A SMART POWER MANAGEMENT SYSTEM BASED ON GIS, RADIO SENSOR NETWORKS, AND CROWD-SOURCED DATA

FINAL YEAR PROJECT UG 2012

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This is to certify that the

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for the undergraduate degree

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ABSTRACT

This thesis is based on our project entitled **"A Smart Power Management System based on GIS, Radio Sensor Networks and Crowd-Sourced Data."** The main point of this project was to conceptualize the idea of smart off the grid mapping of the consumption of the electricity by the user, provided through volunteered geographic information and also develop a hardware device to acquire the irradiance data in real-time environment. The application consists of three modules, a web interface both for the consumer and the administrative users, a mobile application (initially for android) and a prototype for solar energy production mapping at household level. The website interface facilitates the user as well as the admins by providing a dynamic view of the areas along with their respective solar irradiance. The main contribution is focused on the user end who has to provide the usage data in order to get his trends of consumption. Consequently, the more accurate results the user provides, the more resourceful analysis he would enjoy. On the other hand, those users who are unable to install the device can also get an idea about the potential in their vicinity through our android application which allows them to know the irradiance potential in their vicinity along with the Euclidean distance to the place where the measurement was taken with the device.

DEDICATION

We dedicate our work to the untiring efforts of our parents, teachers, friends, colleagues and administrative staff of the institute who had supported us throughout our academic years and without their support we would not have achieved our goals.

ACKNOWLEDGEMENTS

All praises be to Allah almighty for bestowing upon us the knowledge, strength and power to accomplish our tasks.

We are very much thankful and grateful to our project supervisor Dr. Salman Atif who guided us at every step of the project with his expert knowledge and innovative ideas. We are gratified by his help and support that enabled us in accomplishing our tasks in time.

We would also like to thank the administrative and I.T. staff our institute and the staff of Applied Electronics Lab of Institute of Applied Electronics and Computing for their support in our device validation phase.

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
GIS	Geographic Information System
RS	Remote Sensing
IoT	Internet of Things
POI	Point of Interest
OCR	Optical Character Recognition
WAN	Wide Area Network
DBMS	Database Management System
PV	Photo Voltaic
GPS	Global Positioning System
URL	Universal Resource Locator
API	Application Programming Interface
SDK	Software Development Kit
IDE	Integrated Development Environment
XML	Extensible Markup Language
DIY	Do it yourself
VGI	Volunteer Geographic Information
LAPP	Linux Apache PostgreSQL PHP
HTML	Hyper Text Markup Language
CSS	Cascading Style Sheets
SCADA	Supervisory Control and Data Acquisition System

CHAPTER 1

INTRODUCTION

1.1 Background Information

Pakistan is situated in a region where its land enjoys sufficient sunlight. Sufficient enough to harness the power of sun in fulfilling its basic needs of energy. The research done on identifying and mapping those regions which can prove to be quite resourceful in generating renewable energy is being carried out at different scales.

Energy is the “oxygen” of the economy and the life-blood of growth, particularly in the mass industrialization phase that emerging economic giants are facing today as their GDP touches the raises. We can somehow induce a direct relation between energy and economic growth.

Pakistan, being a developing nation, is currently unable to meet its energy demands through conventional means, be it hydel, thermal or nuclear but the concept of smart grids has never really been implemented. A smart grid is an electrical grid which includes a variety of operational and energy measures including smart meters, smart appliances, renewable energy resources, and energy efficiency resources. Smart grid technologies emerged from earlier attempts at using electronic control, metering, and monitoring.

People are also unaware of the significance of the renewable energy and the potential that their houses and buildings possess. The utilization of different DIY devices and sensors provide us with the opportunity to get real-time data within a reasonable cost constraint. Such systems are currently addressing major problems of the information technology domain as they are, if not above, compete with various sophisticated devices which are either expensive or require additional proprietary technology to work with it.

1.2 Objective

The main objective of the project was to conceptualize the idea of smart off-the-grid mapping of power consumption data provided by the user though a VGI-enabled smartphone application and to develop a smart device capable of transmitting real-time data of the solar irradiance to the server where it can be analyzed and visualized in the form of heat map.

1.3 Literature Review

Marcel Súri in *A New GIS-based Solar Radiation Model and Its Application to Photovoltaic Assessments* mainly based the study on r.sun model and its authenticity as compared to other available products. r.sun is a model that estimates the solar radiation during the clear sky and the overcast conditions too. The most important work of r.sun model is that it relieves us from the headache of calculating the solar radiation from the ground data sources by applying difficult and ambiguous techniques like spline function, weighted average techniques etc.

This article also discussed the relationship of solar radiation with different kind of landscapes. The solar radiation is effected by Earth's revolution and rotation, the terrain and atmospheric devaluation like scattering and absorption. After discussing these factors, this article focuses in the implementation of the Solar Radiation Model, this model works in GRASS GIS.

Marcel Šúri in *PV-GIS: a web-based solar radiation database for the calculation of PV potential in Europe* basically studied the concept of making their own GIS database for Europe to map the solar radiation as well including three web applications along with it. It also features some climatic parameters that are required for pointing out the most suitable locations for PV electricity generation. One of the web application includes the feature of letting the user browse through the radiation maps. The second web application tells the user about the daily solar radiation of the designated area and the last web application estimates the amount of electricity that we can generate at a particular area using the radiation data.

The basic model that is being utilized to find out the solar radiation was r.sun. The elevation factor was also eliminated using different equations to make the data more reliable. Along with the ground calculation of the irradiation data, the clear sky global irradiance (Ghc) was also calculated. These global sky irradiances were calculated for particular steps, horizontal surfaces as well as on monthly basis. For calculation of the global irradiation, the cloud cover data was also incorporated to make the data more authentic. It was found after thorough study and numerous calculations that the clouds and the shadowing caused by the nearby feature have different effect on the irradiance values.

The most important part of this project was to impose all of these calculations on a platform so that it might be able to help the general public, so they devised three web base applications for this purpose. First one of the web applications enabled the user to visualize different maps about the solar radiation and related climatic data. The second web application enabled us to estimate the average daily irradiance variation, and the third of the web application was used for the estimation of PV potential.

The results of this product was a consistent GIS database that had never been made before, containing the data about the solar irradiances and climatic parameters. But the major flaw of this project was that it only covered Europe, whole of the world is still deprived of simple irradiation data.

Furthermore different aspect of this model are discussed in detail such as Beam Radiation, diffused radiation for the sunny areas as well as areas with shadows, ground reflected radiation. The significance of this model is further highlighted in this article by describing in detail the fact that radiation can be calculated under overcast condition as well, and formula for this very purpose is also discussed in detail. In the end, r.sun model is compared with the ESRA database and average RMSE is calculated which shows that both have almost the same accuracy.

L. H. Tsoukalas in *From Smart Grids to an Energy Internet: Assumptions, Architectures and Requirements* took an initiative to make people and administration aware of the fact that they need a better transmission and distribution network for the electricity delivery. This all is possible by studying the grids network in detail. The estimated loss due to faulty transmission in USA alone is 80 billion dollars annually, so you can just imagine how much we can save using smart grids around the world. This complex grid network would only be efficient if different components of the system interact meaningfully with each other, incorporating features like self-healing mechanisms so for such a network, internet is considered to be the best way.

A smart grid can detect and correct the incipient problem at a very early stage, can respond to a broader range of information, possesses rapid recovery capability, adapts to changes and reconfiguring accordingly, builds a reliability and security from design and provides operators useful visualizations.

The major setback in the way of smart grids that is being discussed in this article is lack of significant energy storage capacity inside the smart grids but this too can be overcome by using the concept of virtual buffer which enables the users to manage their machine in more intelligent and efficient manner for example the laundry might be shifted to sometime when the workload on the grid is minimal. This process may also be termed as dynamic scheduling, which can turn out be the solution to our future and current energy shortfalls. As we know the, this smart grid systems relies heavily on the prediction, which can fail us at times too but we can cover those failures with the help of precise elasticity models. Using these elasticity tools, customers can negotiate with the supplier to obtain a delicate balance between the generation and the consumption and hence, we can solve our problem of ambiguous predictions.

More so, architectures of the smarts grids are discussed in this article, which include Smart meter with unique address and communication capability, Forecasting capability, multi resolution agents which includes the usage of intelligent agents based on internet that can act on the behalf of their clients to act rationally as they are equipped with sufficient knowledge. Short term precise elasticity model is also one of the key architectural candidates for the internet energy.

In the end, the authors conclude that internet energy can be answer to our most of the future problems but it relies on the further advancement of the technologies that are currently in use. Overall the concept of the smart grids can be a life saver but it requires integration of other works such as economics, regulation, market structures and resource management.

Li Li in *The Applications Of WiFi-based Wireless Sensor Network in Internet of Things and Smart Grid* concentrated on integration of internet of things along with the smart grids, smart agriculture and intelligent environment protection using Wi-Fi as the communication medium. Internet of things refer the interconnection of our daily life objects. It connects the thing with the electronic tag that are 2-Dimensional codes on the object. There are four basic components of IoT namely information collection, two way transmission, treatment and feedback control. The most important part of IoT is said to be smart grids and ever since its inception, it has been a favorite subject of the government as it involves the computer control technology over the existing electricity distribution infrastructure.

Most of the countries now have realized the importance of smart grids and are working on their own smart grids. The article then discusses the development of smart grid in United States. IBM is currently working on smart grids in USA and have also given a proposal, it was named as ‘central nervous system’ of the whole of the power system. The most authentic way to make customers believe in smart grids is to make them realize that it would help them reducing their overall power bills. Japan is also following the footsteps of USA as their government announced the plan to build smart grids on large scale and their main focus is to integrate the smart grids with the solar power. European countries are also not far behind in terms of IoT as countries like Britain, France and Italy are already working on the smart grids while other countries are planning to implement it as soon as possible. China is one of the biggest economy of the world, they too are planning to invest on smart grids, and they are using UHV grids to build their smart grids as they too have realized that they cannot survive without one. The three stages of internet of things are currently under development, first one is information collection, second one collaborative awareness stage and the last one is about extensive polymerization.

The Wi-Fi based sensor networks are discussed in detail in this article, because of the fact that they are low power consumption node and are highly accurate as well. Some of the basic advantages of the Wi-Fi sensors are high bandwidth, non-line-of-sight transmission, large coverage area, cost effectiveness, easy expansion, storage robustness, and small disturbance of the links.

The application smart grids are massive, they include the smart power generation, intelligent power use and intelligent substation and transmission. The most important part in smart grid is data collection. The communication lines must be perfect. Smart grids also use the technology of Power Line Carrier Communication which are either based on the fiber or wireless network. Some of the major applications of the internet of things are in the smart grids, intelligent environment protection, precision agriculture which is about making certain predictions using the factors like wind, air humidity, soil moisture etc.

At the end, the writers conclude to the fact there is a fair possibility of connecting all the objects to internet of things using a very new kind of technology called Wi-Fi and if it is somehow realized someday, would only help us improve.

S.D. Grigorescu1 in *Power Quality Monitoring Systems for Smart Grid Networks* studied the concept of smart grids and green energies and also highlighted the power tools that are required to build these smart grids. Smart grids focuses hugely on the power quality as the use of smaller or larger energy generators in typical networks but most of the power quality analyzers have not yet developed a mathematical formula for a particular standard. The authors, utilizing their own field work experience in measuring the power quality parameters have worked to develop a better tool for the measurements of quality of smart grid systems.

The authors have developed a system called SEMCE DAQ which consists of eight channel acquisition boards and deals with the continuous data and monitors the electrical parameters as frequency, harmonics, power, current and voltage etc. This system is used to perform a 24 hours long analysis on these datasets from which we can extract the values for our needs. Using these statistical calculations, a database is build. This system also incorporates a subsystem that is used for communicating with other users in the network using VPN. The dedicated PC has a software module installed, which works as a server 24 hours a day. The equations used to calculate the harmonics and THD are also discussed briefly.

The software is designed in such a way that even a lay man could use it easily. The 3 seconds and 10 seconds data analyzes this model. Based on this stored data, calculations are visually displayed as tables and charts. The reactive power in non-sinusoidal circuits that is very ambiguous to calculate is also discussed in the article.

