Diagram of the proposed model

4.6 Algorithm

- Look at point steps
- Based on motor control preference

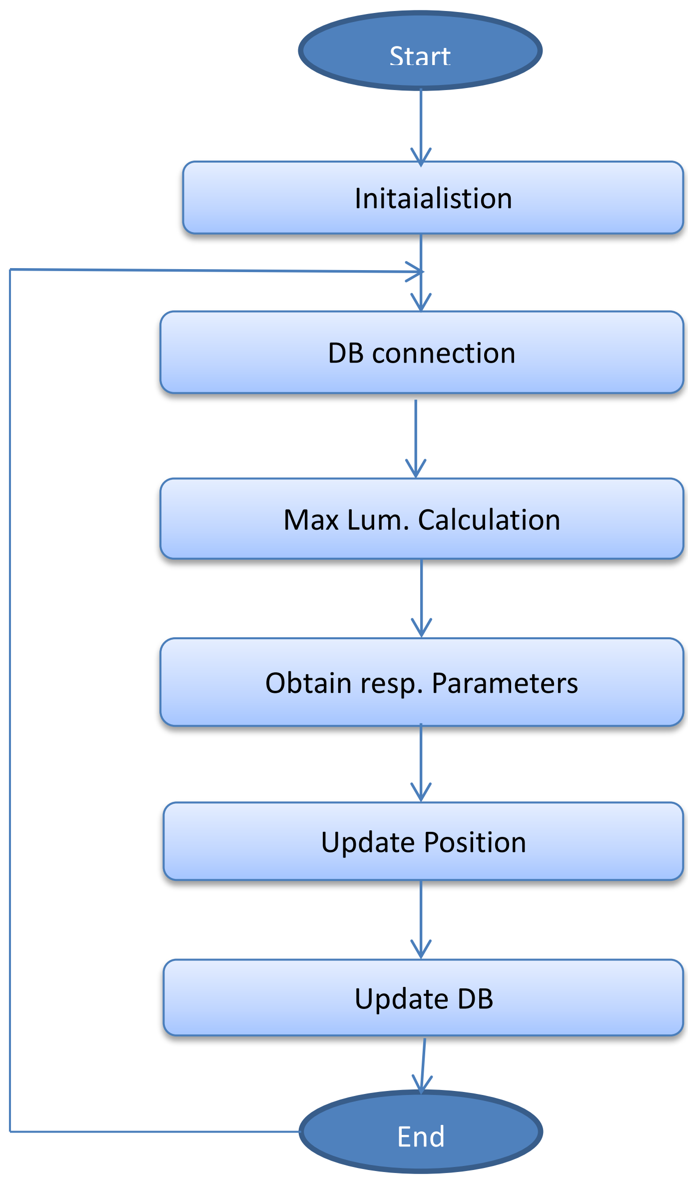


Figure 4.13: Algorithm Flow Chart

The algorithm for the solar panel focusing is very simple and it includes various steps which are explained with the help of a flow diagram. This algorithm is used to look at the point steps which are based on motor control luminance. At the start of the algorithm we first initialize all the components and provide the connection with the database. After the connection has been established the values are collected in the database from the smartphone.

The values are X, Y, Z positions and the luminance values which change continuously with the continuous rotation of the device. These values are updated in the database via wifi which the smartphone has in built. The gyroscope values are also updated. The timer is set for 5min and once we get the required values are a complete iterations, these values are further integrated so as to find the maximum luminance. This can be done by continuous redetections and the integral value of the current luminance to the target luminance after integration gives us the max luminance where the panel should focus and be aligned to in order to get the maximum luminance.

The big panel movement preference depends upon the maximum luminance obtained and the redetections of these parameters and also on the distance covered and also the path gain. The rotation of the big panels is based on the collected model data .The optimal path is selected based on the panel command. Once these parameters are obtained we apply preference for weighing position and luminance information under changing motor swing and setup voltage conditions. Finally the database is updated and this forms a continuous loop and again the database connection is made in order to continue looking for the maximum luminance point with respective parameters.

4.7 Tracking Device: Pan Tilt Mechanism

- Pan degree of freedom
- Tilt degree of freedom

The tracking device is a servo motor control which an amalgamation of two individual mechanisms. When these two mechanisms are combined we get our required motor which can be effectively used for the project. It is a DC motor which rotates smoothly.
It has two axes horizontal and vertical and the y are called the pan degree of freedom and the tilt degree of freedom.

