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DEVELOPMENT OF AN EMBEDDED ACTIVE DUAL AXIS SOLAR TRACKING AND MANAGEMENT SYSTEM

by

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A dissertation submitted in partial fulfillment of the requirements for the degree of Master of Science (Embedded System Design Engineering)

School of Computer and Communication Engineering
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2016

ACKNOWLEDGMENT

Firstly, I would like to express my sincere gratitude to my supervisor Prof. Dr. R. Badlishah Ahmed the dean of School of Computer and Communication Engineering (UniMAP) for the continuous support of my study and related research, for his patience, motivation, and immense knowledge. His guidance helped me in all the time of research and writing of this thesis. I could not have imagined having a better supervisor and mentor for my MSc study.

I place on record, my sincere gratitude to Dr. Phaklen Ehkan postgraduate Chairman at the School of Computer and Communication Engineering for his constant encouragement and helpful comments.

Also I thank all my lecturers and the faculty members of the School of Computer and Communication Engineering (UniMAP), and all the UNIMAP library staff for providing me with all the resources that made my research easier.

Last but not the least, I would like to thank my father Prof. Dr. Meftah M. Abgenah, my mother Mrs. Naema Almagherbi and all of my family for supporting me spiritually, academically and financially to complete my studies and in my life in general.

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LIST OF SYMBOLS

β	Beta
γ	Gamma
δ	Delta
α	Alpha
ζ	Zeta
φ	Phi
ω	Omega
θ	Theta
τ_A	Altitude angle torque
τ_B	Azimuth angle torque
θ_z	Altitude angle
θ_A	Azimuth angle

LIST OF ABBREVIATIONS

PV	Photovoltaic
DOF	Degrees of Freedom
PVP	Photovoltaic panels
MPPT	Maximum Power Point Tracking
SCM	Single-chip Microcomputer
DC	Direct current
HSAT	Horizontal Single Axis Trackers
VSAT	Vertical Single Axis Trackers
AADAT	Azimuth-Altitude Dual axis trackers
MoU	Memorandum of understanding
SBC	Single board computer
w.r.t	With respect to

Pembangunan pengesanan dan embedded pengurusan solar sistem aktif

ABSTRAK

Tenaga solar semakin pesat yang terkenal sebagai sumber penting dalam tenaga boleh diperbaharui. Semata-mata, ia adalah penting bagi mereka yang berhasrat ke arah memaksimumkan jumlah keuntungan yang tenaganya untuk menggunakan kaedah yang akan memastikan keuntungan tenaga maksimum dengan menjejaki kedudukan matahari semasa kitaran hariannya. Kajian ini mensasarkan cara-cara mengumpul tenaga solar penuh diedarkan oleh matahari dengan melaksanakan mekanisme pengesanan yang akan menjejaki matahari kerana ia mengubah kedudukannya semasa kitaran hariannya. Sistem pengesanan dibangunkan adalah berdasarkan kepada mikropengawal sumber terbuka tertanam menggunakan kod sumber terbuka yang boleh diubahsuai dengan mudah. Sistem pengesanan dibina di atas mikropengawal Atmel ATmega328P sebagai pengumpulan data utama dan unit membuat keputusan untuk sistem. pengawal mikro ini adalah sebahagian lembaga pemaju Arduino Uno bahawa mempunyai beberapa GPIOs untuk menyambung peralatan yang berbeza untuk digunakan dalam sistem pengesanan dan dikawal oleh pengawal mikro. Ini peralatan terdiri daripada empat sensor LDR yang akan digunakan untuk mengesan kedudukan matahari dengan membaca pengambilan cahaya dan menghantar bacaan ke mikropengawal untuk diproses, LDR dengan bacaan keamatan yang paling ringan akan menjadi kedudukan yang disasarkan untuk sistem pengesanan untuk bergerak panel solar ke arah menggunakan dua motor servo yang juga akan dihubungkan dengan Arduino Uno melalui pin GPIO, kedua-dua motor servo akan mempunyai tugas yang berbeza, satu servo motor akan bertanggungjawab untuk menggerakkan panel solar secara menegak dan servo yang lain akan bergerak panel solar melintang. Prestasi dan ciri-ciri penjejak solar uji kaji dianalisis untuk menunjukkan keperluan dan kelebihan menggunakan kaedah ini system.it mengesan menunjukkan bahawa sistem tracker solar direka terbenam cekap mengesan matahari dan mengumpul banyak tenaga berbanding panel solar statik. Sebagai tambahan kepada sistem yang dicadangkan mempunyai kelebihan berbanding sistem lain diwakili oleh masa sebenar tracking berdasarkan teknik pengkomputeran obat matahari yang aktif. Sistem pengesanan solar tertanam menawarkan kos pengesanan solar yang cekap dan berkesan di samping program sumber terbuka yang membolehkan untuk peningkatan masa depan dan pengubahsuaian.

