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Astronomical Almanac's Algorithm Based Dual Axis Solar Tracker

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Abstract - *The main problem presently is fossil energy exhaustion; Due to widespread use, nonrenewable energy sources such as petroleum and coal are fast decreasing. Solar energy is sun-derived energy that is environmentally friendly, a renewable energy source that produces no pollution, requires no upkeep, and is completely free. This paper offers the method for sun- tracking by using a dual-axis solar tracking system that uses the latest sun-tracking Astronomical Almanac (AA) algorithm. The hardware is divided into two modules - the weather station and the solar tracking panel area. A weather station is integrated with the system so as to provide users with real-time access to data, allowing them to adapt to the changing weather conditions by tilting the panel axis towards solar energy. The presented design shall be connected to an application permitting the user to access and view the data.*

1. INTRODUCTION

Solar energy is currently gaining a lot of attention as a promising renewable energy source.Renewable energy sources can be used to overcome the energy crisis generated due to the maximum use of Fossil fuel resources[1]. If the use of fossil fuels continues at the same rate, it will lead to its extinction in the near future.

It is possible to use solar energy, wind energy, rainfall, and other renewable resources. Solar energy is free and can be collected with the use of solar panels, solar power is one of the most widely used alternative pathways in renewable energy sources. Solar panels are essentially light-to-electricity converters. Trackers are utilised in these systems to help reduce the angle of incidence. i.e. between the incoming light and the panel, the angle formed by a beam of light with a line perpendicular to the surface, which increases the quantity of energy[4].

All solar panel systems feature trackers since the panels can't create energy unless they're pointed in the right direction. Trackers are classified as either single-axis or dual-axis. Single-axis trackers typically move in regular intervals to compensate for angular position, whereas dual-axis system trackers also move in regular intervals to compensate for angular position.The major difference is while single axis can move in only one particular direction, dual-axis trackers can move in all four directions, including north, east, west, and south, allowing them to collect the most energy from the sun.[1].

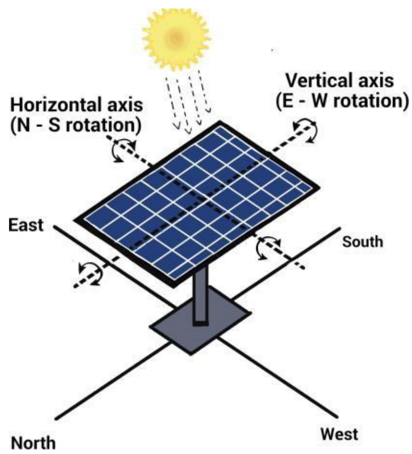

Fig 1: Solar tracker axis design

The more light the solar cell receives, the more power it generates. The efficiency of most of the solar trackers is around 10-15 %, as these trackers mainly depend on LDR(Light Dependent Resistor)[5].].In solar trackers, LDRs are basically used to detect the light levels and track sun movement by placing them in the four corners of the PV panel. LDR-based systems alone might be insufficient to achieve the required performance of the tracker[5]. The required angle for tracking is not accurate and the error rate is high. Due to these many reasons, it is not a good choice to choose an LDR- based system. Hence, the inaccuracy caused by the LDR-based system can be worked upon by using algorithm-based control systems. They can further make the system more intelligent by introducing predictions of sun movement. By using the sun- tracking algorithm our system focuses on increasingefficiency by 30-40 %[5].

Increasing the efficiency of the panel leads to more power and more return on investment, producing greater results. The size of the system, the rates, land limits, weather, feasibility, and other factors all influence the choice of a solar tracker. Horizontal single-axis trackers are commonly used in large projects, whereas vertical trackers are ideal for high latitudes due to their fixed or adjustable angles. In simple home applications, dual-axis trackers and single-axis trackers are commonly used.

It is vital for the panel to be directly oriented to the sun at all times in order to maximise power generation and system efficiency. To do so, our system introduces an algorithmic approach to align the panel towards the sun position automati- cally. You can also manually move the panel using the system's controls. The weather station integrated with our system sends a signal to the system once cloudy or overcast conditions get detected, tilting the panel in perpendicular orientation. A solar tracker system can be made more efficient in one of three ways. The first technique is to raise the efficiency of electricity generation, while the second is to improve control algorithm efficiency, the third way is to use a solar-energy-maximizing tracking system. This project's purpose is to combine the second and third methods for increasing efficiency.