The pan degree of freedom rotates on the horizontal axis whereas the tilt degree of freedom rotates vertically. These movements are combined of two individual motors performing separate set of operations depending on the commands. This kind of movement is very beneficial for our project because it helps to scan the sky in all possible angles and directions and hence providing us with these perfect orientations needed to calculate the maximum luminance for the big solar panels.

Figure 4.14: Arduino servo motor controller

The pan tilt mechanism is very well suited because it has two small motors which do n0ot require a large amount of energy to work and easy to assemble and control. Keeping in mind the reliability, cost and energy efficiency the servo motor control is the best choice to obtain a hassle free movement in both the axis .On receiving the commands the 1m and 180m the motor moves 180 degrees clockwise and anticlockwise. The two motors can be attached or detached as per convenience as both can work simultaneously which has been achieved in this project. The movements are based on a circular rotation so as to give a clear view of the sky and provide innumerable values to work with. Since this process does the exploration of the entire sky we have a lot of values to work with as compared to the big motors or sensors on the panels which give us restricted values, hence not able to find the maximum luminance correctly.

4.8 Motor Control Luminance model

The final step in the architecture and implementation is obtaining the maximum luminance which can be obtained with the help of the target luminance. A maximum limit is set with a timer. Once the rotation is complete and the a set of values have been obtained in the database, the values are iterated from the newest to oldest so that the difference between the current and target luminance can be found out which leads to obtaining the max luminance and this process is a continuous cycle and works in a loop for every iteration. The serial communication helps provide the values in the database and also retrieve it. The motor control preference model keeps on tracking until the timer runs out and a mathematical solution is provided to reach to highest value of luminance i.e. maximum value. This is done with the help of a wifi web service which is connected to the smartphone which provides the basic parameters such as X,YZ axis values and also the luminance values