Development of an embedded active dual axis solar tracking and management system

ABSTRACT

Solar energy is gaining a rapid popularity as an important source of renewable energy. Per se, it is vital for those who aim towards maximizing the total gain of its energy to utilize a method that will insure maximum energy gain by tracking the sun's position during its daily cycle. This research targets the means of collecting the utmost solar energy distributed by the sun by implementing a six sensors dual axis tracking mechanism that will track the sun as it changes its position during its daily cycle. This tracking system is developed based on an open source embedded microcontroller using an open source code that can be easily modified. The tracking system is built on an Atmel ATmega328P microcontroller as the main data collection and decision making unit for the system. This microcontroller is a part of an Arduino Uno developer's board that has a number of General-purpose input/output GPIOs to connect different peripherals to be used in the tracking system and controlled by the microcontroller. These peripherals consist of six light dependent resistors LDR sensors to be used for sensing the sun's position by reading the light intake and sending the readings to the microcontroller to be processed, the LDRs with the most light intensity readings will be the targeted position for the tracking system to move the solar panel towards using two servo motors which will also be connected to the Arduino Uno via the GPIO pins, the two servo motors will have different tasks, one servo motor will be in charge of moving the solar panel vertically and the other servo will move the solar panel horizontally. The performance and characteristics of the six sensors dual axis solar tracker are experimentally analyzed to show the need and advantages of using this method of tracking system. The tests show that the designed embedded solar tracker system is efficiently tracking the sun and collecting much energy as compared to the four sensors tracking system and the static solar panels. In addition the proposed system has advantages over other system represented by real time tracking based on an active sun position computing techniques. The embedded solar tracking system offers cost effective and efficient solar tracking and open source programming which allows for future enhancement and modification.

CHAPTER 1

INTRODUCTION

1.1 Overview

The sun is an important element in this world we live in. Without the sun, nothing could exist because it's the main source of energy for all living creatures. One other advantage that we gain from the sun is solar energy. For millions of years this energy has been used to harvest heat and light to grow plants. Modern day technologies are being developed to harness the utilization of such a clean energy application in order to address the global challenges of climate change and sustainable development. Solar energy is rapidly gaining notoriety as an important mean of expanding renewable energy resources. Solar energy is clean, renewable and is the largest natural source of energy. Engineers have developed various means to collect sunlight and convert it into energy, this process is called solar energy, they have made this possible by inventing what's called solar panels. The main concept of a solar panel is to collect sunlight and convert it into energy as long as the sunlight hits the surface of the solar panel, but when the sun rotates as part of its day cycle the sunlight will not reach the surface of the solar panel, so the energy collected will reduce (Maharaja, Xavier et al. 2015)

To solve the problem of low energy gain from the sun's light, tracking systems are embedded into the solar panels. The basic function of these tracking systems is to track the sun during its daily cycle. To know the sun's position light dependent resistor (LDR) sensors are used to locate the sun's position and these sensors send data to a special program that will convert this data into coordinates. To move the solar panel, motors are used; these motors get the coordinates from the data sent from the sensor and move the solar panel to the desired location which in this case will be the position where the sunlight is at its most intensity. The aim in this project is to increase the sensitivity of the light dependent resistors (LDR) by adding more LDR sensors to the existing tracking system to insure better precision and placement of the solar panels. The main processing unit for this project will be an Arduino UNO single board computer. This system is suitable to be used in homes or small factories that want to save their budget for a long term.