Following are the key elements of architecture of the software:

1. Communication driver.
2. Multi window data for data processing.
3. Database access interface
4. Application software based on calculation and visualization window.
5. Communication software

In the end, it was concluded from whole of the study that the monitoring solution is really powerful and abides by the international standards, and its accuracy is pretty impressive as well so the study was success overall. The outlook of the software application integrated with the web and implemented on PC allow future development and the value of data transmission should never be neglected whenever you consider smart grids.

In this article the integration of IoT with the modern cities is discussed in detail. A large number of different systems can be incorporated in to Internet of Things, while the selected subset of the data can be provided open access for the development of the multiple other departments It usually requires a lot of expertise and time to develop an architecture for IoT mainly because of the fact it is so versatile and requires so many devices to work collectively at a time, sharing data with each other, providing numerous services that too are connected to each other in one way or other, so this paper is all about integration of IoT technologies into an urban must be system. This category is very broad in itself too and is classified in to different categories for our ease. Urban IoT's main aim is to exploit the best and the most advanced technologies to improve the daily life of the citizens and to provide administration a multiple services to improve the daily living standards. This article contain a hefty research about all of the trick and technologies that could be used to help the urban IoT and discusses a smart project named as Padova Smart City Project, which is a conceptual design of an IoT city in Italy.

Andrea Zanella in *Internet of Things for Smart Cities* discussed the integration of IoT with the modern cities. A large number of different systems can be incorporated in to Internet of Things, while the selected subset of the data can be provided open access for the development of the multiple other departments It usually requires a lot of expertise and time to develop an architecture for IoT mainly because of the fact it is so versatile and requires so many devices to work collectively at a time, sharing data with each other, providing numerous services that too are connected to each other in one way or other, so this paper is all about integration of IoT technologies into an urban must be system. This category is very broad in itself too and is classified in to different categories for our ease. Urban IoT's main aim is to exploit the best and the most advanced technologies to improve the daily life of the citizens and to provide administration a multiple services to improve the daily living standards. This article contain a hefty research about all of the trick and technologies that could be used to help the urban IoT and discusses a smart project named as Padova Smart City Project, which is a conceptual design of an IoT city in Italy.

In the end, the authors discuss the solutions that are currently available for the use in urban IoT field. All of the technologies that were mentioned in this paper are kind of standard and are in one way or another already being used industrially and we can easily take advantage of those technologies easily by integrating them into our system of urban IoT. It also focuses on the fact that where the range of the devices available for us to integrate with the our system, it must also be considered that set of open protocols are smaller in number but still all of these technologies can combine to fulfill our main goal, that is to make an urban IoT. Once it’s done, it would further pave way for more innovative and efficient IoT technologies and at the end a concrete proof of urban IoT, the city of Pandova is also discussed.

Jayavardhana Gubbia in *Internet of Things (IoT): A vision, architectural elements, and future directions* proposed the development of Wireless Network Sensors (WSNs), their daily life usage and how can we integrate it with the IoT. Using these sensors we can measure different ecologies and understand them briefly to incorporate them in our IoT. The combination of such information yielding sensors would automatically result in Internet of Things. The set of communicating sensors can also enable us to develop Common Operating Picture. Along with these WSNs we can also use some modern technologies such as RFID tags and embedded sensors that can act as actuator nodes and the internet of things is revolutionizing the web architecture as well. As we continue to our way from www to web2.0 and web3.0, we are actually moving towards the IoT in a rather fast lane and need for the data to solve specific problems and queries is increasing day by day. This paper presents a central vision for the implementation of IoT technologies on a very large scale, worldwide may be. The main and important technologies and domains are discussed in detail in this paper. Aneka which is formed by the communication of public clouds with the private clouds is also discussed as the possibility and we need to converge the WSNs, the internet and the distributed in order to make IoT engulf the World.

At the end, the authors conclude by laying emphasis on the communication technologies yet again as according to them they are bringing closer the vision of Internet of Things, where the sensing and communicating functionalities integrate with each other giving rise to rich new sources for the information. According to the authors, the evolution of the new systems like mobile solely lies on the way the application would be designed on them and IoT would benefit from it the most. In this paper a revolutionary idea of user-centric cloud based model for obtaining this goal, which allows the necessary flexibility to meet the diverse need of different sectors. A scalable cloud network is proposed to utilize the IoT. We can compute, network, store and visualize things using this framework which provides us the facility of independent growth as well. The cloud at the center of the system would only help it. The challenges that we are going to face are also being highlighted which include the appropriate interpretation and visualization of large amount of data set, the security challenges and the data management issue as everything is done on a massive scale but whatever challenges we are facing, they will stop the international community from embracing the Internet of Things sooner or later.

In another article named as Solar thermal power plants for solar countries — Technology, economics and market potential the authors Helmut Klaiß, Rainer Köhne, Joachim Nitsch, Uwe Sprengel discuss the prospects of thernam power in detail. According to them solar power plants can be the answer to the ever growing needs of the residential and industrial needs without considering the fossil fuels into the frame, and can cause the global CO_2 emission to reduce drastically.

In the very beginning of this article, the economic and technical aspects of the solar power plants are being discussed. By the inclusion of certain experiments it is proven that solar power can be integrated with the normal power plants and utilities to produce the decentralized electricity supply chain. Experiments were carried out on the power demand of twenty five of certain Mediterranean countries and strategies to implement the solar power are devised. These experiments and strategies also kept the economic activities of the region under consideration as well as focuses on the infrastructure and the already present electricity grids.

We observed the findings of another article, “*The potential of concentrating solar power in South Africa*” by Thomas P. Fluri in detail as well. In this article, Geographic Information System has been used to identify all the potentially good sites for the implementation of solar power at a large scale in South Africa. The areas are considered if they fulfill the following conditions:

- Suitable land use profile
- Vegetation is not vulnerable to any disease
- Area gets sufficient solar exposure
- Close to transmission lines
- Area is sufficiently even

Different maps indicating the places with different amount of potential regarding solar potential have been created. Installations of parabolic trough plants are usually taken in to consideration. It was estimated that around a total of 547 GW of electricity can be produced if we are to utilize all of afore mentioned potential sites efficiently.

The next article from which we took some help from was “Smart Grid — The New and Improved Power Grid: A Survey” by Xi Fang ; Tempe, Satyajayant Misra ; Guoliang Xue ; Dejun Yang (IEEE). The next generation of power grids is dubbed to be the Smart Grids. They use two way flows of the electricity and the demand information. Using this flow, it generates a widely distributed, efficient and calculated method of electricity delivery networks. In this article, the authors surveyed the data available on the smart grids till 2011. The three main systems that were studied are:

- Smart protection system.
- Smart infrastructure system.
- Smart management system.

The authors discuss different ways in which these systems can be integrated with each other as well as explore more innovative ways to combine them to give out more efficient results. For the smart management, following are some of the must factors that should be considered while designing or implementation stage:

- improving energy efficiency
- reducing cost
- profiling demand
- controlling emission
- maximizing utility

Failure protection procedures were also studied in detail as in author's view they cannot be neglected in s smart infrastructure. The security factor also plays a key role in differentiating a smart network from a just a network.

For the smart management system, we explore various management objectives, such as improving energy efficiency, profiling demand, maximizing utility, reducing cost, and controlling emission. We also explore various management methods to achieve these objectives. For the smart protection system, we explore various failure protection mechanisms which improve the reliability of the Smart Grid, and explore the security and privacy issues in the Smart Grid.

The last article that we reviewed for this project was Smart grid management & visualization: Smart Power Management System by Grace Q. Tang. The study contains 5 major sections, namely: smart power system modeling; real time power system monitoring; system engineering database collection and management; grid condition checking and maintenance and smart grid power system fault analysis. It has been observed that Smart Power Management System allows grid management and visualization to be very constructive by incorporating live monitoring data and previous engineering data into an integrated system, analyzing situations based on several diverse modules and enabling one to acquire, monitor and control real time data accurately. Different situation modules of Smart Power Management System may be generated and modified in light of the client's specifications for its grid status and requirements for operation. Moreover, the integration of Neural Networks incorporates intelligent modeling in this system. This poses as a very efficient solution to solve problems in power system engineering, system design, grid operation, maintenance and management. Wireless channels to cellular phones or other mobile devices for maintenance staff can help in modifying the intelligent functions of Smart Power Management System. In case there is a system acting abnormally, real time signals of from it can be transmitted to field maintenance. Indeed, it is because of Smart Power Management System, that all functions that are needed can be put together in order to complement automation control for independent power system substations in the times to come, to monitor real time system data, to update real time system information, to pinpoint weak grid points, enable the field maintenance personnel maintain power system facilities in a satisfactory condition, to carry out power systems fault analysis and operator training, system troubleshooting and repair and to facilitate the maintenance with emergency contingencies, operations, control centers for smart grid management and visualization.

Smart Power Management

System data collections in this study include real time information from:

- SCADA (supervisory control and data acquisition system)
- EMS (energy management system)
- DMS (distribution management system)
- GIS (geographic information system)
- SER (sequence event record system)
- DFR (digital fault recorder system)
- Smart metering data
- Operation event data
- Power quality (voltage, Frequency)
- Protection system fault data (fault currents, voltages, phase angles…etc.)
- Asset management data
- Demand response
- Power system operation
- Operator training
- Station maintenance data
- Engineering data

Furthermore, the study shows that the results, derived from major captured power system fault events/blackouts, of power system performance fell into following categories: Correct and appropriate (System operated correctly and achieved desired results as designed.), Correct and inappropriate (System operated correctly as designed but the result was not what was intended.), Incorrect and appropriate (System operated incorrectly but this prevented another more severe trip and avoided a major cascading failure.), Incorrect and inappropriate (System operated incorrectly and this ignited a cascading outage.)

According to this paper, following are the considerations when it comes to power system fault:

- Reliability.
- Dependability.
- Communication.
- Redundancy.
- Stability.
- Efficiency.

The basic ending of this article tells us about the dire need there is to install solar plants in South Africa to harness the unimaginable amount of solar power, whose location are spread uniformly throughout the country. A relationship with the availability with the water is also under study which suggests that lack of water would cause the solar power plants to be shifted somewhere else.

1.4 Study Area

Our study area was focused to Sector H-12, NUST. Islamabad.

