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Design of Intelligent Solar Tracking System

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Team Members

	Student Names	Student ID
1	Mohammad Alabdulqader	201701835*
2	Abdulrahman AlGranees	201600997
3	Saud Alkhammas	201601160
4	Ahmed Alabdulqader	201600585
5	Mohammed Alismail	201500815

Project Advisor:

Dr. Bouchaib Zazoum

Abstract

Solar panels absorb sunlight and convert it to electricity, making them the future of renewable energy. A solar panel is made up of solar (or PV) cells that can be utilized to produce electricity using the effect of PV. Photovoltaic simply means that they turn sunlight into electricity. Solar panels are classified into three categories: monocrystalline and thin film. Each kind of solar panel has its own set of benefits and drawbacks, with polycrystalline panels being low-cost and low-performance, mono-crystalline panels being high-cost and high-efficiency, and panels of the thin film being portable and versatile but having the lowest efficiency. Solar panels have a lot of benefits, including the ability to last up to 40 years, the use of the most abundant resource, sunshine, and the fact that they are both cheaper and more environmentally friendly than fossil fuels.

Solar power is the most rapidly expanding energy source. This project's main aim is to create a highly accurate solar tracker. There are two parts to the project: hardware and software. Solar plate, DC motors with operating boxes, LDR (Light-dependent resistor) sensor, and electronic components circuit make up the hardware component. The software component reflects the system's thought actions, or how it behaves under various weather conditions. A solar tracker system with having dual-axis was used to design and execute the project. Devices that monitor solar energy must be used in solar power systems to optimize the energy output from the sun. Energy can be used by using dual-axis trackers as they monitor sun rays from solar panels that are switched in different directions. This solar panel can rotate in any direction. Our project is also designed to detect whether changes. The motors, sensors i.e., rain and temperature sensor, display are all operated by Arduino.

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Furthermore, our thanks goes to Dr. Faramarz Djavanroodi for his suggestions and creative ideas, as he was caught up throughout the semester yet we had received their full support in order to have our project to be standing the best out there.

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List of Acronyms and Symbols that are used in the report:

V	Volt derived unit of voltage
A	Ampere derived unit of current
MOSFET	Metal-oxide Semiconductor Field Effect Transistor
LDR	Light-dependent Resistor
LED	Light-Emitting Diode
DC	Direct Current
PV	Photovoltaic
RE	Renewable energy

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Chapter 1: Introduction

1.1 Project Definition

The population of the world is growing at an exponential rate, and so is the oil demand. Oil and coal, which are currently the world's primary sources of energy, are predicted to be phased out in the coming century, posing a serious problem in supplying mankind with a cost-effective and reliable source of energy. Designing and constructing effective and reliable solar power systems is the subject of several research studies. Solar monitoring systems and controls have become the most critical components of a solar system for improving and optimizing solar energy absorption performance. Alternative energy supplies with low operating costs are urgently needed. In warm countries, the energy that can be obtained from the sun is considered to be the cheapest and most abundant form of energy.

We can use solar energy by using photovoltaic cells and then use the photovoltaic effect to obtain electrical energy from solar energy, which can be used in a variety of applications. Since the sun is one of the major sources of energy, to track solar radiation a dual-axis tracker has been created to track the radiation in all directions. This tracker takes sun energy as an input and then converts it into electrical energy. By placing the panel perpendicular to the source, maximum energy can be absorbed. As a result, instead of using a fixed panel, the solar tracker is used to optimize energy output and increase proficiency by 40%. In the daytime, a tracker with a single axis rotates the panel from the sides having independence of one degree. In comparison, a current type of trackers follows the sun’s movement from all directions.

We're combining a dual-axis solar tracking device with a weather sensor in this project. It uses different types of sensors to detect temperature, raindrops, and humidity, and the performance of these sensors is shown on a liquid crystal display (LCD). In this project, Arduino has been used to rotate the system towards the maximum intensity of the sun. Motors operate on the instructions given by the Arduino program. Weather conditions are detected using sensors. Man has required and used Energy at a growing pace for his survival and well-being for the past million years. Solar energy has the potential to become a reliable energy source that does not pollute the environment. As a consequence, this approach is more efficient and beneficial for obtaining full capacity.