1.2 Embedded Systems

A system is a set of programs or connected hardware that has one or many tasks. The term Embedded System is commonly used with computer systems that are dedicated to a certain function or many functions within a larger system. The main advantages that an embedded system has over any general purpose computer is that it has lower power consumption, smaller size, portable and light weight, costs less and rugged operating ranges. Embedded systems nowadays exist everywhere like robotics, automobiles, airplanes, digital cameras, home appliances and even mobile phones (Mazidi and Mazidi 2000).

There are many platforms that are considered to be embedded systems one of them is called the Single Board Computer (SBC). The SBC can carry out the tasks that a general purpose computer can do because it has a processor, storage unit, RAM and I/O ports that can be used to connect to other hardware devices and an operating system.

SBC companies are widely spread and each company designs its own board based on the developers needs for example Raspberry PI A and 2 Model B, Technologic Systems, Beagle Bone and many more (DeMicheli and Sami 2013).

Microcontrollers are considered to be embedded systems.

1.3 Open Source Technologies

Open source technology is the development and production philosophy of making available the developed source code of the software to end users and developers not only to see the code but they can also modify and use it as per their own needs. The name Open Source is not only limited to software, but there can be open source hardware, where the end users can develop the hardware and modify it to suit their own needs (Crowston and Howison 2005).

1.4 Problem statement

There are many problems that occur in the available types of solar tracking systems. one of these problems is that most of the developed systems move the solar panel in one direction or as known to designers as a single axis tracker which tracks the sun's movement vertically. Because of this problem, the power that can be generated is low. The second problem is even if the solar tracker is a dual axis tracking system which means it can track the Sun's position vertically and horizontally, the precision of the tracker is not quite convincing because it uses four LDRs to locate the sun's position, one other issue with the already developed dual axis systems that the price for the tracking systems is very high for the users who want to uses more than one tracking system. The available solar tracking systems developed by many researchers have been only focusing on how to make the solar panel track the Sun without considering the price or the level of complexity of the system, therefore this is considered a problem for many users that want to use the researchers' work. Because for some users they are using more than one Solar Panel to collect the Sun's light; so, for this they need to use a tracking system for all of their solar panels, this would cost the user a lot of money because the researchers did not consider using cheaper components to build the tracking system. One other problem with the available Sun tracking systems is that most of them operate using a high level programming language, this will make it hard for future developers to understand the code used in it if any further upgrades or maintenance is needed, so if the developers of these current solar tracking system are not available, then, no one can do the upgrades or maintenance needed.

1.5 Aim and Objectives of the Research

The aim of this project is to utilize the maximum solar energy through Solar Panels by applying the following:

- To design a precise system that can detect and compare the intensity of light by using six LDR sensors.

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- To design a precise system that can detect and compare the intensity of light by using six LDR sensors.

- To design a system that is able to move a Servo-Motor based on the intensity of light and show the voltage intake of Solar Panel on digital voltmeter.
- To design an open source and easy to use algorithm for the system for other developers to develop or use.
- To design a low cost tracking mechanism.

1.6 Research Scope

This project is focused on designing and building the prototype of solar tracking system that would be a starting point to build the realistic solar tracking system. Therefore, this prototype will cover the scope as follows:

- Move 90° vertically and 180° horizontally west and east.
- Use two Servo-Motors for vertical and horizontal movements.
- Use 6 Light Dependent Resistor (LDR) as sensors.
- Use a digital voltmeter to show the voltage intake of Solar Panel.
- Develop an open source tracking code.

1.7 Thesis Outline

This thesis consists of five chapters that are described as follows:

- The first chapter discusses the overview of the project, objective research, project scope, problem statement and thesis organization.