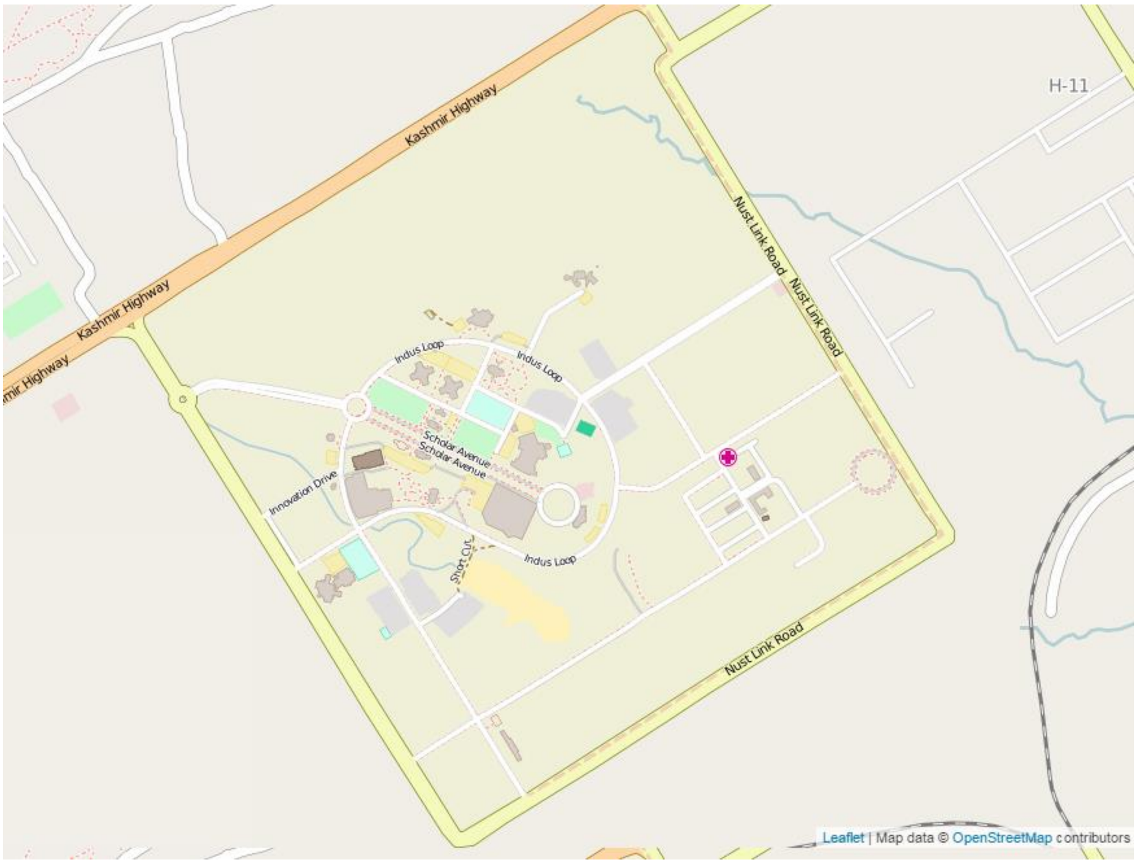

Figure 1. Area of NUST

CHAPTER 2

METHODOLOGY

2.1 Baseline Idea

Solar radiation assessment plays a key role in assessing the potential generated by the photo-voltaic cells. The main concept of the project revolves around the idea of smart power distribution system, utilization and promotion of solar energy. This project aims to give services to the users in order to identify and quantify the potential generated by photo-voltaic power generation systems in their vicinity using smart system of sensors and specific task-oriented hardware components. These hardware components provide a very efficient and resourceful approach of data collection and communication with servers and other compatible devices. Integration of modern hardware components such as Arduino and Raspberry Pi along with advanced technologies and frameworks not only add value to the project but also provides the liberty of customization to the users in utilizing maximum benefits from these system of devices. We studied different articles and tried to extract different solar irradiance mapping from them, one of the best article related to this topic was "A review of concentrating solar power plants in the world and their potential use in Serbia" by the authors "Tomislav M. Pavlović, , Ivana S. Radonjić, Dragana D. Milosavljević, Lana S. Pantić". In this article, the principles on which the solar tower power plants, parabolic dish power plants, parabolic trough power plants and power plants that uses the Fresnel reflectors and their potential in Siberia are under consideration. In addition, some other solar plants that are deemed to be successful in other parts of the world are discussed as well. The articles includes the study about the first ever CSP solar plant that was installed in USA in 1982 and since then, 29 other CSP power plants have been constructed while 31 are still under development stages. Power of some of the power plants has been mentioned below using the data from around the globe:

- •Parabolic trough power plants (0.25 to 345 MW)
- •Solar tower power plants (1.5 to 20 MW)
- •Parabolic dish power plants (1.5 MW)

The largest CSP plant in the world that generates 345MW of electricity was also taken in to consideration in this paper. This plant is located in Mojave Desert, USA. Along with the total solar potential calculation, the future and the present solar activities of Siberia are also discussed in this article as this article draws special attention to the activities of Siberian government regarding solar potential as in the very end the installation of number of solar power plants in

Siberia are suggested by the authors. Keeping in view the findings of this article we devised our basic hardware structure.

Development of a device that consists of a solar panel, an Arduino Uno, a Raspberry Pi 2 Model B, a DWA-131 Wireless N™ Nano USB Adapter and a Skylab SKM53 GPS receiver. This device is employed to calculate solar potential from the incident radiation of the sun and then relay that information to the server where it is stored in a database table. The process is automated to get the real-time data from the sensor and for that it was developed to relay the information after one minute of time interval. The rows in the PostgreSQL database, hosted on our LAPP server, are updated simultaneously.

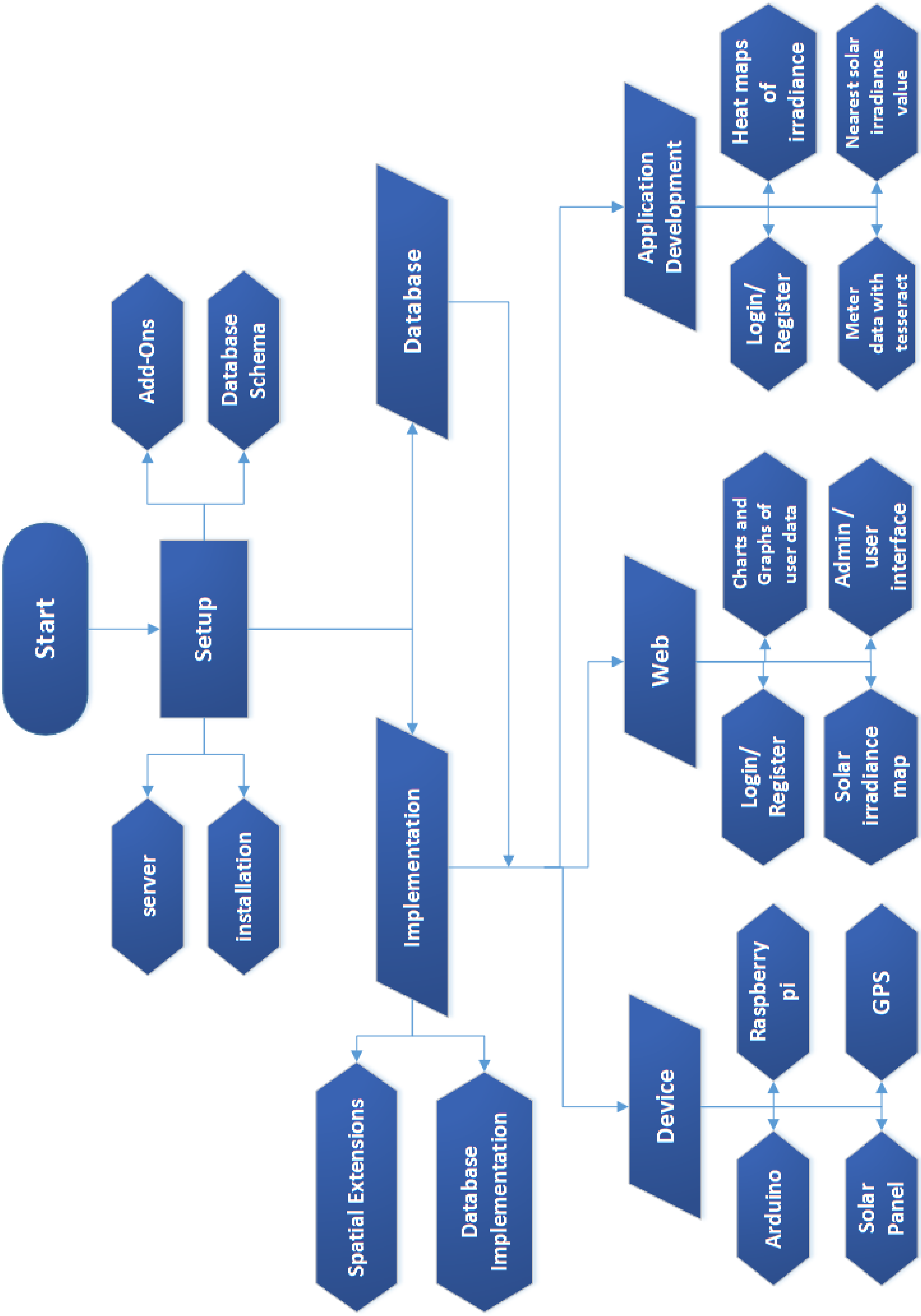

Figure 2. Working flowchart of the complete project

2.2 System Design

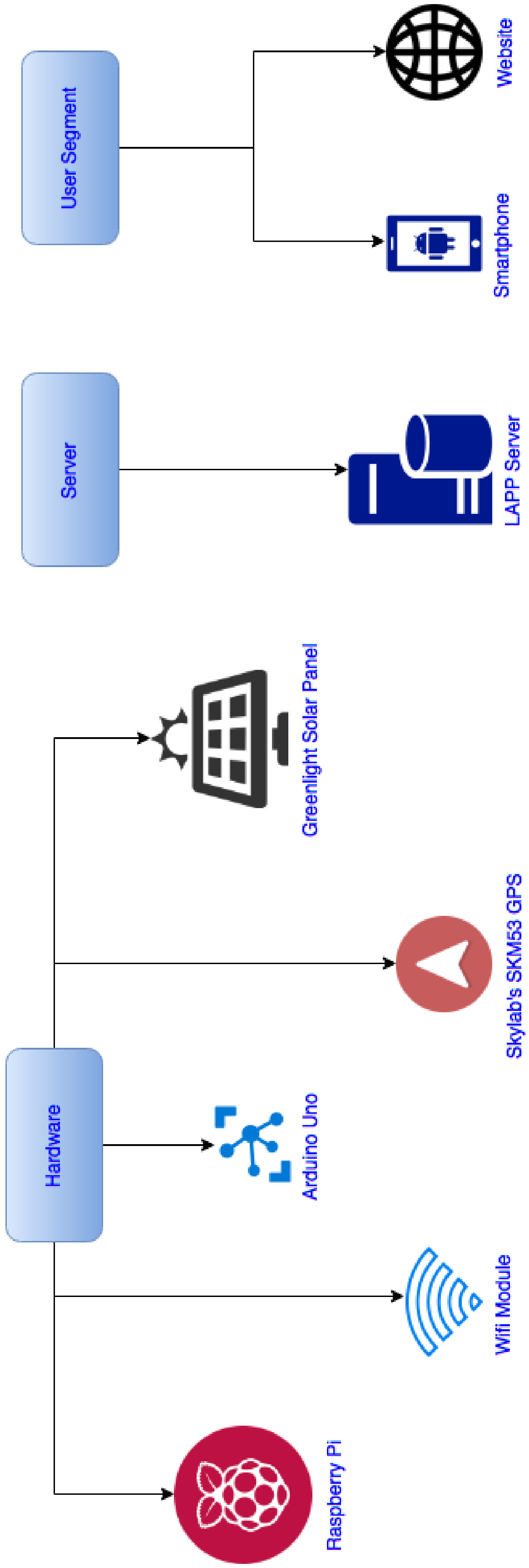

Figure 3. System Architecture

The architecture of the project was designed and categorized into three major parts;

1. Hardware
2. Server
3. User segment

2.2.1 Hardware

Hardware component of the project was designed by keeping in view the main objective of irradiance data acquisition and its transmission to the server where it would be saved in the table of solar potential data. Our hardware provides us with the real-time data of the irradiance where it is installed along with the coordinates of its location that it acquires through GPS, attached to it. The device also has a Wi-Fi module attached to it which is used to transfer the acquired data to the server using 3g/4g connectivity or wireless internet shared to it using hotspot. Our hardware that includes a raspberry pi, Arduino Uno and a Skylab GPS is interconnected. It works using a power bank for up to 3 to 4 hours continuously. Our hardware was tested in IAEC, NUST for the voltage and power values and it was found out that the data it was providing us was well within the tolerating zone. Everything was well under the budget of ten thousand rupees.

Arduino Uno was used because of the fact that it is used worldwide in different projects of different complexities and is very reliable. It can be a source of very fast prototyping which was one of the major requirements of our project. We needed to instantly display our data on to the map so that we can visualize it in almost no time and for that arduino was the suitable most thing. Pre wiring and free code libraries of Arduino are easily accessible, that was also one of the major reasons of using Arduino as our main hardware component. Another one of the major advantage of Arduino was the automatic unit conversion which was essentially required in our project as we needed to calculate the voltage output from the solar panel and from that we had to derive our power.