1.2 Project Objectives

The project's objective is to gain maximum performance by maintaining the position of the solar panel perpendicular to the solar source. The control unit ensures that the solar array remains oriented toward the sun, and the dual axis solar PV panel uses data from astronomical sources as guidance. It can be mounted in a variety of locations with minimal changes.

Using the altitude and azimuth angles as a guide, the panel's vertical and horizontal motion can be determined. The system uses mathematics to ensure the motion of DC motors. It uses a weather sensor kit (i.e. rain sensor and temperature sensor) to detect all kind of weather and display it on screen.

1.3 Project Specifications

An initial flow diagram has been designed for project implementation. The power supply is providing energy to the whole system, next is the rectifier. The rectifier is used to convert AC to DC, the alternating current that flows in more than one direction to direct current that only flows in one direction. For reversing process inverter has been used, it removes fluctuation in current flow. Few examples of rectifiers are mercury-arc valves, semiconductor diodes, and vacuum tubes. Copper stacks and some silicon-based switches are other examples of rectifiers. A fine wire pressed against a crystal of galena served as a point-contact rectifier in early radio receivers known as crystal radios. A voltage regulator is a device that automatically maintains a steady voltage. Both positive and negative feedback options are available in a voltage regulator device. It makes use of electromechanical or electronic components. Then there is Arduino that connects sensors to the display. Following is the initial flow diagram of our project before implementation

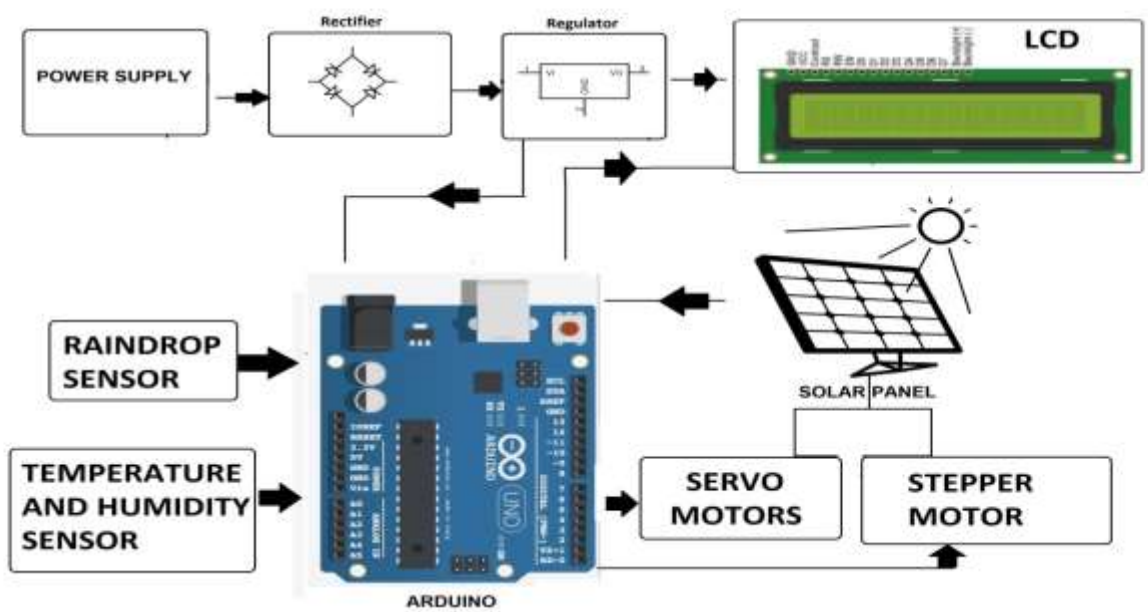

Figure 1 Initial flow diagram of solar panel with weather sensor kit

1.4 Applications

As nonrenewable power source assets become scarce, the use of inexhaustible assets for power delivery is growing. Day by day, solar panels are becoming more and more common. The solar panel captures the sun's energy and stores it in the tank. This vitality can be called upon when needed. This project shows how to use the vitality contained in the batteries. Solar panels must consume as much solar energy as possible. This can only be possible if the panels are still oriented toward the Sun. As a result, solar panels should always face the Sun. This project explains how a sun monitoring solar panel works. PV plates, reflecting devices, optical lenses, and other devices are directed toward solar light using trackers. Trackers are used for aligning the whole system to optimize energy output because the sun's location changes as the day progress, changes with every season, and the weather of the day [1].