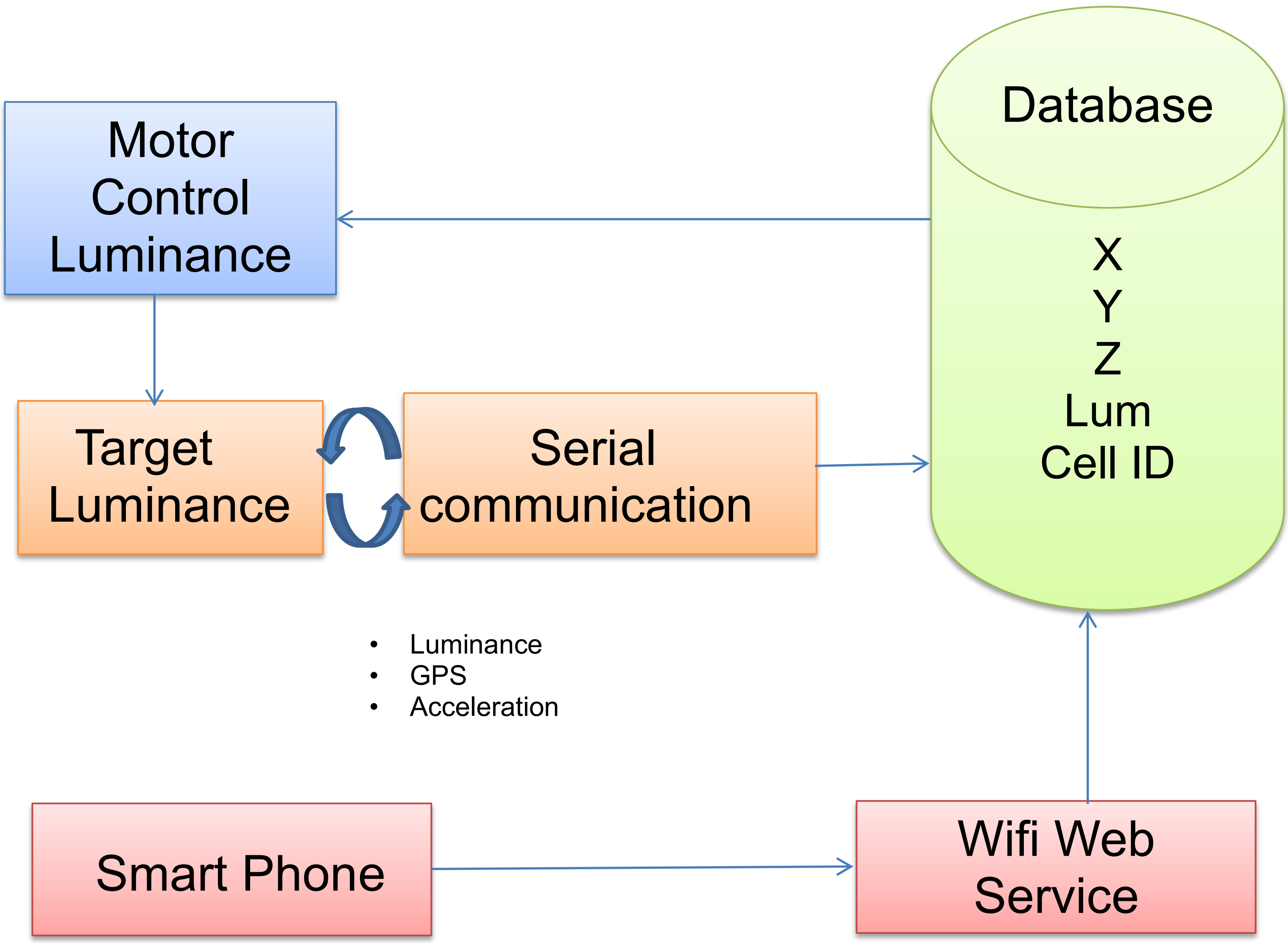


Figure 4.15: Block Diagram of Motor Control Luminance

Redetection

Here is the code how the redetection takes place and how it helps to get more accurate values.

```
  //if(i%2 == 0){

            //current database value
            float newx = resultSet.getFloat("rotx"); //simplified line distance view
            float newy = resultSet.getFloat("roty");
            float newz = resultSet.getFloat("rotz");
            float newlum = resultSet.getFloat("lum");

            double dmaxNew = Math.sqrt((max.x-newx)*(max.y-newx) + (max.y-newy)*(max.y-newy) + (max.z-newz)*(max.z-newz));

            //1. for each reading update max in case of better value or overwriting
            Point n = new Point(newx,newy,newz,newlum);
            Point closest = n.getListClosest(plist);
            double pointpref = newlum;
            if( closest != null ){

                pointpref = closest.lum; //+ closest.lum*0.4*closest.redetect;
            }
            double maxpref = max.lum; //+ max.lum*0.4*max.redetect;


            if(pointpref > maxpref || dmaxNew < 10){

                max.x = newx;
                max.y = newy;
                max.z = newz;
                max.lum = newlum;
            }


            //2. move to max = set max new cur position, and collectlum als dist und lum on path or ends for now
            if(max.x != curx || max.y != cury || max.z != curz){

                double dist = Math.sqrt((max.x-curx)*(max.x-curx) + (max.y-cury)*(max.y-cury) + (max.z-curz)*(max.z-curz));

                if(dist < 1) dist = 1;

                //start und end luminance as increments for now


                collectLum += (curlum+max.lum)-dist;

                curx = max.x;
                cury = max.y;
                curz = max.z;
                curlum = max.lum;
            }
            else{

                collectLum += curlum;

            }

            //redetect optional später in count list halten
```

```
//get min distance to elems in plist
double mindist = 1000000;
int minidx = 0;
int j = 0;
for (Point p : plist) {


    double pointdist = Math.sqrt((p.x-n.x)*(p.x-n.x) + (p.y-n.y)*(p.y-n.y) + (p.z-n.z)*(p.z-n.z));
    if(pointdist < mindist){
        mindist = pointdist;
        minidx = j;
    }

    j++;

}

if(mindist < 10 && (plist.get(minidx).lum-newlum)<30 ){

    plist.get(minidx).redetect++;
}
else{
    plist.add(n);
}


//}//end i mod 2

System.out.println(i+"\t"+df.format(collectLum));
i++;



}
```

4.9 MySQL

The most important factor in this project is the connection to the Database and transferring values to MySQL (phpMyAdmin). It is based on the relational database management system.