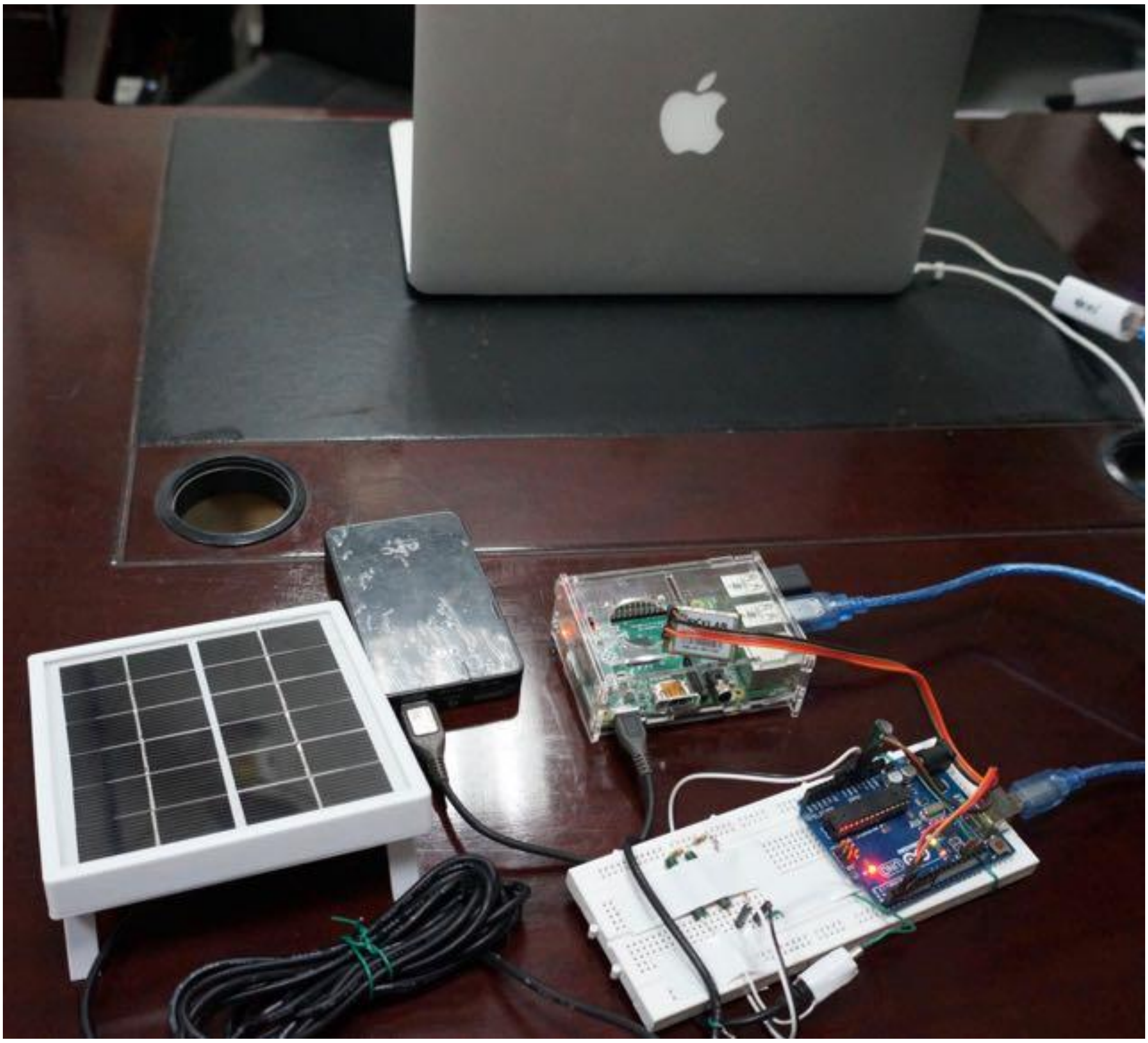

Figure 4 hardware components

2.2.2 Server

The server used in the project is LAPP and it was exposed to the internet using a global IP address. On the server, our database was deployed. The spatial extension of the database was enabled to facilitate the incorporation of spatial datasets which could be used for analysis. The server was also used to host our project website. The data acquired through android application was also transmitted to the server as JSON objects where these objects are decoded using a PHP script and saved in the database through an SQL query. LAPP stack is a popular open source web platform commonly used to run dynamic web sites and servers. It includes Linux, Apache, PostgreSQL (instead of MySQL), and PHP/Python/Perl and is considered by many the platform of choice for development and deployment of high performance web applications which require a solid and reliable foundation.

2.2.3 User Segment

The user segment consists of client-end components designed to interact with the administrative authorities and the users who are interacting either through website or android application. The user segment are further categorized into roles of viewer and operator. The viewers are given the authority to view the heat maps of irradiance data whereas, the operators have additional features of viewing the electric grid map of NUST and furthermore they can select the part of the grid that needs to be shut down or given excessive power by looking at the power consumption.

2.3 Project Components

The project was divided into three major components;

- Solar panel device for real-time irradiance data acquisition
- Mobile phone application for the crowd-sourced data acquisition
- Website with admin and user roles for the heat maps of solar irradiance data and map of the NUST area.

Figure 5. Project Components

2.3.1 Android Application

Android applications are develop in java programming languages. Once installed in device application runs in its own Virtual Machine (VM) separated from other applications. Android system implements the system of least privilege that is each application has access to the components which are required by it. Application can ask for other components if required but the permission is only given the user at installation time. This is the way android makes it secure. Android applications are Built in java along with XML, java provides functionality and XML is used for layout and taking permission purpose. We decided to go with the android application because of the following reasons:

- Multi-tasking.
- Ease of notification.
- Easy access to thousands of applications.
- Phone options are diverse.
- Can install more ROM.
- Widgets.

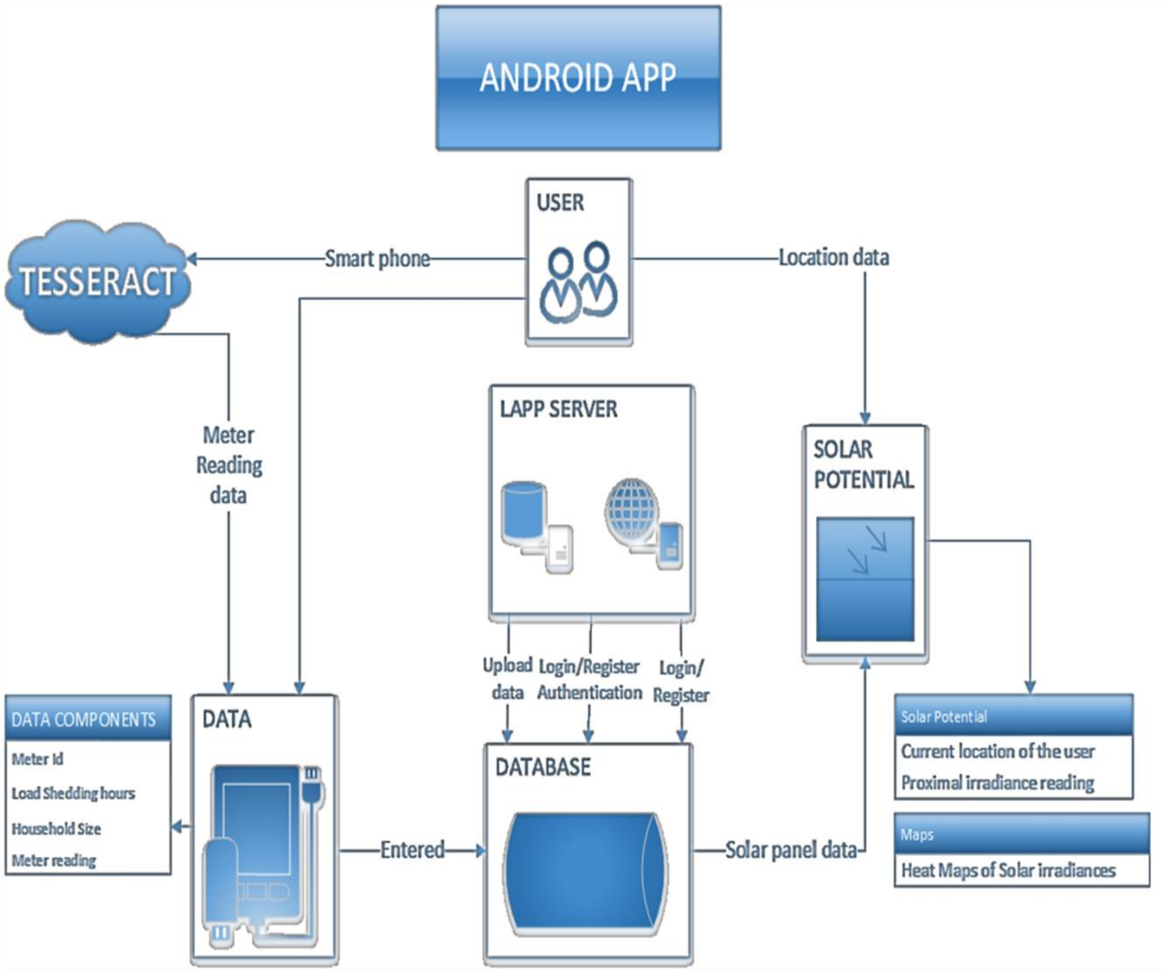

Figure 6 Android application framework

Our Android Application revolves around the idea of collecting crowd sourced data (through input from user), inserting it in the database and carrying out the analysis. These user needs a valid username and password to log into the application. The new users can also register themselves on the android application. There are 2 ways to detect the meter reading; the user can do that either manually, or by using Tesseract:

2.3.1.1 Manual - By clicking on "Meter Reading", the user is asked to input : "Meter ID" , "Meter Reading", "Load shedding Hours" and must select their House Size (Large, Moderate or Small). On clicking the Submit button, the information is inserted in the database from where, further analysis can take place.

2.3.1.2 Tesseract - By clicking on "Meter Reading Tesseract", an interface taking feed from the camera shows. On clicking a picture by positioning the frame on the part of the meter that shows reading, Tesseract performs OCR, and simultaneously, the database is updated.

Apart from the data input from the user, our android application also allows the user to get the nearest value of the irradiance which is acquired from the device and saved in the database along with the Euclidian distance from the irradiance measurement instance. This allows the users who have not installed the device in their homes to get the readings from their vicinity from where the device has relayed value to the server.

Additionally, the registered users can also view the solar irradiance in the form of heat map which is based on the google maps API.

The mechanism of the android application is explained below;

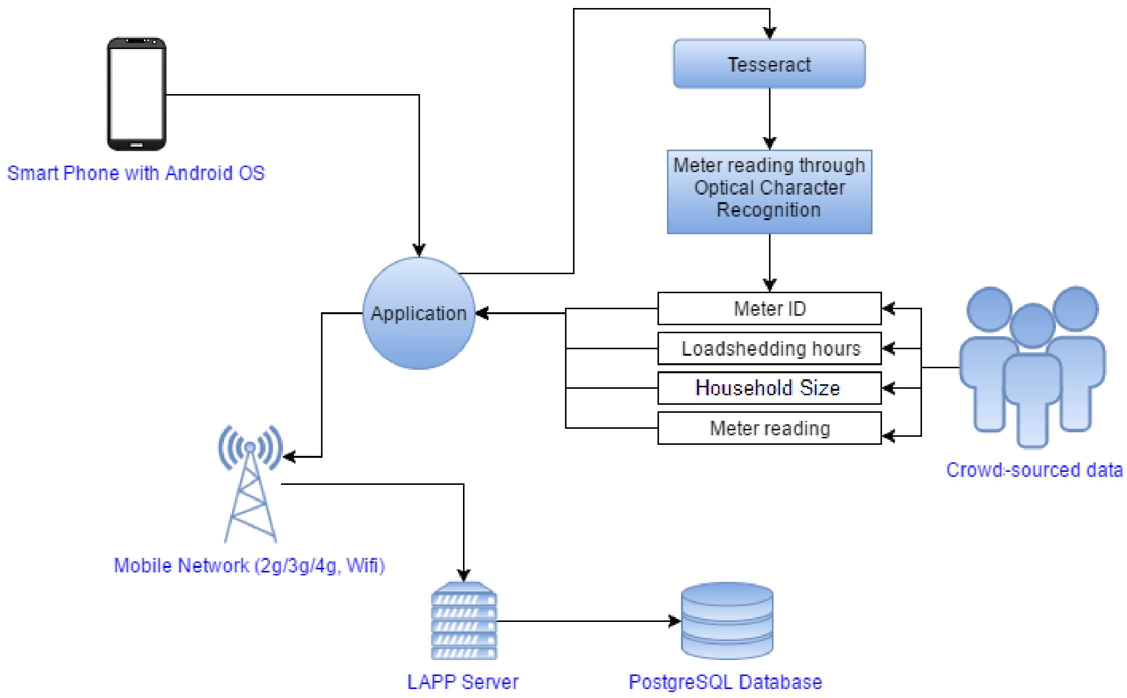

Figure 7. Android application mechanism

2.3.2 Tesseract

Optical Character Recognition, or OCR, is the process of electronically extracting text from images and making them useful for a variety of applications, ranging from document editing, free-text searches, or compression, to extracting the information from number plates of cars.