Chapter 2: Literature Review

2.1 Project background

Sun-synchronous navigation entails rotating a robot (solar-powered rover) in such a way that its solar panel is still facing the sun, resulting in full battery charging and therefore allowing the rover to operate for long periods. Solar tracking systems are divided into two types based on their construction: single axis and dual axis. As compared to a fixed solar panel device, the tracking system increases the effectiveness of sunlight energy converted by around 30% [3]. It also has a simpler and less costly construction, making it reliable for a broad range of applications. On the other hand, the project offers greater performance on the absorption of solar energy, despite its substantial increase in construction complexity and installation cost. It has the potential to be up to 41% more effective than a fixed panel system [4]. This solar tracking system is unusual in that it uses the sun as a guiding source rather than the earth as a reference point. It also uses a weather sensor to sense the weather conditions to help generate the data of weather conditions. For example, there is a rain sensor to sense the quantity of rain and a temperature sensor to monitor the increasing or decreasing temperature of the day.

2.2 Previous Work

The study and investigation of collecting maximum energy from a system of the photo-voltaic array on a solar energy tractor were published in a Solar Energy Engineering Journal (Vol.133) (SAPHT). There were four to five light-dependent resistive sensors. In contrast to the horizontally fixed mode, experiments using the solar energy tracker devices revealed that 30 percent more energy was obtained. The sun rays were detected directly using the light detectors. As a shading system, an obstruction was placed between each pair of LDRs. A microcontroller was used to interface the hardware and software parts of the system. To drive motors and drive actuators, a power MOSFET was used. The results that were obtained at the end of the experiment showed that the system was reliable and effective [2].

A single-axis solar tracker tracks the movement throughout the day i.e. from east to west, whereas a dual-axis tracker also tracks the seasonal declination in the movement of the sun, according to the International Journal of Scientific & Engineering Research, vol. 3, 2229–5518. Concentrated solar power projects concentrate a broad area of solar energy through a narrow beam of trackers i.e. lenses or mirrors. Using the photoelectric effect, PV transforms light into an electric current. The conversion of sunlight into electricity is known as solar power. On regular days, test results show that tracking solar plates have a 26 to 38 percent higher power efficiency than fixed plates. And it varies to some degree on cloudy or rainy days [3].

Mirdanies et al. [7] have defined the tracking mechanism and command circuitry. A parabolic through a single alignment solar power plant system was used to incorporate this solar tracker system. A simple and low-cost tracker device was used in this research study that is made of a blend of a tracking device and a sensor for the light. The sun's location is first calculated in this method using a calculation centered on a timing system. Concerning the west-east direction, the sun track was thought to be a track that is half a circle with sunrise at 0 degrees and sunset at 180 degrees. The entire track angle of the sun was divided by the time of sun movement to get the sun movement angle per second. In addition to this straightforward estimation, the sun's approximate location at the time is then corrected using input from the LDR sensor. Mirdanies et al. [8] suggested an upgrade to the previous system. Further set of rules were used to detect the time of dawn and dusk to the worldwide location and time in analysis. The ideal angle that is vertical to the location of the sun is then analyzed by separating the solar tracker by the above determined periods of sunrise and sunset. It has one a alignment tracker centered on dawn and dusk times estimates and a feedback system. Corresponding to the model results, when compared to previous techniques that were tested, the system produces satisfactory results with time error ranges of less than 0.1 seconds in calculating dawn and dusk times.

The localizing of the sun concerning the movement of earth can be defined by two different angles concerning specific earth coordinates: azimuth angle and elevation angle.

A dual-axis tracker mechanism for controlling both angles i.e. azimuth and elevation angle of the panel needs improvement for maximum solar energy absorption. It is capable of increasing sunlight obtained by nearly 10 percent as contrasted to a single-axis tracker. Mirdanies et al [9] performed a report on the design and the model of an immense process that calculates the ideal angle of elevation of a solar panel, and the findings were positive. The algorithm generates a StDev error of around 0.15 degrees, according to the results.