- Chapter 2 has the literature review. It will view in brief the work that has been already done by previous researchers and the results that they have found out.
- Chapter 3 includes the project methodology. It will discuss the methodology of the system, circuit design, software design and the mechanical design. It contains detailed description for the hardware and software development. It will explain in more details the electronic component that had been used and the methods used to develop the hardware.
- Chapter 4 shows the results of testing the system developed.
- Chapter 5 will conclude the whole project and give future recommendations.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Solar tracking is an important part of solar energy collection, because it maximizes the energy collected by following the Sun's location during the day as many researchers have found out by experiments various types of tracking methods. In this chapter the work done on solar tracking by various numbers of researchers is reviewed.

2.1.1 The Earth's Movement around the Sun

The earth rotates around the Sun on a level called elliptical orbit having the Sun as the foci. A year can be defined as the time earth takes for completing this orbit. The relative locus of earth and the Sun is appropriately shown by means of celestial sphere around earth. The equatorial plane and celestial sphere intersect in polar axis and celestial equator. The motion of the earth around the Sun can be visualized by ostensible motion of the Sun in elliptic tilted at 23.458 degree w.r.t celestial equator. The angle between the lines that join the centers of the earth and the Sun and its prognosis on the equatorial plane is known as solar declination angle (δ). On March 20/21 and on September 22/23, this angle becomes zero. The rotation of the earth around polar axis is one revolution per day. This is represented by the rotation of the celestial sphere about the polar axis and prompt locus of Sun is labeled by hour angle v, the angle between the meridian of the site and meridian passing through Sun. At solar noon, the hour angle is zero and this rises in the east. For observers on the surface of the earth at a place with latitude φ, an expedient coordinate system is described by one vertical line at location that crosses the celestial sphere on two points, the nadir and the zenith, and subtends the angle φ with polar axis (see figure 2.1).

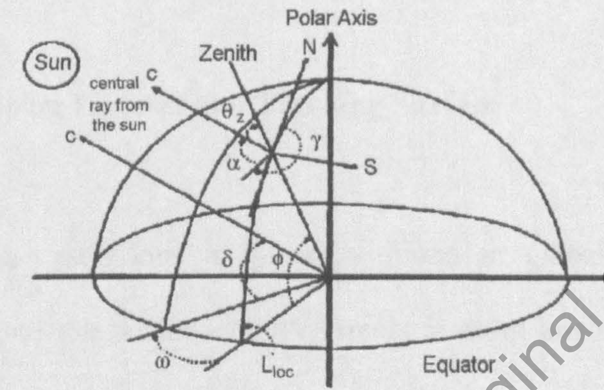

Figure 2.1: Graphic depiction of solar angles (Markvart, 2000)

The big circle that is perpendicular to vertical axis is horizon. The latitude (φ) of a location can be defined as the angle made by radial line that joins the location to earth's center with line's projection on equatorial plane. The rotation axis of the earth crosses the surface of the earth at 90^0 of North Pole latitude and 90^0 of South Pole latitude. Any place on earth's surface can be described by intersection of latitude and a longitude angle. The α, solar altitude angle, thus can be described as the vertical angle between the direction of rays of the Sun passing through the point and the prognosis of the rays of the Sun on the horizontal plane as represented in figure 2.1. Alternatively, the altitude of the Sun can be defined in solar zenith angle i.e. θ_z that is vertical angle between rays of the Sun and a perpendicular line to horizontal plane from the point defined by $\theta_z = 90^0 - \alpha$. γ_s i.e. solar azimuth angle is defined as the horizontal angle from south to horizontal projection of rays of the Sun (Khlaichom and Sonthipermpoon 2007). In order to calculate the solar positions and for defining relationship between stated parameters, many surveys are conducted. A FORTRAN program is used by Walraven to calculate the value of the parameter for Sun's position. The parameters computed were for time, Sunset and Sunrise actual times, elevation, local azimuth, and declination and the computed Sun's position was within 0.018 of accuracy (Walraven 1978).