Tesseract is a powerful OCR Engine that can be used on a number of operating systems under the Apache 2.0 license. It is probably the most accurate open source OCR engine available. It is widely used because it can read and convert a wide variety of image formats to text in different languages (over 60). It can do this with the help of Leptonica Image Processing Library. According to a report, it was considered one of the top 3 engines in the 1995 UNLV Accuracy test.

Although Tesseract does not have a built-in GUI, it has a fully featured API. Figure 2.4 shows the Tesseract OCR architecture by Google. In our study, we incorporated this technology to extract information from Meter Readings - by clicking a picture of the meter reading, Tesseract performing optical character recognition and inputting the extracted data into the database.

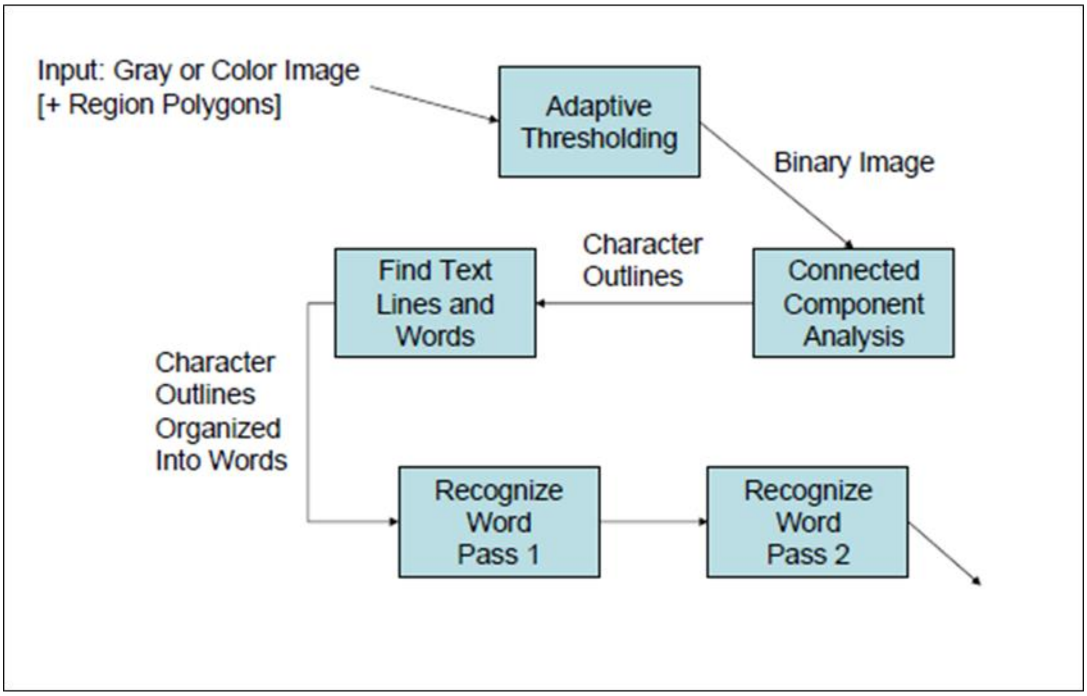

Figure 8 Tesseract OCR Architecture

While opting for the tesseract and crowd sourcing, a lot of care was taken because of the authenticity of this kind of open work and a lot of articles about crowdsourcing were read by us. One of them that actually helped us a lot was "*Crowdsourcing information via mobile devices as a migration enabler towards the Smart Grid*" by "Stamatis Karnouskos" in which he explained that Mobile devices are more actively governing our lives than ever before. In the field of energy, however, this technology can be made use of as a mean for correspondence between the consumers and the other people involved in the Smart Grid system. Majority of simulations call for extra equipment on the user's end with a specific end goal to gather metering information so as to utilize it for energy optimization; nonetheless, comparable data can be obtained from the users and the quality of data might be somewhat similar to, or superior to the inactive techniques applied these days (particularly when considering anticipated future user activity). It is indeed established that cell phones can be of great help in communicating user-generated information, aside from enabling methodologies managing analytics, etc. Therefore, getting energy information from the users (through mobile devices) can serve as enabling technology till the time Smart Grids and their potential is fully realized and implemented. The architecture incorporates the following components:

- Energy Service Manager
- Notification
- Billing
- Analytics
- Metering

And on the enterprise side:

- Security Manager
- Device Manager
- Business Data Manager
- Trusted Third Party

2.3.3 GPS

Skylab's SkyNav SKM53 was used as a receiver to acquire location data from the GPS satellites. The receiver was attached to the Arduino Uno and the location data that it acquires is relayed along with the solar potential data to the server where it is stored in the database.

SKM53 is widely used in the following domains;

- LBS (Location Based Service)
- Vehicle navigation system
- PND (Portable Navigation Device)
- GPS mouse and Bluetooth GPS receiver
- Timing application

The basic features of the receiver include;

- Ultra-high sensitivity: -165dBm
- 22 tracking/66 acquisition-channel receiver
- WAAS/EGNOS/MSAS/GAGAN support
- NMEA protocols (default speed: 9600bps)
- Internal back-up battery
- One serial port
- Embedded patch antenna 18.2 x 18.2 x 4.0 mm
- Operating temperature range: -40 to 85℃
- RoHS compliant (Lead-free)
- Tiny form factor ：30mm x20mm x 8.5mm

Figure 9 SKYLAB SKM53

2.3.4 Solar Panel

Greenlight planet is available in the market for around Rs. 700/-. This is a very low powered panel with area of $0.0121m^2$. The solar panel acts as an irradiance measurement device for measuring incident solar insolation on it. The readings from the solar sensor were taken through Arduino's analog pin 1 where the readings of voltage are transmitted. These readings were then used to calculate the power of the panel when it is exposed to sunlight using the following formula;

$$P = VI$$

Where,

P = Power in watts

V = Voltage in volts

I = Current in amperes

Using the power we calculated the irradiance by using the following formula;

$$\delta = P/A$$

Where,

δ = Irradiance in watt/m^2

P = Power in watts

A = Area of panel in m^2

Solar panel was also validated and calibrated manually using electronic digital multi-meter. We tested the panel in the Applied Electronics Lab of Institute of Applied Electronics and Computing. The readings were taken at various places within the campus and the values were calculated using the above mentioned formula.

Figure 10. Greenlight Solar Panel

The solar panel work required a lot of literature reviews, one of the articles that would be worth mentioning here was "Concentrating solar power – Technology, potential and policy in India" by Amita Ummadisingua and M.S. Sonibin. The main concern that is being raised in this article is about shifting towards the renewable energy resources like solar and wind as the other energy resources like petroleum and coal are gradually moving towards the extinction and are causing immense change in the environment and have given air to the flames of the climatic crisis that we are facing on the global level. To all of these problems, a solution which is discussed in detail in this article is solar energy. According to the authors, solar energy is our answer to the all of the above mentioned questions. It can provide us up tp 25% of our total energy by 20150 if we start to work on it carefully and tactfully. All those countries that can exploit the solar energy and has a potential worth mentioning are discussed and explored it this article and the all of the major future plans by different countries regarding solar potential are also discussed in this article. Then later in the article, authors' focus shifts on the India's solar power potential in the states if Gujrat and Rajisthan. The Jawarlal Nehru National Solar Mission has been discussed in detail by the author as they understand that this policy of Indian government can be very helpful in long-term running of energy needs in India.

2.3.5 Arduino (UNO)

An open-source electronics prototyping platform that is Arduino forms the basis of all electronic components of the system. A full-fledged Arduino system incorporates both hardware and software components - the former being a physical programmable circuit board (otherwise referred to as microcontroller) and the latter, an IDE (Integrated Development Environment) that runs on computer, is used to develop and upload computer code to the physical board. As a piece of hardware, the Arduino can operate either independently, when connected to a computer, or connected to other Arduino's, or other electronic devices and controller chips.

Arduino was used a microcontroller to handle the sensors attached to it which includes; An SKM53 GPS which requires 5V input voltage, and a solar panel which is attached to the analog 1 pin of the Arduino. Although, other models of Arduino could also be used in this device, however, operating voltage provided by Arduino Uno best suited our requirements of integrating solar panel and GPS module with it, efficiently.

The following table contains the specifications of an Arduino Uno:

Table 1. Arduino Uno Specifications

COMPONENTS	**SPECIFICATIONS**
Microcontroller	ATmega328P
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (maximum)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
PWM Digital I/O Pins	6
Analogue Input Pins	6
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB - (0.5 KB of which is utilitized by bootloader)
SRAM	2 KB (for ATmega328P)
EEPROM	1 KB (for ATmega 328P)

Clock speed	16 MHz
Weight	25 g
Width	53.4 mm
Length	68.6 mm

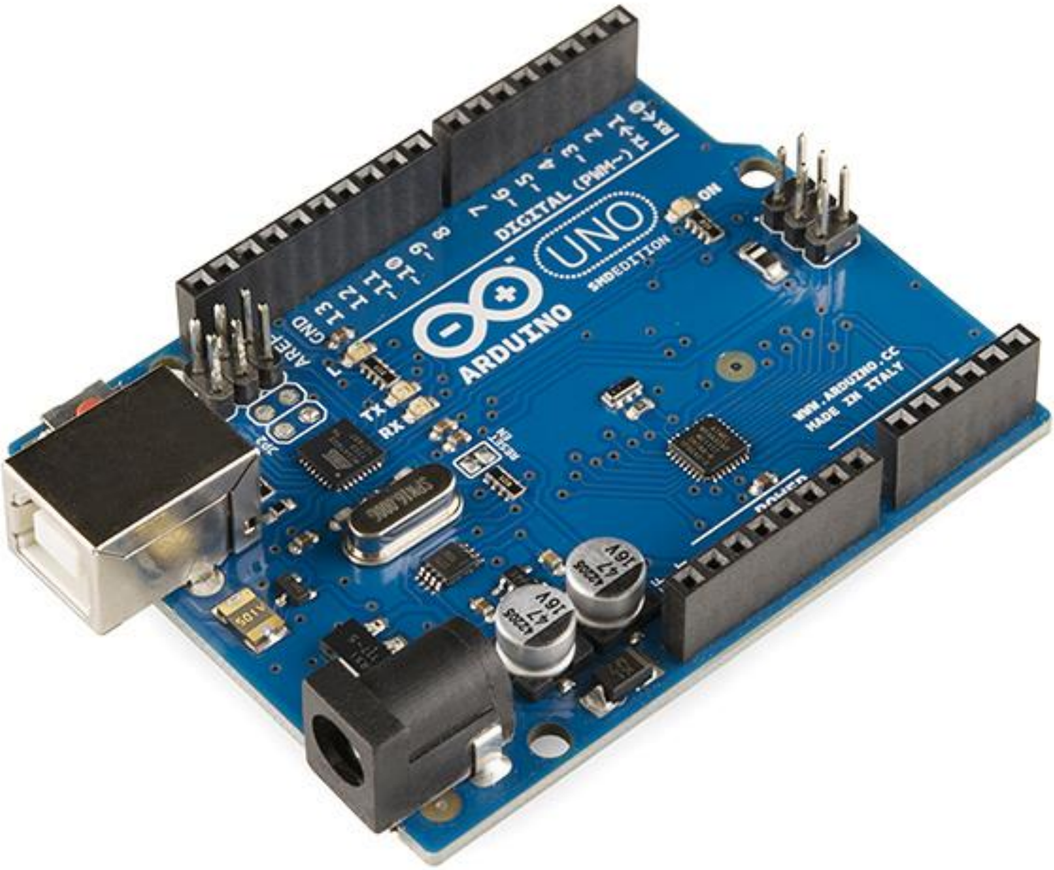

Figure 11 Arduino Uno

2.3.6 Raspberry Pi (Model 2B)

A Raspberry Pi is a rather small computer initially designed for education, inspired by the 1981 BBC Micro. Due to its small size and affordable price, it was quickly adopted for projects that require more than a basic microcontroller (such as Arduino devices mentioned above).