The steps required to achieve the connection are:

- Connection to MySQL server to the JAVA program
- Using JDBC
- Load the driver
- Send SQL queries
- Retrieve results

Connection to Database

Figure 4.16: Database

- Table constructed in MySQL
- Parameters are set in the table
- Program connected to the webserver
- Updating of the Luminance value

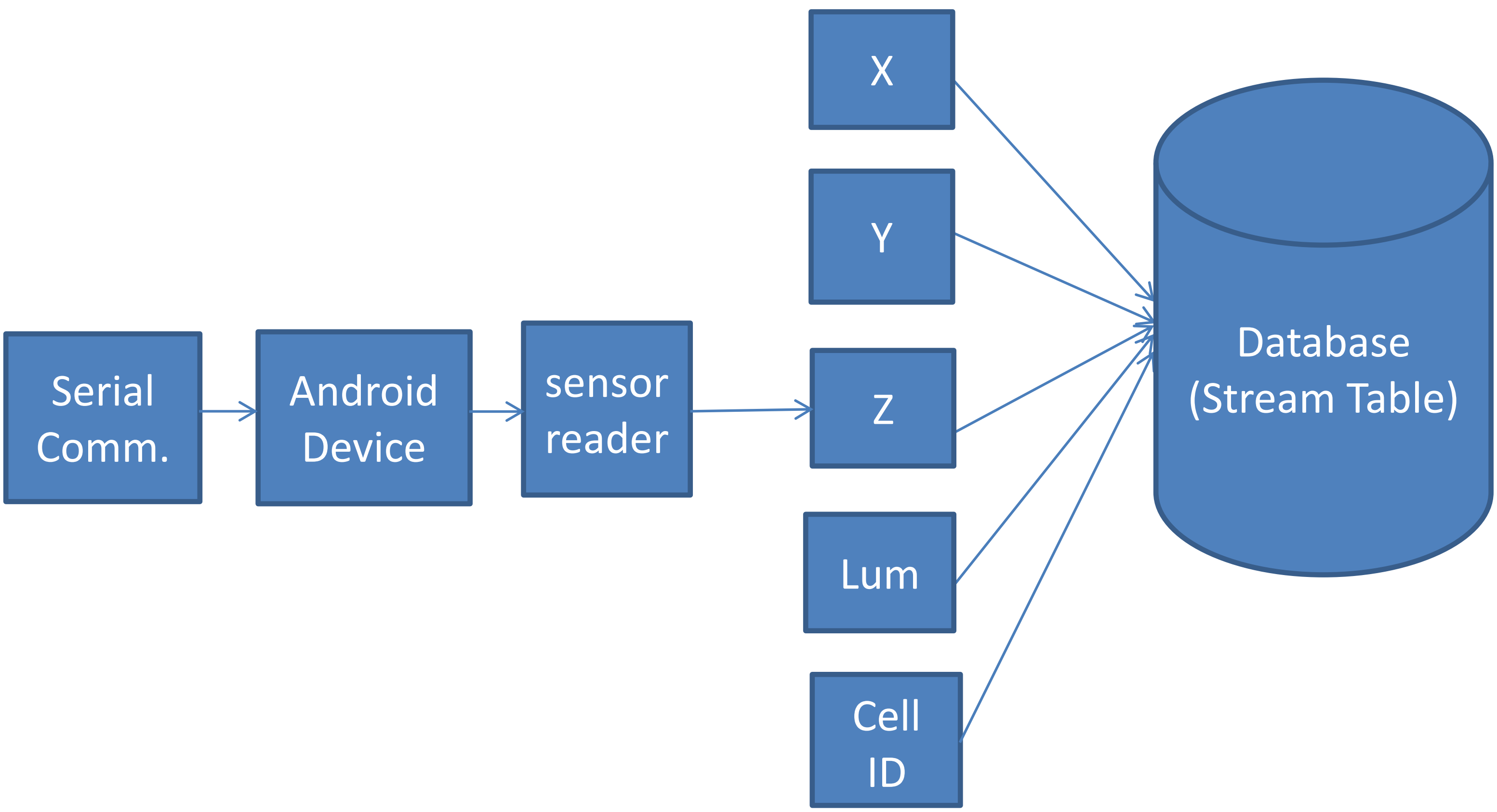


Figure4.18: Block Diagram of Database Connection

4.10 Result analysis

The results are represented in a graphical form which depict the comparison between three models and which one gives the best output. As the comparison shows that the full stream model with redetection improves and reaches a greater accuracy with time when compared to a full model with no redetection or a skip model with redetections. Hence, the goal of this project was achieved as the results are way more productive and precise compared to the existing state of the methods. The solar tracking becomes more efficient and is more reliable to produce precise values for the movement of big solar panels also saving a lot of energy by using a small calibration motor.