Research has been carried out on visual camera-based solar energy detection done [9] to explore further alternatives for supporting dual-axis solar tracking systems. It uses image processing to localize and monitor the location of the sun when it is sunny and there are no clouds. A high-resolution camera detected the location of the sun in this project. The basic goal of the image processing method was to identify the sunlight source from the image and determine the sun's location about the image frame. There are four main stages of the process: conversion of captured image into the greyscale image, identifying potential contours like a circle, sifting, and locating base location of the sun. The calculated center location of the sun on this correlated image frame corresponds directly to this center. The best accuracy achieved by this method has an error of around 11 pixels, according to the results. With a resolution of 3864 x 5152 pixels, a focal length of 35 mm, and a sensor size of 6.17 x 4.55 mm, the camera used in this project has an error of about 0.02 degrees.

Considering all of the previous work on the solar trackers and the algorithm behind tracking solar energy, the report proposed a combined solution of a two-alignment process and picture treating based on the recognition of the sun. The key objective of this project is to create a weather-resistant, continuously accurate solar tracking device.

Chapter 3: System Design

3.1 Design Constraints and Design Variables

3.1.1 Specifications of the project

i. The timing allowed for adjustment – It was instructed that our project system must be able to focus on the maximum intensity of the sun in less than three-quarters of a minute.
ii. Power restriction – The controller part of the system must use a little part of the connected battery when daylight is not sufficient.
iii. To obtain the most amount of light, the control part should constantly monitor the angle of the sun to ensure that the panel is still perpendicular to the direction of the sun.
iv. The controller should always check the presence and intensity of rain.
v. The temperature sensor should always send a signal to the controller that will display the temperature of the environment on display.

3.1.2 Design Variables

i. Temperature sensor- This sensor is an electronic device that is being used to detect the temperature differences between the system and the surroundings and then translating the obtained value into an electrical signal.
ii. Rain sensor- A rain sensor is a form of switching domain that detects the presence of rain. It operates as a switch, and the idea behind it is when it is raining outside, the switch is usually locked.

iii. Control Unit- The control unit relays information and coordinates the positioning system's movement.
iv. Position Sensor- This sensor can be modified to satisfy the system's precise accuracy and power requirements.

3.1.3 Design Constraints

i. Time- One semester was allotted to us for the completion of the given project.
ii. Allowed Cost-budget of $200 was set aside for the funding of this project.
iii. The circuit system is to be trusted for rainy days.
iv. To control the dual-axis rotation of the system.
v. If time allows, the additional goal is to send the output of the system i.e. the position of the system, power consumption of the system, and other outputs to the device that is not nearby.

3.1.4 *Final design*

There is a slight difference between the initially proposed design and the final design of the project. It has a solar panel that will rotate with the intensity of light, a weather sensor to sense the weather conditions, and send the signal to the controller to display it on a screen. There is a temperature and a rain sensor in a kit to detect weather conditions. Two light sensors (photoresistors), an accelerometer, a microcontroller, a motor driver, a DC motor, and a motor that can run on 12V were all part of a control system. A speed-reducing gear and pulley were used to link these to the solar panel and frame structure. Figure 1 and Figure 2 are showing the images of the final design.