However, the Raspberry Pi is slower than a modern laptop or desktop. It is, nevertheless, still a complete Linux computer and can provide all the expected abilities that implies, at a low-power consumption level.

The current model B comes with four USB ports, an Ethernet port for connection to a network, and 1 GB of RAM, as compared to A Model that comes with a smaller RAM. Its features may be summarized as below:

- A 900MHz quad-core ARM Cortex-A7 CPU
- 1GB RAM
- 4 USB ports
- 40 GPIO pins
- Full HDMI port
- Ethernet port
- Combined 3.5mm audio jack and composite video
- Camera interface (CSI)
- Display interface (DSI)
- Micro SD card slot
- VideoCore IV 3D graphics core

Figure 12 Raspberry pi 2B

2.3.7 Wi-Fi (DWA 131)

The DWA-131 Wireless N™ Nano USB Adapter is a convenient wireless connectivity solution for desktop or notebook PCs. It rids us from having to connect Ethernet cables to the PCs. The DWA-131 has the ability to enable 802.11n wireless connectivity by utilizing the desktop or notebook PC's USB port. Powered by Wireless N™ technology, the DWA-131 provides a faster wireless connection and a superior reception when compared to other models. The DWA-131 is designed for greater coverage and higher bandwidth networking. The features of DWA-131 are as follows:

- Micro-size WLAN USB adapter for placement anywhere.
- Convenience of Plug & Play installation.
- Fully 802.11g compatible.
- 802.11n compliant.
- Powered by the USB port; no external power source required.
- USB 2.0 standard
- Secure connection to a wireless network using WPA/WPA2 (Wi-Fi Protected Access)
- Great reception (the device can be placed anywhere and shall be receptive)
- Supports Infrastructure networks via an access point
- User-friendly configuration and diagnostic utilities.

•

Figure 13 Wi-Fi (DWA 131)

2.3.8 Website

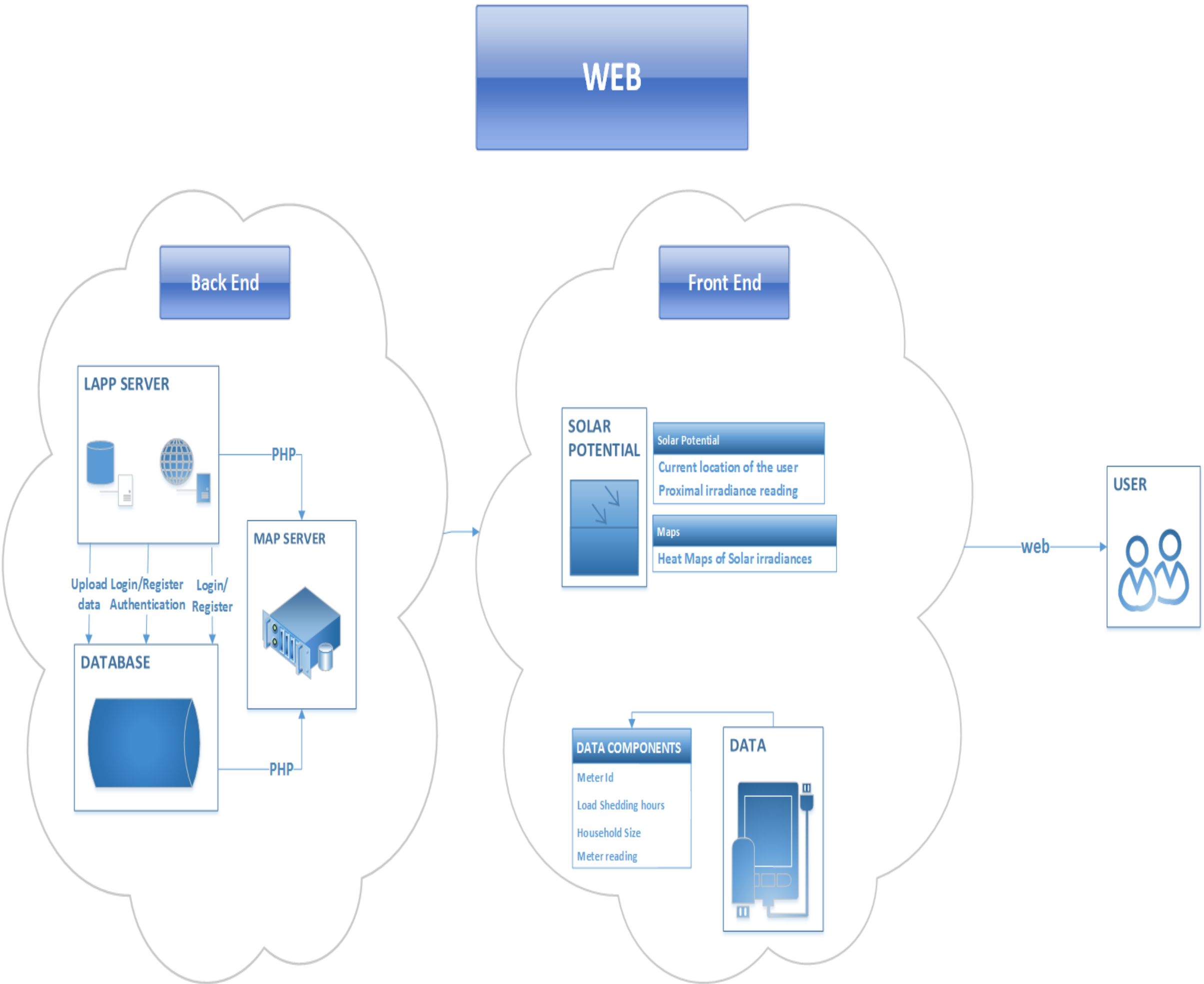

Figure 14. Website mechanism

The website homepages for admin and user (respectively) are shown below:

Figure 15. Admin Homepage

Figure 16. User Homepage

2.3.9 Mapserver

MapServer is an Open Source geographic data rendering engine written in C. Apart from browsing GIS data, MapServer enables the user to create "geographic image maps", that is, maps that can help users locate content.

MapServer was initially developed by the University of Minnesota (UMN) ForNet project in cooperation with NASA, and the Minnesota Department of Natural Resources (MNDNR).

MapServer is now part of OSGeo standards, and is under the supervision of a large number of developers from around the globe. It is supported by a diverse group of organizations that invest in improvements and maintenance, and operated within OSGeo by the MapServer Project Steering Committee comprising developers and other contributors.

- Advanced cartographic output
  - Scale dependent feature drawing and application execution
  - Feature labeling including label collision mediation
  - Fully customizable, template driven output
  - TrueType fonts
  - Map element automation (scalebar, reference map, and legend)
  - Thematic mapping using logical- or regular expression-based classes
- Support for various scripting and development environments
  - PHP, Python, Perl, Ruby, Java, and .NET
- Cross-platform support
  - Linux, Windows, Mac OS X, Solaris, and more
- Support of numerous Open Geospatial Consortium (OGC) standards
  - WMS (client/server), non-transactional WFS (client/server), WMC, WCS, Filter Encoding, SLD, GML, SOS, OM
- A multitude of raster and vector data formats
  - TIFF/GeoTIFF, EPPL7, and many others via GDAL
  - ESRI shapefiles, PostGIS, ESRI ArcSDE, Oracle Spatial, MySQL and many others via OGR
- Map projection support
  - On-the-fly map projection with thousands of projections through the Proj.4 library

Mapserver was used in our project because of the fact that it is robust and quite responsive as compared to its competitor. Also our server operates in command line interface using linux shell so, we needed a mapping server that can be easily executed using the command line interface. Mapserver provides the response time of about 0.4 to 0.6 second. On the other hand, Geoserver provides the response time of about 0.8 seconds. Besides that, Mapserver also supports more memory in terms of loading a tile from the spatial database or the shapefiles.

In addition to Mapserver, we chose Open Street Maps, another one of the main stream Open End platform that has high accuracy. Android applications are develop in java programming languages. Once installed in device application runs in its own Virtual Machine (VM) separated from other applications. Android system implements the system of least privilege that is each application has access to the components which are required by it. Application can ask for other components if required but the permission is only given the user at installation time. This is the way android makes it secure. Android applications are Built in java along with XML, java provides functionality and XML is used for layout and taking permission purpose.

2.3.10 CSS

Cascading Style Sheets (CSS) is a style sheet language which is used for describing the details of other markup languages. Mostly used to change the style of web pages and user interfaces written in HTML and XHTML, the language can be applied to any kind of XML document. It is used to separate the designing of the webpage from its core coding. It was used in the designing of our portal.

2.3.11 Google Charts

Google Charts API has been used to make few of the charts for the portal. It is a free tool developed by Google for making graphical charts in PNG format and data representation coded in a web page using a URL string.

These charts are very good for visualizing the data in a website. Some of the type of charts provided by Google charts API is Pie Charts, Line Charts, Area Charts. Colum Chart and Tree Maps. We are using Google Charts API because it is very user friendly and easy to use.

2.3.12 HTML

HTML stands for HyperText Markup Language. It is the standard language to create web pages. It uses the concept of tags. All web browsers can read HTML files. It is the building blocks of all websites. It also supports images. Along with CSS (Cascading Style Sheets), styling of the webpage is done. Different sections of the document can be differentiated and style by using different tags and styling each tag differently in CSS.

2.3.13 AJAX

Ajax stands for Asynchronous JavaScript and XML. It is a group of techniques. It is used on the client-side for creation of Web applications. Some of its features are:

- Send and retrieve data to and from a server
- Allow user interaction
- Web pages are updated asynchronously
- Dynamic and Continuous User Experiences

The main use of Ajax is that it updates the content of a webpage without refreshing the whole page. Google Maps, YouTube, and Facebook use Ajax.

2.3.14 jQuery

jQuery is a JavaScript library which is fast, cross platform and feature rich. It is a Document Object Model (DOM) manipulated library. It is used for client side scripting of HTML. It is an open source library. jQuery is the most popular library used for creating animations and building Ajax application with much simpler APIs. Some of its features are:

1. Open Source
2. Create your own user defined plugins.
3. Multi-platform supported
4. Cross Browser
5. Easy to use
6. Fast processing

2.3.15 PostgreSQL

To store our geospatial data, we are using PostgreSQL. It is an open source database system. It is used because of its reliability, data integrity and correctness. Some of its features are:

- Handles geospatial data
- Multi OS supported
- Support foreign keys
- Stores binary large objects
- Multi programming language interface
- A vast library
- Creation of own custom data types

2.3.16 JavaScript

JavaScript is both client side and server side scripting language used in the development of web applications. It allow better interaction with the user. It is also considered an assembly language of the web. It also find its uses in game development, computer applications and mobile applications. Some of its features are:

- Multi-paradigm language
- Object oriented supported
- Handles date and time
- Can detect the user's pc specification
- Cross platform

2.3.17 PHP

As mentioned earlier, PHP is a server-side scripting language. It was designed to be used for web development. It has now become one of the most server side language. Initially PHP meant Personal Home Page but that has been changed to Hypertext Preprocessor. Some of the features of PHP are:

- General purpose scripting language
- Runtime execution
- Support for command-line scripting.

- Multi-OS and multi-server supported
- Accepted by most databases e.g. MySQL
- It is available free and is open source

2.3.18 Apache

For our server, we have used Apache. We used Apache as it is an open source server and it can be used on a wide variety of operating systems e.g. Linux and Microsoft Windows. According to a statistics of 2013, more than 50% of servers in the world used was Apache. Some of its features are:

- Multi operating system
- Simple configuration
- IPv6 supported
- Caching
- Easy to use

2.3.18 Leaflet

Leaflet is one of the very useful open-source JavaScript libraries that are used to produce web mapping applications. Since it is lightweight, yet compact nonetheless, Leaflet is the ultimate solution with all the mapping features.