2.1.2 Radiation on an Inclined and Tracking Surface

The data of solar radiations is generally found in global radiations form on horizontal surface and the position of PV panels is at an angle to horizontal plane. Consequently, the energy input to the PV system has to be calculated accordingly. There are three steps of this calculation. Firstly, for determining the beam and diffuse components of global irradiations on horizontal plane, the data for the site is used. This can be done by the use of extraterrestrial daily irradiation B_0 as reference and by calculating the ratio $K_T = G/B_0$, called clearness index where G is daily global irradiation on horizontal plane, and K_T can be described as the mean reduction in solar radiation by atmosphere in a month at a specified.

Secondly, diffuse radiation is found with the use of practical rule that the diffuse fraction D/G of global irradiation is general function of clearness index K_T. As B=G-D, this technique determines bean irradiation and diffuse on horizontal plane.

Thirdly, apposite angles dependence of all factors is used in determining the beam irradiation and the diffuse on inclined surface. Allowing reflectivity of contiguous area, the albedo can be determined too. By adding above stated three elements, one can get total daily irradiation on inclined surface (Poulek and Libra).

The Sun move on the sky in the day. The projection of collector area on plane perpendicular to the directions of radiations in fixed solar collectors is given by function cosine of angle of incidence (see figure 2.2).

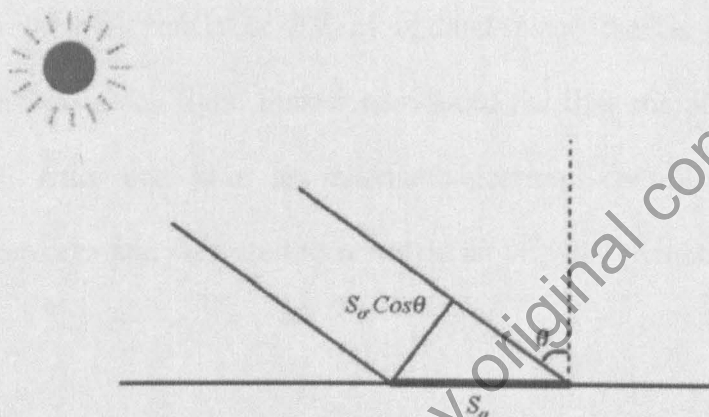

Figure 2.2: The θ, angle of incidence of solar radiation (Poulek and Libra)

The angle of incidence is denoted by θ and the higher the value of θ, the lower the power is. In case of the usage of tracking collectors, theoretical calculation of extracted energy is done presuming maximum irradiation intensity at $I=1100Wm^{-2}$ falling on the area perpendicular to the radiation direction. Taking the length of the day as t=12h=43,200s, the intensity of tracking collector is always oriented optimally facing the Sun as compared to the fixed collector perpendicularly oriented to the radiation direction at the time of noon only. The collector area is denoted by S_0.

2.1.3 Energy Gain in Tracking Systems

One axis can be used for the implementation of solar tracking but if more accuracy is required then obviously two-axis Sun-tracking systems will be required. Two kind of Sun tacking systems are available for two-axis as; polar tracking and elevation/azimuth tracking. The solar tracker increases the accumulated energy and this is a device that preserves photo thermal panels or PV in optimal place that is perpendicular to radiations of the Sun in day light. Finster introduced the first completely mechanical tracker in 1962. After one year, an automatic-electronic-control mechanism was introduced by Saavedra that was used to orientate an "Eppley pyrheliometer" (Poulek and Libra).

There is no need to place tracker direct towards Sun for efficiency. If the purpose is achieved by 10^0, 98.5 percent output of full tracking the output can be taken. While if it is cloudy, foggiest positions, 20 percent of the annual gain may be reduced. In a typically good area, the range of annual outcome would be 30 percent to 40 percent are normal. The range of outcome may vary between zeros to 100 percent in any day (Taki, Ajabshirchi et al. 2011).

Agee et al. examined field applications and trends in market of technologies related to solar tracking, the allied costs and expenses, requirements for maintenance and ways to improve their efficiency. These researches include program-control systems, hydraulic systems and trackers based on sensors like single-axis or dual-axis types and trackers based on polar-axis. For installations of lower capacity, hydraulic systems found to be more suitable. Moreover, they asserted that the performance of polar-axis