2. SYSTEM DESIGN

2.1 Structure of solar tracker system

This study demonstrates how to use a basic and low-cost Internet of Things strategy to oversee and regulate a smart dual-axis solar tracker system. Our system showcases that maximum power is generated automatically, as the tracker keeps tracking the position of the sun. Figure 2 depicts the structure of our system. The main elements of our system are the tracking unit, positioning unit, manual control system, sensors, and IoT application. Here the system uses ESP32 as a control unit that manages the servo motors and sends signals to the system. Four solar plates of 4 volts each, generating 6v-60 mAh output are connected to two SG90 servo motors. These servo motors are used for the vertical and horizontal movement of the panel and provide ease in rotation and tilt movement of the panel.

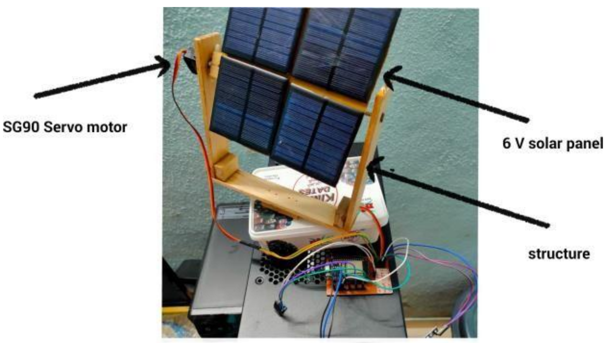

Fig 2: Solar tracker

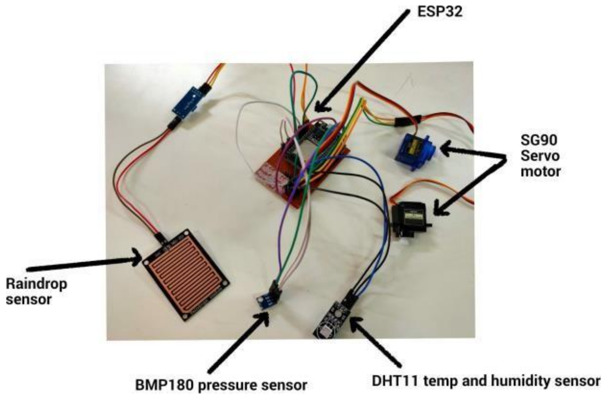

Fig 3: Weather station

A raindrop sensor, which monitors moisture, is part of a weather station. A BMP180 digital barometric pressure sensor is used to take note of the change in speed of wind or altitude. The DHT11 sensor is a popular and inexpensive sensor. It uses a capacitive humidity sensor and a thermistor to monitor the environment. All these sensors are connected to ESP32. The primary purpose of weather sensors is to provide data on current weather conditions. An IoT application called Cayenne is used to monitor and keep track of the output data generated by the sensors. Cayenne employs the Message Queuing Telemetry Transport (MQTT) protocol. To communicate with the Cayenne cloud, you must utilise the MQTT protocol. The dual-axis solar tracker can rotate and shift automatically in order to track the sun's location according to an algorithm, or can also be manually handled by the user through this IoT application.

2.2 WORKING MECHANISM

Firstly, the system detects the sun's position by the algorithm and sends data to the controller (ESP32). The programme calculates the azimuth and elevation angle of the sun given latitude, longitude, date, and time. Based on the values derived from the algorithm the panel position gets set. This information is processed by the controller, which then sends commands to the servomotors (S1 and S2) to spin the panel towards the sun. The left-right (L-R) servo motor rotates the solar tracker on the vertical axis (East/West), while the up- down (U-D) servo motor rotates the solar tracker on the horizontal axis (South/North). The data from the solar tracker, such as temperature, humidity, and rainfall, is displayed in real time by the IoT monitoring app.