Leaflet is incorporated in projects where, whilst maintaining a GIS environment, simplicity, performance and usability is desired. It works effectively across all leading desktop and mobile platforms. Aside from being extensible, with lots of plugins, Leaflet has a visually appealing, easy to use and well-documented API and a simple, comprehensive source code. Our decision to opt for Leaflet was governed by the presence of certain properties of the library, which are mentioned.

The main Leaflet object types are summarized below:

- Raster types (TileLayer and ImageOverlay)
- Vector types (Path, Polygon, and specific types such as Circle)
- Grouped types (LayerGroup, FeatureGroup and GeoJSON)

- Controls (Zoom, Layers, etc.)

A variety of utility classes are also available, like interfaces for dealing with projections, transformations and interacting with the DOM.

Additionally, plugins enable support for a number of other types of layers.

Table 2. Leaflet Plugins

GeoJSON	GeoJSON function
KML,GPX, WKT, TopoJSON, CSV	Leaflet Omnivore Plugin
WMS	TileLayer.ms subtype
WFS	Via 3rd party plugins

CHAPTER 3

RESULTS

3.1 Android Application

We have developed an android application that allows the users to input their data as well as view a Solar Irradiance Heat Map and conduct self-analysis and take necessary actions. Working of the android application is described below;

User can log into the application by providing the correct credentials.

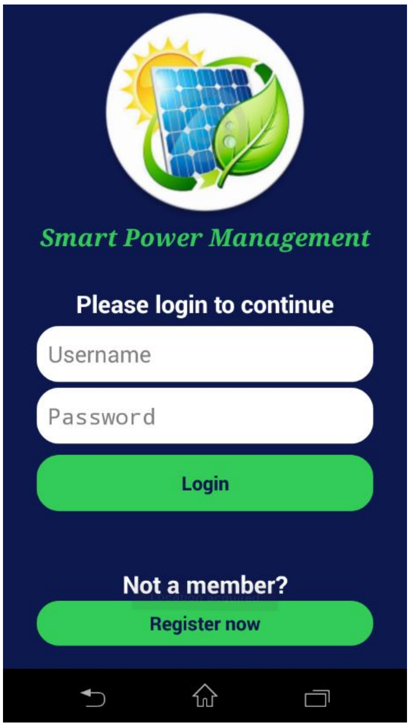

Figure 17. Android Application Login Page

In case the user is new to the application and he is not able to log in to the application, he/she can register themselves to use the application. When the user clicks on the register button, a registration form is opened. When the user tries to register with a username that already exists in the database, he/she is notified with the toast notification in the application and he/she needs to select another username in order to register for the application.

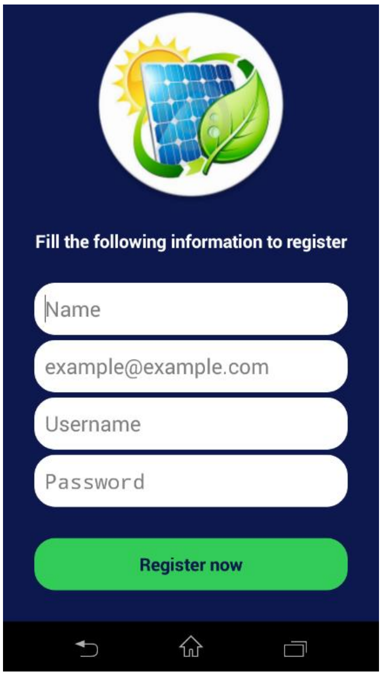

Figure 18. Android Application Register Page

The users are also given the utility of changing passwords by clicking on the change password button that takes them to the following page;

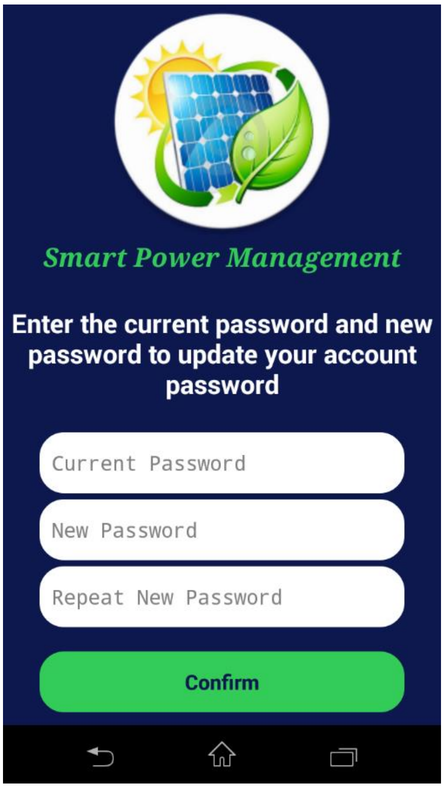

Figure 19. Android Application Change Password Page

Next, a main dashboard appears. The user can enter relevant information (i.e. Meter ID, Meter Reading, Load shedding Hours and Household Size) The meter reading can be also be taken through capturing a picture of the household electricity meter panel.

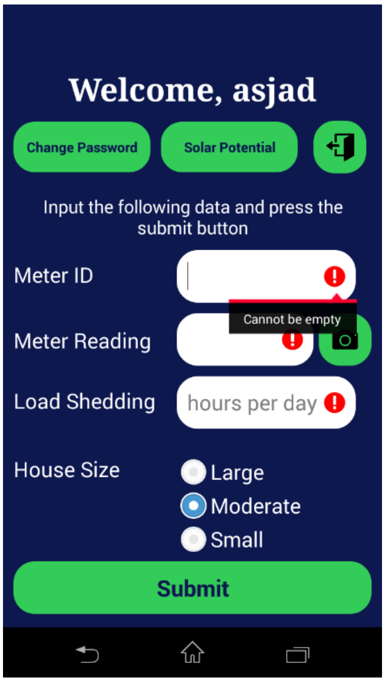

Figure 20. Android Application Main Dashboard

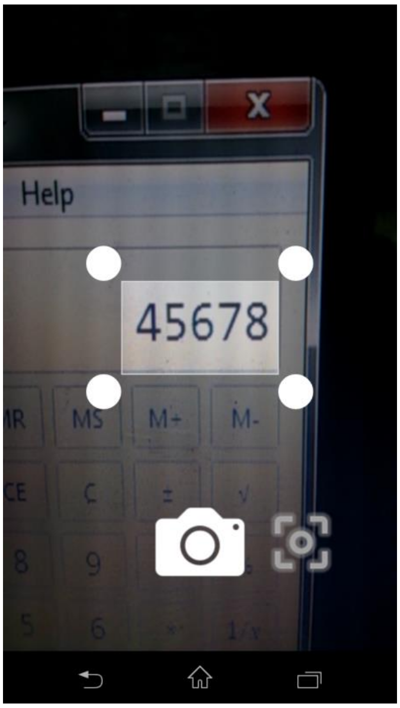

Figure 21. Android Application Meter Reading (Tesseract)

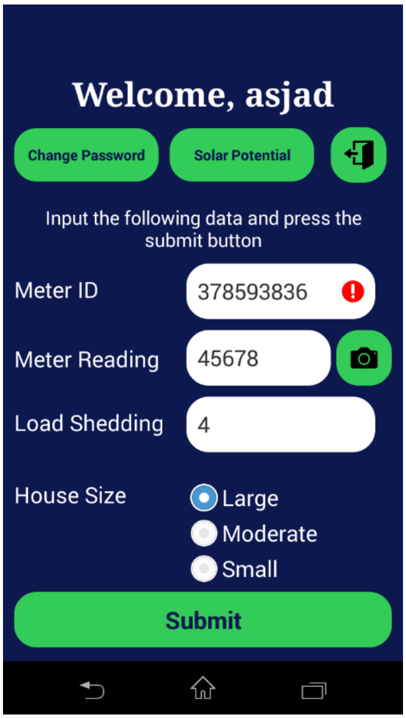

Figure 22. Android Application Main Dashboard with example data

On the same page, there is a button that navigates to a page showing the distance to the closest point where solar irradiance has been measured. This feature specifically facilitates those users who have not acquired the device yet but still want to get an idea of the irradiance value with respect to the proximal value measured in the vicinity of the user.

Figure 23. Android Application closest solar irradiance page

A button on this screen now can navigate the user to a Solar Heat Map. Solar irradiance heat map allows the user to visualize the solar potential of the area and also helps in identifying the areas with maximum and minimum value of the irradiance.

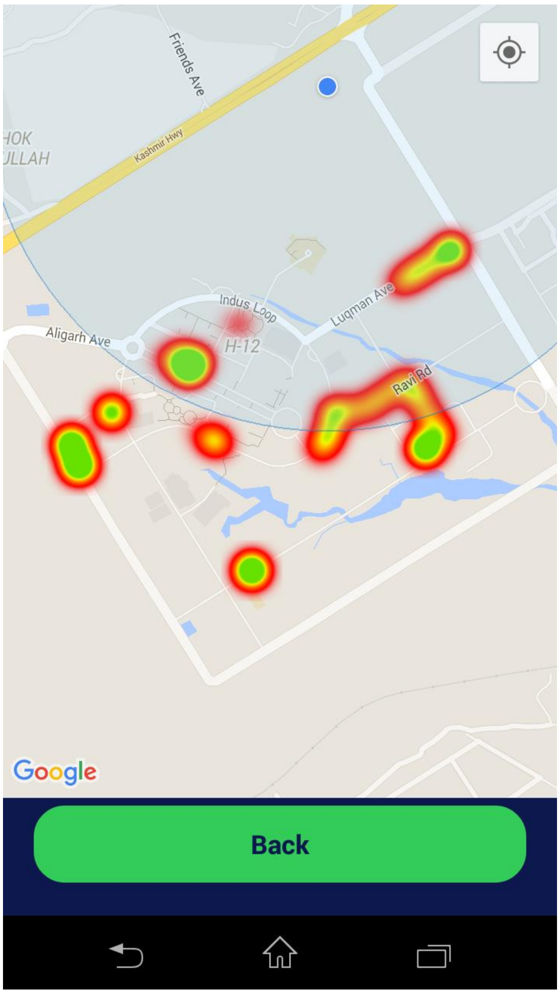

Figure 24. Android Application Solar Heat map Page

Furthermore we published our project online on LinkedIn and plan to make the source code available on Github as well. The initial user response has been tremendous with more than 400 hits in just three days. People have registered as volunteer data providers to the system. However, stress testing the software has not been done in accordance with the global standards. We plan to put it through various checks and see if the system is capable of bearing with as well as the database design at the backend. We would also like to make it more of data analytics platforms where further analysis of user requirements, possibilities of money saving etc. can be discussed.

3.2 Website

On the website, the user and admin both have different roles in terms of viewing the results. When the user logs into the website, he/she is able to see the heat maps of the solar irradiance data.

Figure 25. Website Solar Map

The users are also given the privilege to download the android application installer file from the website by logging into the site and clicking on the image of shown in the figure below.

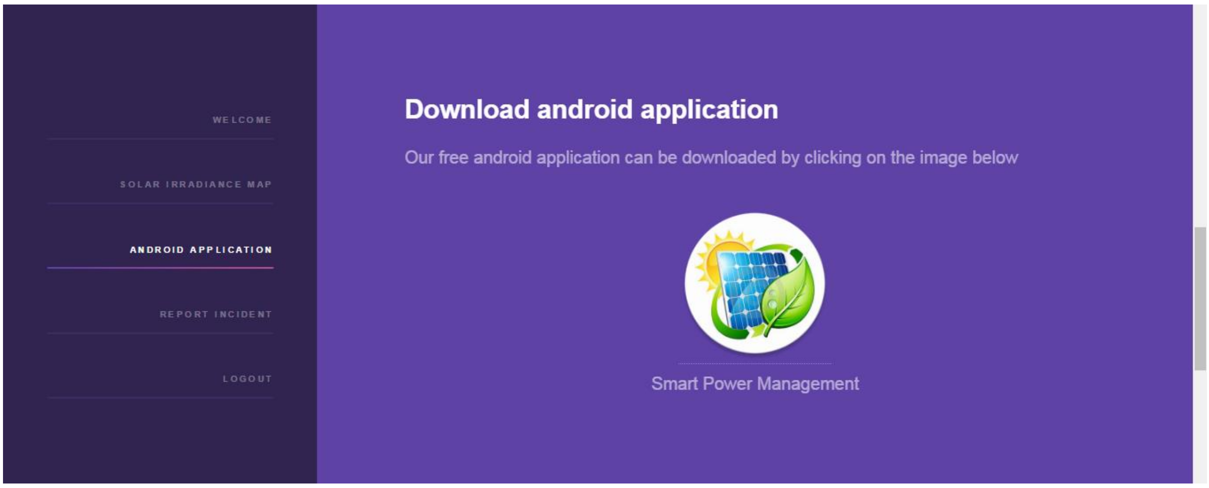

Figure 26. Website Android Application Download Page

On the other hand, when the admin logs into the website, he/she is able to see heat map of the irradiance data (same as that of user). Additionally, the admin can see the Electric grid data of NUST as show below;

Figure 27. Website Electric Grid Map Page

In addition to it, the admin can also view point data input from the user along with its overlaid on the map.