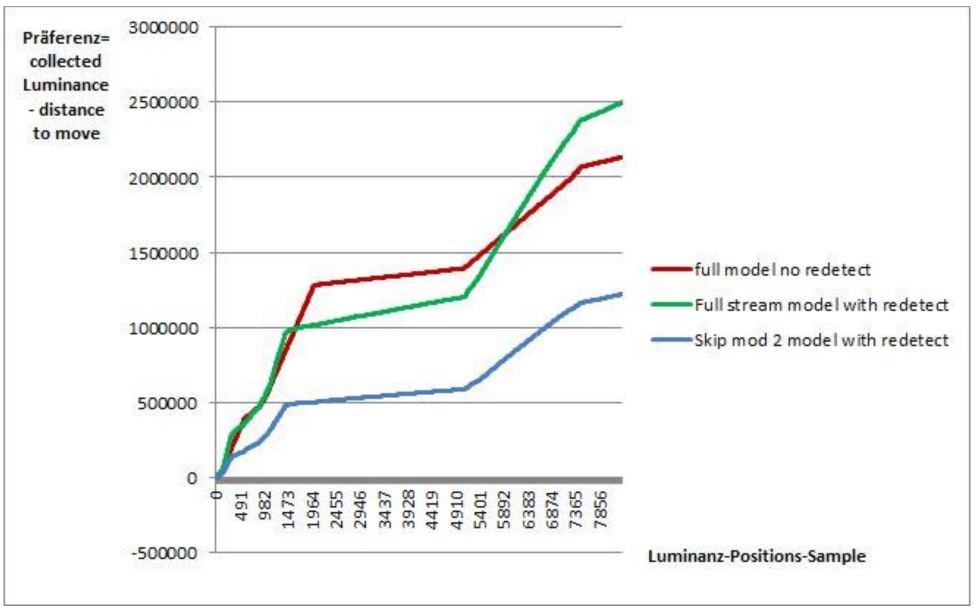
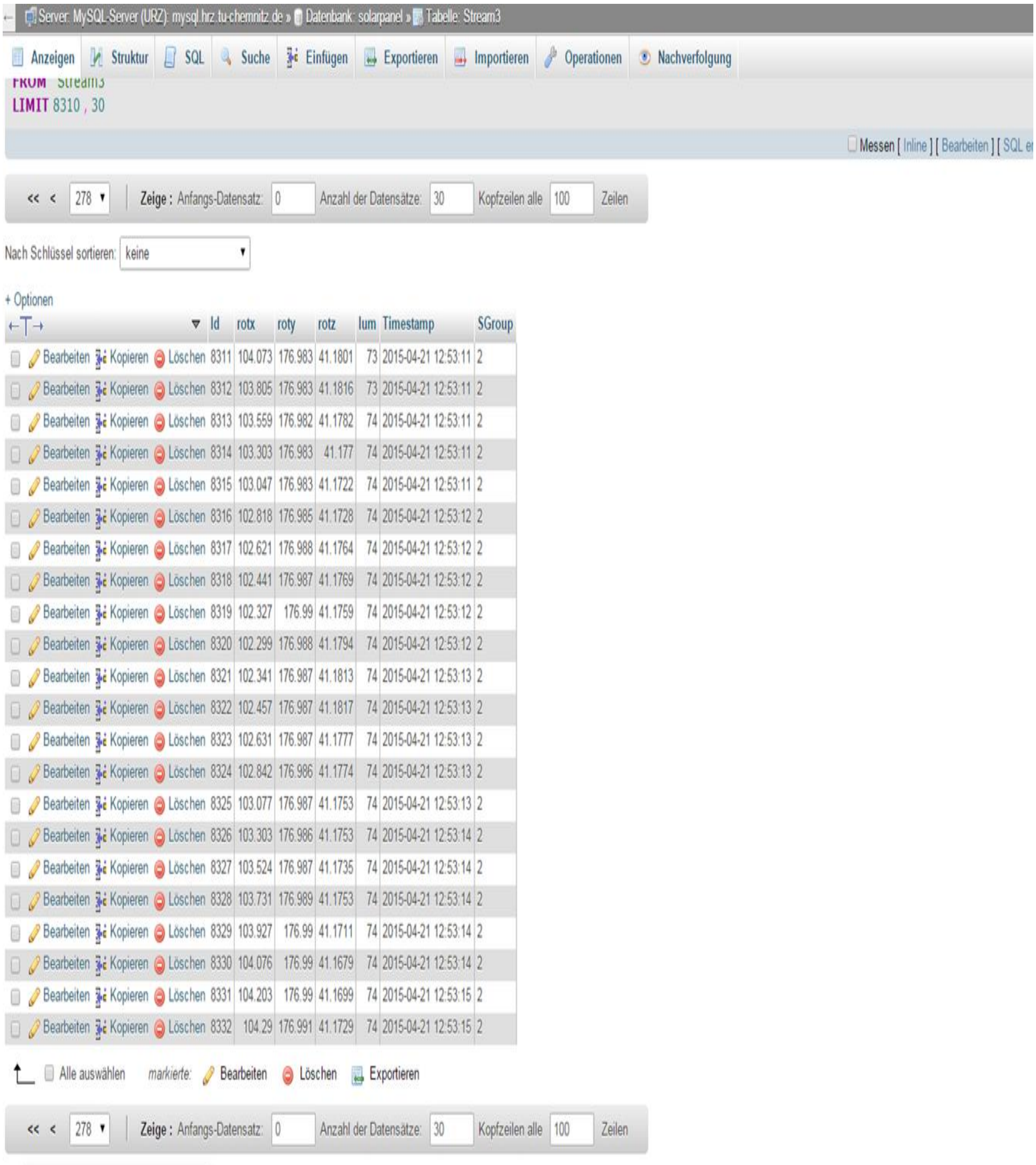