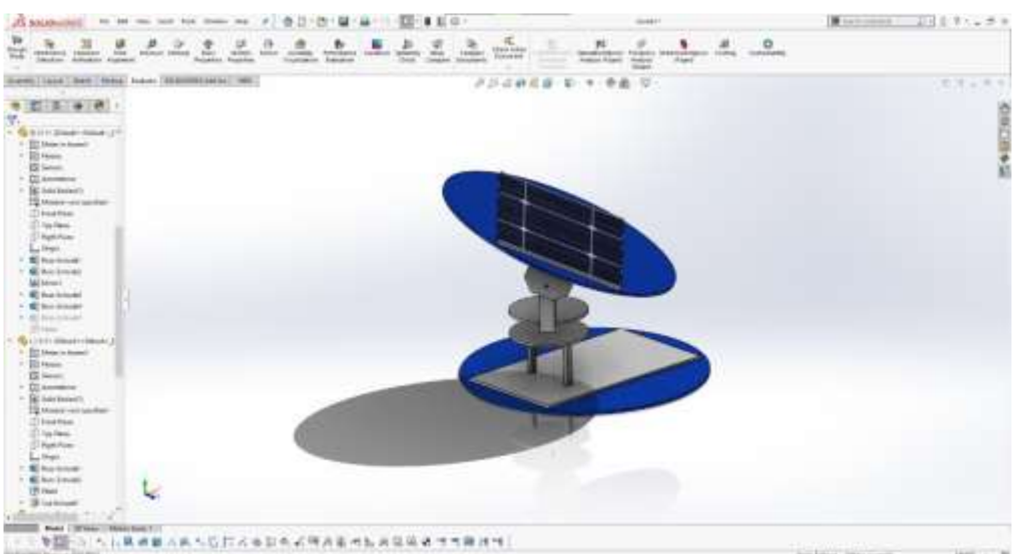

Figure 2 Complete design Side 1

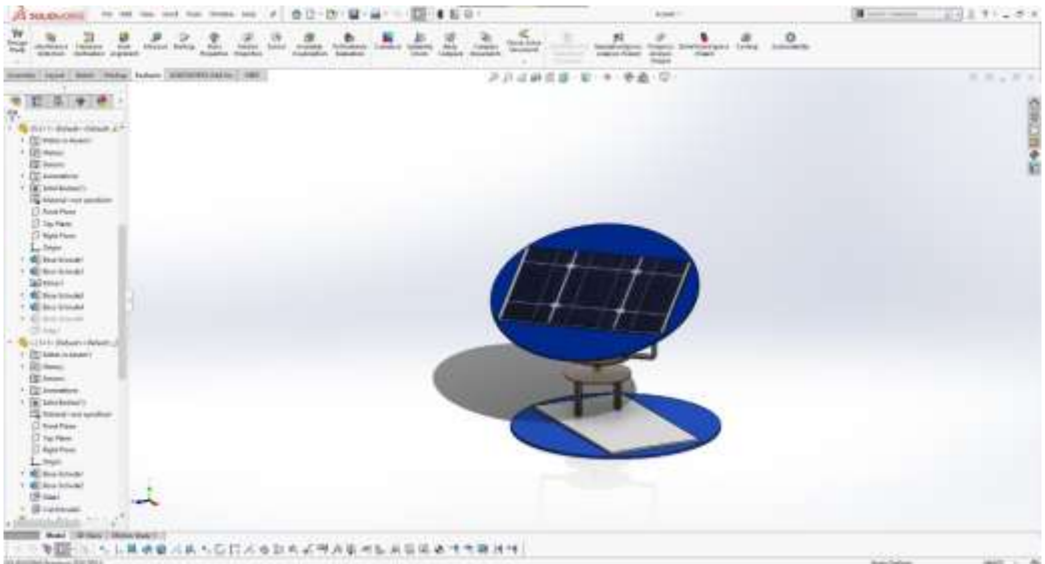

Figure 3 Complete design Side 2

3.4 Selection of Components

Setting up the required hardware was the initial step in constructing the tracker for our project. A typical dual-axis tracker system with a weather sensor kit consists of the following units:

- Mounting unit for the whole system
- Solar panel to direct towards sunlight
- A DC Motor
- An embedded system i.e. Microcontroller
- Power supply
- Rain sensor
- Temperature sensor

- Solder iron

- Supporting and interconnecting mechanisms.

Each unit's configuration and requirements differ depending on the application, but their functions and interconnections are nearly identical. Following is the final selection of components:

Figure 4 Stepper motor

As the name suggests, the stepper motor divides the complete cycle of rotation into many small steps. Not all DC brush motors are stepper motors, stepper motors are brushless. Many electromagnets having teeth are arranged around a central gear-shaped piece of iron in stepper motors, on the other side. To turn the motor shaft, one electromagnet first provides power and this creates the magnetic attraction between gear teeth and electromagnet teeth. As a result, when the first electromagnet is turned off the next one is turned on and the process is repeated.

Figure 5 Servo motor

It is an electric device that is powered by a specific mechanism known as a servomechanism. , A DC Servo Motor is the one that is used as a powered system and is connected to a servomechanism. On the other hand, there is an AC servo motor that is powered by an AC source. A servo motor is used for precise position, location, acceleration, and velocity. It has a feedback sensor for better positioning of the system. In our project, it helps to rotate the system towards the maximum intensity of solar radiation.