The IoT monitoring application was built using the Cayenne my Devices platform. Cayenne connects any device to the Cayenne cloud via the MQTT protocol. Once linked to the network via a smartphone or computer, the user can analyse all of the statistics in the IoT application. The solar tracking system has two modes of operation: manual and automatic. A button on the Cayenne dashboard is being used to toggle between both two modes. When not in use, the manual mode is chosen; alternatively, the algorithmic mode i.e.automatic mode is opted. As a result, the user has all of the necessary information about the environment and the performance of the PV panel. Furthermore, when the manual option is activated, the user can simply control the servomotor positions to orient the PV panel from east to west using the L-R servomotor or from south to north using the U-D servomotor. If the automatic mode is chosen, the algorithm will be run. As a result, the user can operate the system to obtain precise environmental conditions and collect the greatest amount of energy from the PV panel.

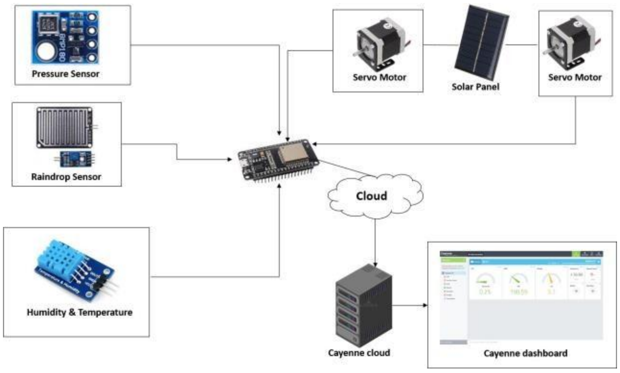

Fig 4 : Working mechanism of the system

Moreover, the data collected from weather sensors is useful to detect overcast or rainy weather conditions. The tracker is programmed to automatically orient the panel perpendicular to the sun when such conditions are detected, as research proves it to be the most efficient position in case of such scenarios.

Though the energy collected shall be less compared to normal sunny days.

3. ASTRONOMICAL ALMANAC'S ALGORITHM

The Astronomical Almanac's algorithm or simply sayingthe AA algorithm has been implemented in our system. Our algorithm is used to identify or determine the position or location of sun at any time, any day of a specific geographical location. The sun's position is affected by the rotation of the earth, hence the sun's position is dependent on the acquired date, time, location - latitude, and longitude. The solar position and the most suitable tilt of the panel towards the sun are calculated using this method, which changes throughout the day. One of the factors through which you can improve the solar tracker efficiency and reduce its error rate is by implementing an algorithm that tracks every movement of the sun and can generate up to 20-30% of more energy than that of a regular LDR-based system. The method is used because of its easiness, serviceability, and ability to rapidly take into account the solar position and compute the output. The algorithm determines the solar azimuth and elevation angles of the sun. Using these angles, the solar panel is then oriented toward the sun. The AA algorithm takes many factors into account. Various inputs such as year, day, time, latitude, and longitude are given to get the output parameters - sun azimuth angle, sun elevation angle.

In order to understand the working of the Astronomical Almanac's algorithm, We must first understand the terms used in the algorithm thattracks the sun's movement.

A. Time

The time input in our algorithm specifies the gap between the observed Julian date and JDate- 2451545, which represents January 1, 2000.

JDate = JulianDate(year, month, day);

B. Declination

The sun's declination is the angle formed by the equator and a line drawn from the Earth's centre to the sun's centre. The tilt of the Earth on its axis of rotation around the sun causes this angle to change.The following formula is used to compute the declination angle:

Sin(sin(Obl)* sin(L_true))
Where,

Obl(oblinquity of ecliptic)
(epliptic long)

C. Right ascension

Ascension to the right Right ascension (RA) and declination (DEC) are to the sky what longitude and latitude are to the Earth's surface. The east/west direction (like longitude) is rep- resented by RA, while the north/south direction is represented by Dec. (like latitude).

The following formula can be used to compute the
RA: sin(L true) * cos(Obl), cos(L true)

D. Hour Angle

Angle of the Hour, the azimuth and elevation of the sun are calculated using an hour angle, declination angle, and right ascension.