Figure 4.19: Graphical Representation of result comparison



Id	rotx	roty	rotz	lum	Timestamp	SGroup
8311	104.073	176.983	41.1801	73	2015-04-21 12:53:11	2
8312	103.805	176.983	41.1816	73	2015-04-21 12:53:11	2
8313	103.559	176.982	41.1782	74	2015-04-21 12:53:11	2
8314	103.303	176.983	41.177	74	2015-04-21 12:53:11	2
8315	103.047	176.983	41.1722	74	2015-04-21 12:53:11	2
8316	102.818	176.985	41.1728	74	2015-04-21 12:53:12	2
8317	102.621	176.988	41.1764	74	2015-04-21 12:53:12	2
8318	102.441	176.987	41.1769	74	2015-04-21 12:53:12	2
8319	102.327	176.99	41.1759	74	2015-04-21 12:53:12	2
8320	102.299	176.988	41.1794	74	2015-04-21 12:53:12	2
8321	102.341	176.987	41.1813	74	2015-04-21 12:53:13	2
8322	102.457	176.987	41.1817	74	2015-04-21 12:53:13	2
8323	102.631	176.987	41.1777	74	2015-04-21 12:53:13	2
8324	102.842	176.986	41.1774	74	2015-04-21 12:53:13	2
8325	103.077	176.987	41.1753	74	2015-04-21 12:53:13	2
8326	103.303	176.986	41.1753	74	2015-04-21 12:53:14	2
8327	103.524	176.987	41.1735	74	2015-04-21 12:53:14	2
8328	103.731	176.989	41.1753	74	2015-04-21 12:53:14	2
8329	103.927	176.99	41.1711	74	2015-04-21 12:53:14	2
8330	104.076	176.99	41.1679	74	2015-04-21 12:53:14	2
8331	104.203	176.99	41.1699	74	2015-04-21 12:53:15	2
8332	104.29	176.991	41.1729	74	2015-04-21 12:53:15	2