Figure 6 Digital display

The above-shown device is a device that displays the formerly processed information in a visual format. An electronic display receives input in the form of an electrical signal. It is used for displaying temperature and rain sensor values.

Figure 7 Arduino UNO

It's an Atmega328-based microcontroller board created by Arduino. cc. It's an open-source platform, which means the boards and software are freely accessible, and anybody can tweak and improve the boards for better performance. IDE is the name of the program that is used for Arduino modules (Integrated Development Environment). The board has 14 digital I/O pins and 6 analog pins, allowing it to be connected to any circuit outside of the board. External devices that can be linked via these pins benefit from the versatility and ease of use provided by these pins.

Figure 8 Digital multimeter

This is one of the most useful devices in electronics to measure a variety of electrical characteristics. It can be used to calculate the voltage and current of the components, capacitance, and inductance of the devices, etc. The system can also be used to measure the operation of transistors, diodes, and electrical continuity. It is intended for use in a laboratory or workshop where it will be stationary. We used it in our project to detect current and voltage flow in the circuit and to check values of the current and voltage of the components to see if they are within the safe limit or not.

Figure 9 Solder iron

A soldering iron is a hand-held soldering tool. It generates heat for the solder to flow into the joint between two workpieces. An insulated handle and a hot metal tip make up a soldering iron.

We used solder iron to test the temperature sensor working. Being in contact with the soldering iron, the sensor shows a high temperature. The temperature suddenly drops while we remove the solder iron contact with the sensor.

Figure 10 Solar panel

A solar panel is a photovoltaic module. It is an assembly of photovoltaic cells arranged in a system. They convert solar energy into an electric current. It provides sunlight to the system. Photovoltaic modules produce electricity using the photovoltaic effect, which uses light energy from the Sun. The top layer or the back layer of a module may be the structural member. Mechanical and moisture damage to cells must be avoided. The output power of every module is rated by output power and that power can range from few watts to as much as 400 watts (W).

Figure 11 Charger

3.5 Manufacturing and assembly (Implementation)

The prototype was assembled during few weeks. The team was able to complete the initial Electrical part in a few weeks, but the team had to spend quite some time constructing the mechanical part of the project due to difficulties in selecting and locating components. Figure 17 shows the complete prototype of our project.

Figure 12 Completely Constructed Prototype

Chapter 4: System Testing and Analysis

4.1 Experimental Setup

The project's implementation phase was carried out in conjunction with the completed design work from the previous chapter. As the main purpose of the control system is to continuously check the position of the sun to achieve the optimum power output, presence of rain, and the increasing/decreasing temperature of the environment. This can be measured by contrasting the system's current position to the solar position using microcontrollers and an accelerometer. The platform must be within 5° of the actual location of the sun. The solar panel's maximum misalignment from the light source was between 0° and 4° during experiments. The temperature sensor was tested through a soldering iron and a rain sensor with some water droplets from a glass.

4.2 Results, Analysis and Discussion

Since the photosensor, we used can work with any form of light that is visible, initially, the prototype was tested indoors using a light bulb as a light source. The system was successfully able to rotate with the direction of light and was keeping itself align with the light source. Due to the characteristic of the LDR photosensor, light detection had a slight delay, but this is suitable for solar PV applications since the sun travels slowly and steadily during the system's operation. The unit was able to identify and track the motion of an indoor light source during the functionality test. This was valid for both indoor and outdoor lighting (from a floor lamp) (sunlight). The tracker made proper use of the stepper motors, allowing the PV panel to rotate in a broad range of directions, as planned. Below is the demonstration of a tracker as the effect of light falling on it.