DEG TO RAD * GrHrAngle + Lon - RA;
where,

RA(Right ascension)
Lon(longitude)

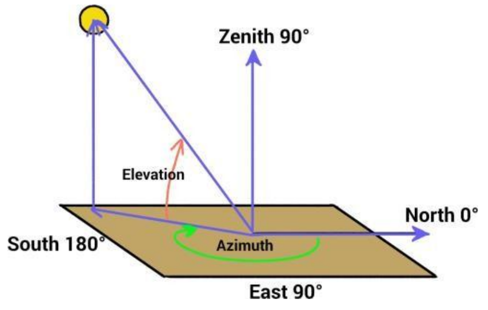

Fig 5: Solar angle variation

E. Solar azimuth angle

The azimuth angle indicates the compass direction the sunlight is coming from. The azimuth angle changes during the day and can be determined using the following formula:-

azimuth = PI + atan2(sin(HrAngle), cos(HrAngle) *sin(Lat)

- tan(Decl) * cos(Lat))

F. Solar elevation angle

When the sun is directly overhead, the elevation angle is 0 degrees at sunrise and 90 degrees at sunset. It's the complement of the zenith, the angle between the horizontal plane and the sun's centre ray. Th_e elevation angle is the distance between the horizontal plane and the angular height of the sun in the sky. The following formula can be used to compute the elevation angle,

elevation = sin(Lat) * sin(Decl) + cos(Lat) * (cos(Decl) * cos(HrAngle))

where,

HrAngle(hour angle)
Lat(latitude)

Decl(declination)

Our solar tracker by default is set in automatic mode and will be using the algorithm embedded in ESP32. The initial position of our solar panel is 0- degree azimuth and will orient according to the input parameters supplied

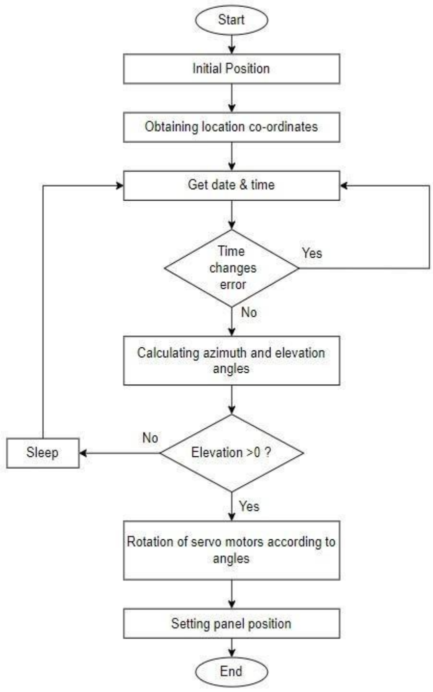

Fig 6: Flowchart of AA algorithm

The Wifi SSID and password is set up into code along with the latitude and longitude to get the current date and time. Next, the timezone was set to IST-5:30 so that our algorithm works on the basis of the local time.

The Network Time Protocol (NTP) server, namely 0.uk.pool.ntp.org is used to synchronize the clocks between computers, devices, and networks over the Internet. If the system fails to acquire the time information, then it keeps on repeating the process till it receives the appropriate data. Time acquired is in the HH:MM:SS format along with day, month, and year. The sun's azimuth and elevation angle are calculated using the input parameters, and the signal is then supplied to the servo motor. The servo motor is set into motion and sets the panel in the appropriate position.These servo motors tilt the panel in the desired position. The panel tilts a minimum from 0 degrees to a maximum of 180 degrees.

Once the servo motors rotate the panel up to a certain degree the setting of panel position is completed.

4. SOFTWARE DESIGN

A. Arduino IDE

The Arduino Integrated Development Environment, or Ar- duino IDE, is a platform for writing code that includes com- mon functions and other features. It connects to the Arduino hardware, allowing it to upload

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and communicate with pro- grammes. It is compatible with the C and C++ programming languages. The controller in this project is programmed using an IDE, which allows users to alter codes before uploading them to the microcontroller through a USB wire.

B. My devices cayenne

myDevices is a company that specialises in Internet of Things (IoT) solutions. It provides an end-to-end IoT platform. Cayenne was employed as an IoT application in our project. Cayenne connects any device to the Cayenne cloud via the MQTT protocol. Data can be transferred and received from the device to the system and vice versa once the connection is established. Various libraries, such as the CayenneMQTT library, were installed in the IDE using the library manager in order to use the MQTT protocol. Information such as ClientID, password, and username were required to establishauthentication.