Figure 4.17: Updated Values in the Stream Table

Results

Index	Full stream model with redetect		Skip mod 2 model with redetect		full model no redetect
0	-128,74	0	-128,74	0	-128,74
1	49,26	1	-128,74	1	49,26
2	227,26	2	49,26	2	227,26
3	402,45	3	49,26	3	405,26
4	757,45	4	227,26	4	583,26
5	1113,45	5	227,26	5	761,26
6	1470,45	6	403,45	6	939,26
7	1827,45	7	403,45	7	1117,26
8	2184,45	8	760,45	8	1295,26
9	2542,45	9	760,45	9	1473,26
10	2901,45	10	1118,45	10	1651,26
11	3300,45	11	1118,45	11	1829,26
12	3759,38	12	1537,39	12	2007,26
13	4238,38	13	1537,39	13	2185,26
14	4708,38	14	2007,39	14	2363,26
15	5138,38	15	2007,39	15	2541,26
16	5537,38	16	2437,34	16	2719,26
17	5936	17	2437,34	17	2897,26
18	6396,39	18	2896,65	18	3075,26
19	6934,33	19	2896,65	19	3364,11
20	7212,33	20	3432,4	20	3642,11
21	7765,64	21	3432,4	21	3920,11
22	8048,64	22	3712,4	22	4467,03
23	8331,64	23	3712,4	23	4748,03
24	8614,64	24	4253,15	24	5029,03
25	8897,64	25	4253,15	25	5310,03
26	9180,64	26	4534,15	26	5591,03
27	9463,64	27	4534,15	27	5872,03
28	9746,64	28	4815,15	28	6153,03
29	10029,64	29	4815,15	29	6434,03
30	10534,29	30	5096,15	30	6715,03
31	11057,13	31	5096,15	31	6996,03
32	11553,67	32	5582,69	32	7277,03
33	11969,85	33	5582,69	33	7558,03
34	12150,85	34	5822,69	34	7839,03
35	12331,85	35	5822,69	35	8120,03

36	12512,85	36	6062,69	36	8401,03
37	12693,85	37	6062,69	37	8682,03
38	12874,85	38	6302,69	38	8963,03
39	13055,85	39	6302,69	39	9244,03
40	13236,85	40	6542,69	40	9525,03
41	13417,85	41	6542,69	41	9806,03
42	13598,85	42	6782,69	42	10087,03
43	13779,85	43	6782,69	43	10368,03
44	13960,85	44	7022,69	44	10649,03
45	14141,85	45	7022,69	45	10930,03
46	14322,85	46	7262,69	46	11211,03
47	14608,46	47	7262,69	47	11492,03
48	14964,8	48	7601,64	48	11773,03
49	15321,45	49	7601,64	49	12054,03
50	15680,3	50	7957,42	50	12335,03

Chapter 5

Summary and Outlook

To save fossil fuels for the future generations and to preserve them, we have to opt for new alternate sources of energy. To achieve this we need to implement this idea by which we can gain maximum efficiency and accuracy in solar power generation. The movement of a circular model is very smooth and it provides better reliability which saves more energy as compared to the prediction method of the dual axis tracker. More values were obtained by exploration of the sky which enabled to get closer to the desired result and obtain the maximum luminance gain over a path gain. A small calibrated motor using motor movement preference was configured which continuously reads data from various sensors and stores it in the database The values were helpful for the mathematically correct rotation based on the GPS coordinate system. The values were obtained after repeated iterations which were used to guide the big solar panels to move to highest point which gives the maximum luminance. A latency vector was introduced for the smooth movement. This in turn helped the movement of the big solar panels. The obtained values after being stored in the database were integrated for better performance in the next loop. The Redetection factor was introduced to reduce the anomalies caused during the process so that more accurate points were obtained for the rotation of the big solar panels. As a result by aligning the panel using small motor up to 50% of energy was saved during the process. The luminance across the entire path was considered to maximise the gain. When compared to the state of the art big panel movement using big heavy calibrated motors it can be concluded that the proposed model in the report is much faster ,components are easily available, very less setup time, obtains more data amount which makes it a fast model update. . Several tracker technologies currently are available on the market. However, the different tracker technologies come with different characteristics such as the additional cost of maintenance, added cost of solar power unit at installation, accuracies of tracking, reliability and effectiveness in improving efficiency. The designed system requires minimum maintenance with a practically good level of improvement of system efficiency for the comparative cost of acquisition of systems of similar output capacity and provides detailed operational knowledge at an unprecedented level.