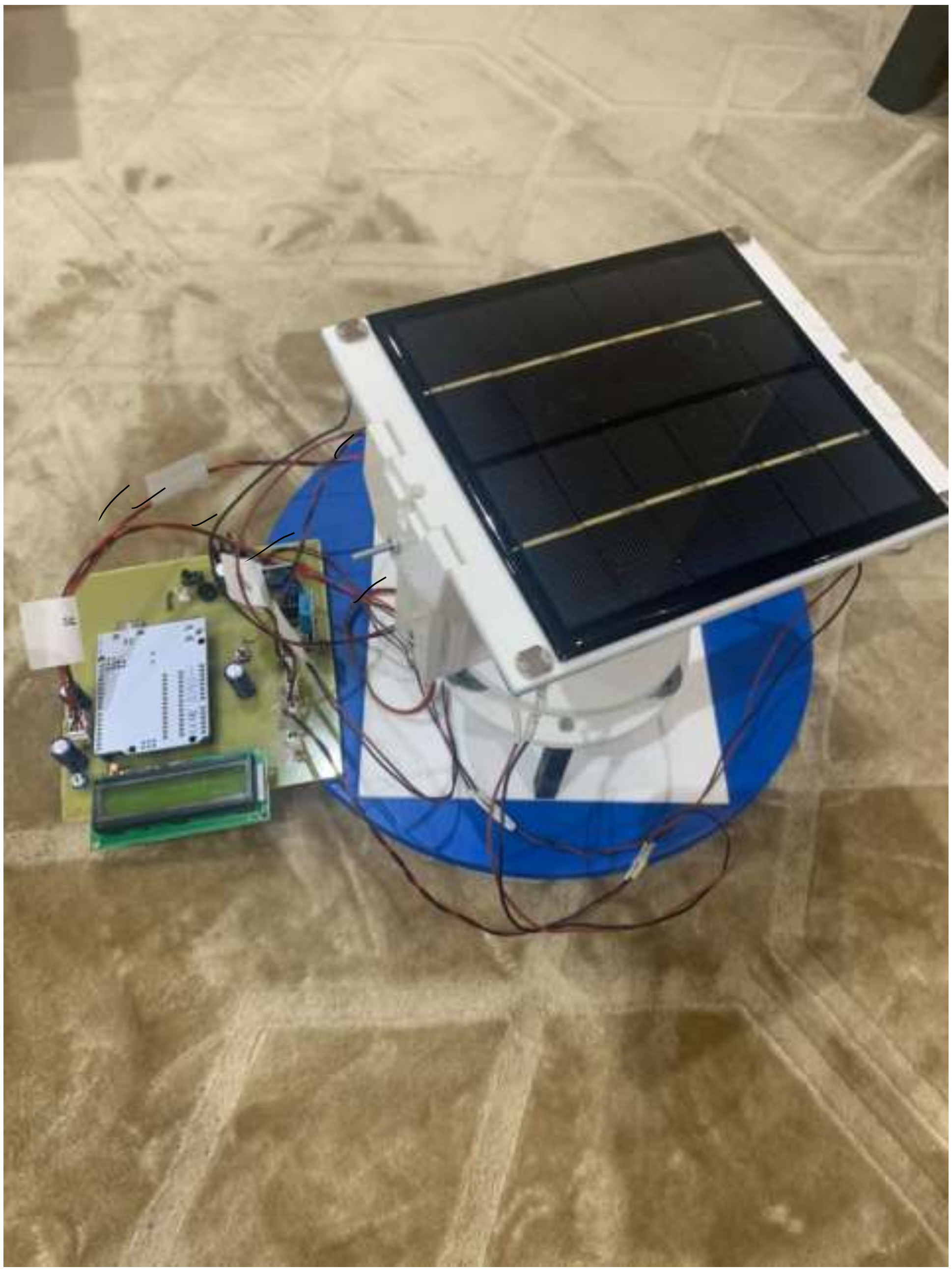

Figure 13 Demonstration of solar tracker

Figure 21 demonstrates the function of the rain sensor. As the water drops on the rain sensor, the value of rain is changing on the digital display. Figure 21 and Figure 22 show the changing value of rain with the increase in the number of water droplets.

To check the functionality of the temperature sensor, solder iron has been used to raise the temperature of the system. Below is the figure attached that are demonstrating the changing value of the temperature on the display, as the temperature of the soldering iron is increasing.

However, the solar tracker was far from ideal, with defects and limitations. The blocking of motor cables was a major error in the initial implementation. Twisted cables restricted stepper motor rotation and sometimes stopped the tracker from operating. With the addition of additional measuring hardware and improvements to the microcontroller software, this issue was addressed in the updated version. While a complete solution to this problem necessitates rearranging the motors and adjusting the mounting layout of the control board, this method was not explored in this project.