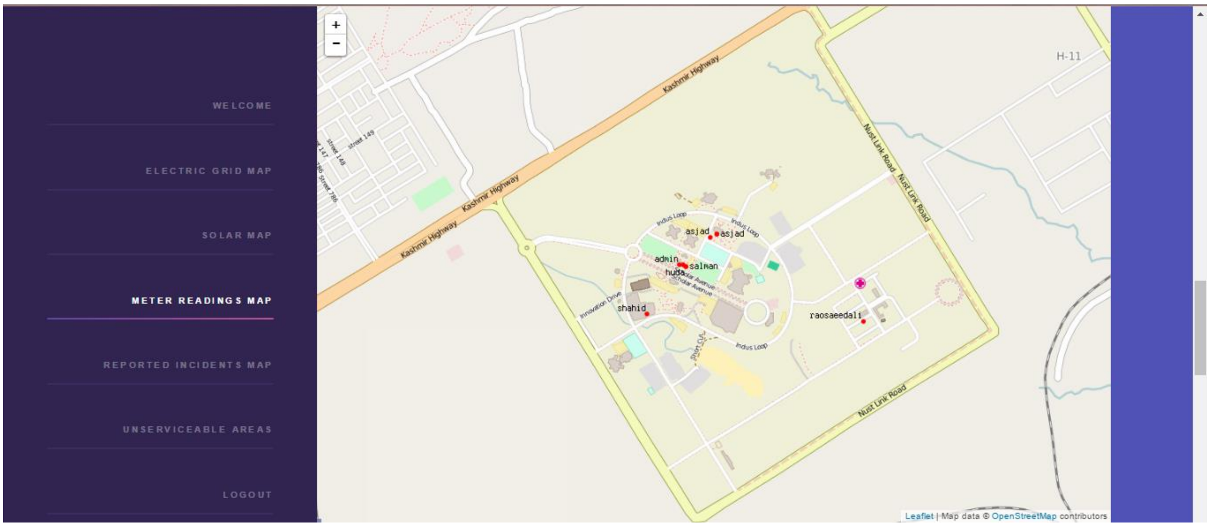

Figure 28. Website Meter Readings Map

Another option made available to the admin in our site is to stop providing electricity to a certain area using their consumption values or if any kind of fault is detected or reported there.

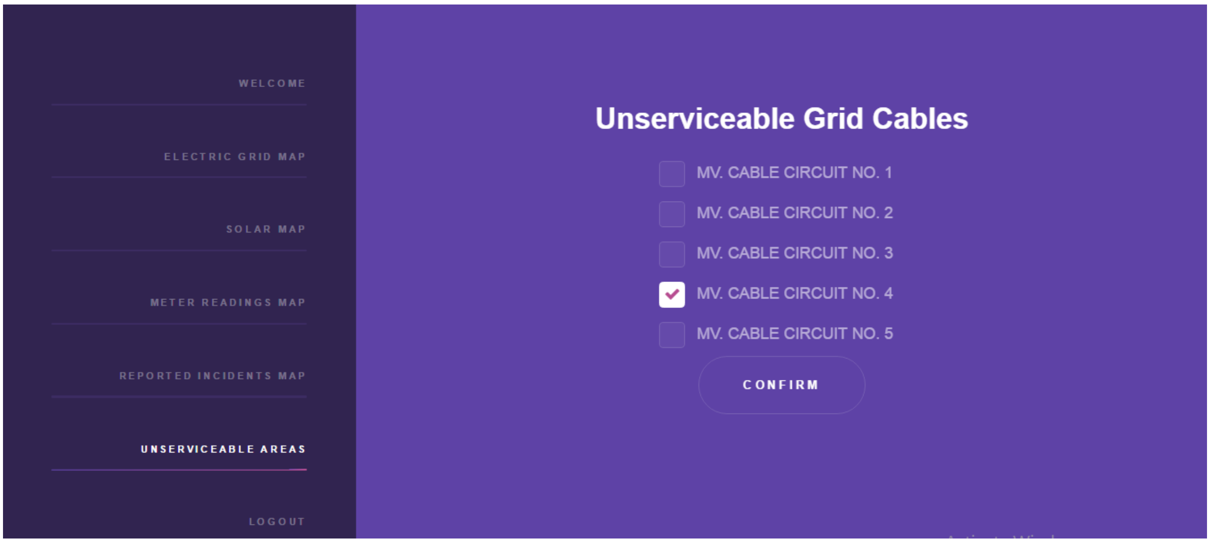

Figure 29 Website Unserviceable Grid Option

As an attempt to establish efficient maintenance, we have incorporated the concept of "optimal routing" in the system. This is for both the user's and the admin's convenience. In order to report a problem (power failure, transmission line breakage etc.) to the authority, the user can place a marker on the problem area by going to the "Report a Problem" tab on the website. Upon placing the marker, the information is relayed to the admin end. Thus allowing them to locate the problem area and report to it at the earliest. Moreover, on the admin's screen, the most optimal route to the location of concern is highlighted - so that report time is as minimal as can be. The algorithm being used to generate the shortest route is “contraction hierarchies” which calculates the shortest-path routes much more efficiently than Dijkstra's algorithm or previous highway-node routing approaches.

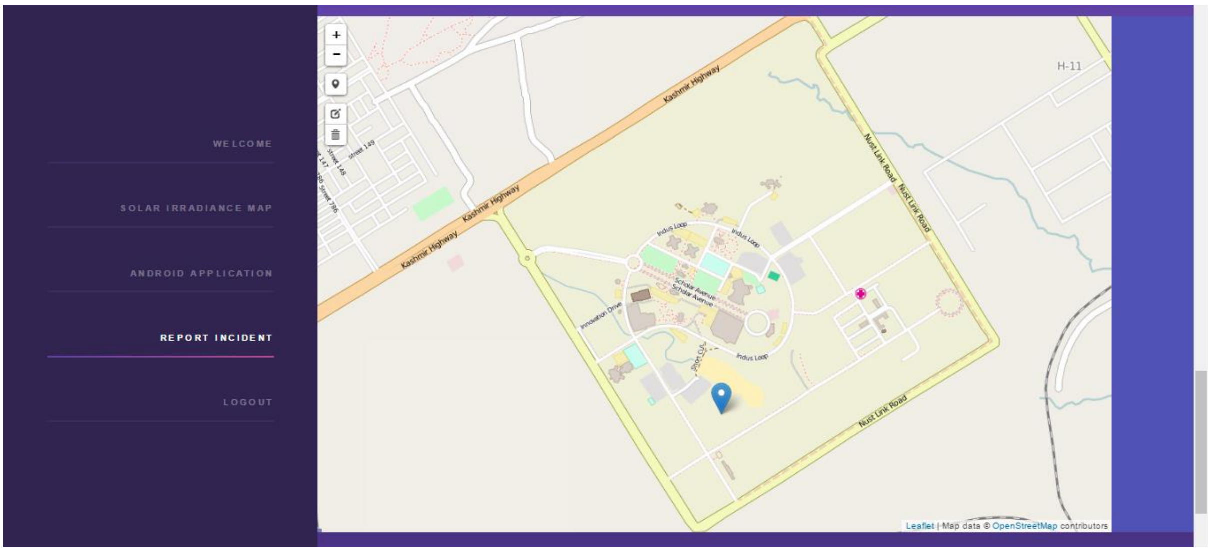

Figure 30. Users Incident Reporting Page

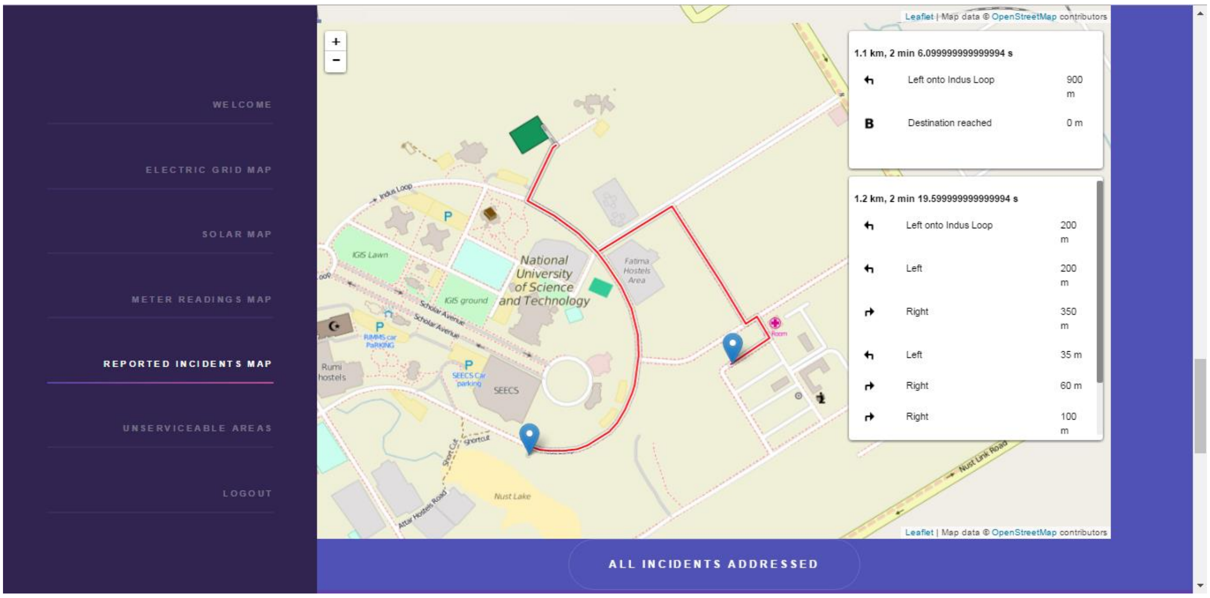

Figure 31 Reported Incident Maps

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

Our study was concluded on grounds of the fact that the accuracy and reliability of the results is directly influenced by the accuracy of data provided by the user. Having said that, it must be noted that our system thrives on crowd sourced data. Needless to say, as the amount and diversity of input data increases, the accuracy of the analysis increases.

This system is in its initial stages and can be considered as a prototype to the complete smart power management system. The aforementioned objectives were achieved to some extent, in the sense that the public was made aware of the benefits of harnessing solar potential available in their respective areas. Also, the technologies GIS and Radio Sensor Network were utilized to the best of our capacity and reach.

4.2 Recommendations

In order to facilitate the users with accurate and reliable results, the system requires active user participation due to the lack of smart meters in the country.

Also, the aim was to allow the users to get equipped and well versed with the solar potential status in their vicinity. Being aware of the value of it, they can easily harness its potential to the maximum. Further utilizing the results of this study, value added services based on the incorporation of smart algorithms aimed at providing efficient transmission of electricity in peak and off-peak hours would not only enhance the overall productivity of the system but also it would help in conserving the electricity and lessening the short-fall of power generation and consumption to a certain extent.

4.3 Limitations

Firstly, the smart grid solution is limited due to the unavailability of smart meters in the country. We cannot get readings of the household electricity meters in real-time; hence our reliance on the users to upload their accurate data. This poses a major obstacle in the way to generate accurate and resourceful analysis results without cross-validating the user input data with actual values.

Secondly, the heat maps generated on the web as well as the android application automatically introduce errors in those nearby points, through interpolation, of which there is no value present in the database. Moreover, it also causes error in those measured points which are close to each other as it aggregates their individual values.

CHAPTER 5

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