Bibliography

1. Reissner, D.; Caspar, M.; Hardt, W., Energy-efficient adaptive communication by preference-based routing and forecasting, *11th International Multi-Conference on Systems, Signals & Devices (SSD)*2014, 11-14 Feb. 2014

2. Daniel Reißner, Wolfram Hardt "In Process Homogeneous Object-Binding Structure for Preference Zone Based Decision Making", Knowledge-Based Software Engineering 11th Joint Conference JCKBSE 2014, Volgograd Russia, September 17-20, 2014

3. Android Sensoren, acc, luminance, http://developer.android.com/reference/android/hardware/SensorManager.html

4. Hardware Modelling Of Automatic Solar Tracking System Srinivas Arun Tej P, Kalaiarasi N, S.S Dash

5. O. Bingöl, A. Altintaş, Y. Öner -"Microcontroller based solar-tracking system and its implementation"

6. T. Tudorache, L. Kreindler -"Design of a Solar Tracker System for PV Power Plants "

7. H. Mousazadeh, A. Keyhani, A. Javadi, H. Mobli, K. Abrinia, and A. Sharifi, "A review of principle and sun-tracking methods for maximizing solar systems output," Renewable and Sustainable Energy Reviews, vol. 13, no. 8, pp. 1800–1818, 2009

8. SIPS: Solar Irradiance Prediction System Stefan Achleitner∗ Computer Science and Engineering The Pennsylvania State University, University Park, PA 16802 ,Tao Liu and Alberto E. Cerpa Electrical Engineering and Computer Science University of California, Merced, CA 9534

9. Jazayeri, M.; Uysal, S.; Jazayeri, K., "Experimental analysis of effects of installation alignment and solar insolation on power generation by solar panels," *Global Humanitarian Technology Conference (GHTC), 2013 IEEE* , vol., no., pp.35,40, 20-23 Oct. 2013;

10. Vasile, A; Drumea, A; Neacsu, C.; Angel, M.; Stoichescu, D.A, "Automatic system and energetic efficiency optimization algorithm for solar panels on mobile systems," *Electronics Technology, 2009. ISSE 2009. 32nd International Spring Seminar on* , vol., no., pp.1,5, 13-17 May 2009

11. Chong, K.K.; Wong, C.W. „„General formula for one-axis sun tracking system and its application in improving tracking accuracy of solar collector Solar Energy.

2009, 83, pp.298-305.

12. A.,Boudinov, H. “Design and construction of a system for sun-tracking”, Renewable Energy. 2004, 29, pp.393- 402.

13. Roth, P., Georgieg, A.,Boudinov, H. “Design and construction of a system for sun-tracking”,
14. Renewable Energy. 2004, 29, pp.393- 402.

15. Saxena, A.K.; Dutta, V., “A versatile microprocessor based controller for solar tracking,” Photovoltaic
16. Specialists Conference, 1990., Conference Record of the Twenty First IEEE, 21-25 May 1990, Page(s):1105 -1109 vol.2 .

17. Pritchard, D., “Sun tracking by peak power positioning for photovoltaic concentrator arrays,” IEEE
18. Control Systems Magazine, Volume 3, Issue 3, August 1983, pp. 2 – 8 .

19. T, Esram and P.L. Chapman, “Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques,” IEEE Transactions.

20. G. Chicco, J. Schlabbach and F. Spertino, “Performance of Grid-Connected Photovoltaic Systems in Fixed and Sun-Tracking Configurations”, in *IEEE - Power Tech*, Lausanne, 2007, pp.677-682.

21. T. Tudorache and L. Kreindler, Ed, “Design of a Solar Trackers system for pv power plants,” *Acta plytechnica Hungarica*, Vol. 7, No 1, 2010.

22. O. Gouda, G. Amer, T. Elkhodary, and M. Awaad, “Optimum Design and Implementation of Tracking PhotoVoltaic Power System based on Plc and Micro Controller,” *14 th international middle east power system conference*, Dec, 2011, paper ID-128.

23. Y. J. Huang, T. C. Kuo, C. Y. Chen, C. H. Chang, and P. C. Wu ,“The Design And Implementation of a Solar Tracking Generating Power System,” *Engineering Letters*, 17:4 EL_17_4_06.

24. http://www.qbotix.com/