Chapter 5: Project Analysis

5.1 Impact of Engineering Solutions

Our project aim is to generate maximum power through non-polluting means as the sun is an enormous source of energy that has only recently been discovered. It has vast resources that can be used to produce renewable, non-polluting, and long-term energy, resulting in zero global warming emissions. Solar energy has recently been discovered to be able to be harvested and processed on a global scale, to potentially replace traditional energy sources. Solar energy has become increasingly important as the world shifts its attention to cleaner energy sources.

5.2 Contemporary Issues Addressed

Solar energy is chosen because it is environment-friendly, readily available, and in abundance. The research-based on solar PV technology is important in increasing the current efficiency of the energy obtained from the solar source, in line with the value of taking in solar radiations as a substitute source. One way to do this is to use solar tracking to increase the strength of the radiation received from the source [4]. While it is said to be costly, the expense can be reduced indirectly if performance is improved. This is critical for the system's long-term survival and stability, as well as the technology's long-term viability. Solar monitoring will become the most viable technology in solar energy harvesting shortly, helping to increase current capability alongside biomass and wind power generation systems. The solar electricity generation capacity in the GCC is especially high, at 300MW [5]. Nonetheless, the GCC government has committed to a long-term commitment to the production of renewable energy (RE) through a variety of funding and promotion initiatives.

Chapter 6: Conclusions and Future Recommendations

6.1 Conclusions

We concluded in this paper that a dual-axis solar tracker is more effective in terms of electrical energy output than a single-axis tracker or a fixed device. When opposed to the fixed system, the dual-axis tracking system gains almost 40%. And, since the tracking system used with a dual-axis tracker is more complex, it can be more costly and less accurate than a fixed system. As compared to a fixed system, the gain of single-axis tracker systems is around 28%, resulting in a balance between optimum power collection and system simplicity.

Single-axis monitoring is almost universally regarded as superior to stationary panels. Dual-axis tracking is also superior to both stationary and the normal tracker. The procedure recorded that the rise in energy extraction ranges from 12 to 69 percent; however, it seems that the 69 percent figure is underestimated. LDRs are used in almost all the procedures that have been published. However, LDRs are voltage-based, and tracking systems are highly voltage-sensitive. The use of light to frequency conversion is a precise and sensitive procedure because the frequency is directly proportional to irradiation. That is to say, it is proportional to power, especially current.

The prototype complied with all of the design criteria and specifications outlined in the Capstone Senior Design Project's previous semester. The solar panel will pivot from one extreme at 10 degrees to the other extreme at 165 degrees in 16.1 seconds at a full rotation speed. This satisfies the requirement of traveling the distance in under 30 seconds.

Although the project was successful in developing a system with the basic specifications, there are still major drawbacks and limitations with the device's performance, as addressed before in the report. In future growth, it may be possible to overcome these limitations and boost the device's performance.

The study also revealed that it is not appropriate to continuously monitor the altitude angle in areas on either side of the equator where the altitude angle does not exceed 30°, such as our region, but that it is preferable to do off-line tracking, where four to eight movements of 8° to 10° each per year are largely adequate and more than 98.36 percent extraction can be harvested compared to continuous tracking.

The project was a success in terms of achieving its aim, which was to study and catch up with current developments in the field of energy exploitation, which I set out to do when I began it. It's an excellent resource for those working on similar systems. The expertise and experience gained from this project can be used to create a variety of applications in the future.

Different photovoltaic systems were compared in this study. To investigate the effects of trackers i.e. single-axis and double-axis trackers, the relationships between components are made based on their location in the sky, and then configure the differences from the data obtained from previous projects. The results indicate that the energy that is received by a panel with a single-axis tracker was way more than that of a fixed panel project. It can be concluded from various studies that constructing a solar farm with single-axis tracker systems is a viable choice for generating electricity from solar energy.

6.2 Future Recommendations

Although the final form of the project has met all the criteria and specifications, there are some suggestions from the team for future developments.

A weatherproof case should be used to house the control circuit (microcontroller, motor drivers, battery, and breadboards). This will shield the entire control circuit from the external elements, which would otherwise cause problems in wet environments.

The photo resistors should also be enclosed in a light-proof material that only allows light to penetrate from a more pointed direction. By filtering out incident light rays and concentrating more on brighter light sources, the system's accuracy could potentially improve.

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