There are two main modes in our system: auto and manual. To switch between the two modes, a switch button is added in the Cayenne IoT application. Our system operates in auto mode by default. When the button is active the system shall automatically switch to manual mode thus allowingthe user to manually handle the tracker. The user cancontrol the panel position if the manual option is selected. If the automatic mode is chosen, the algorithm shown in Figure 6 will be used.

5. RESULTS AND DISCUSSION

Our prototype system is displayed in Fig.7 The ESP32 is powered by a computer through a USB cable. With the IoT application, the Wifi establishes internet connectivity. The data from the solar trackersystem can be monitored once the connection with the IoT application is established.

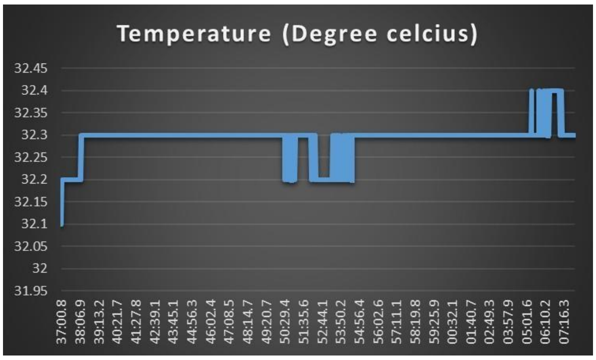

Fig 7: Environmental measurements (temperaure)

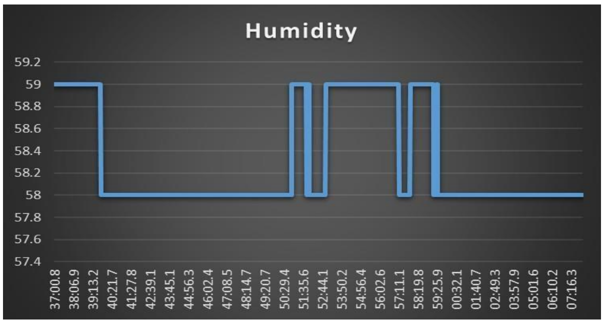

Fig 8: Environmental measurements (Humidity)

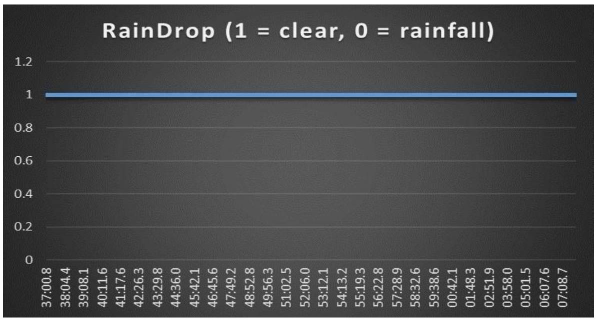

Fig 9: Environmental measurements (Raindrop)

The real- time sensor information namely the temperature, humidity, pressure, and rainfall can be displayed in the IoT application. The auto mode is activated first and hence the servo motors are automatically controlled through the algorithm. Theservos will tilt and align the panel in direction of thesun based on the angles calculated. When the servos are switched to manual mode, the widgets are usedto control them. The slider is linked to the servo motor which when increased or decreased passes the degree value and tilts the panel as per user given

input. This can save power as the panel can be positioned in one particular direction for an entire season such as winter, or rainy. Though this shall also reduce the PV energy generated due to the panel not being able to move.

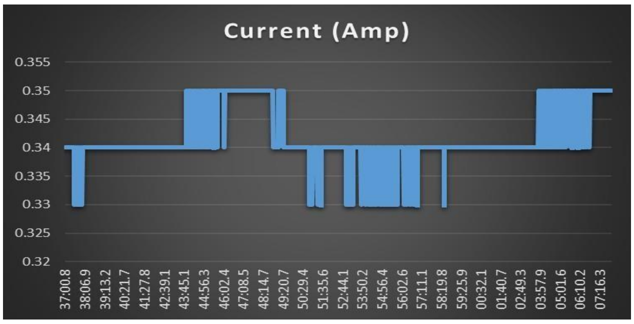

Fig. 10: Environmental measurements (Current)

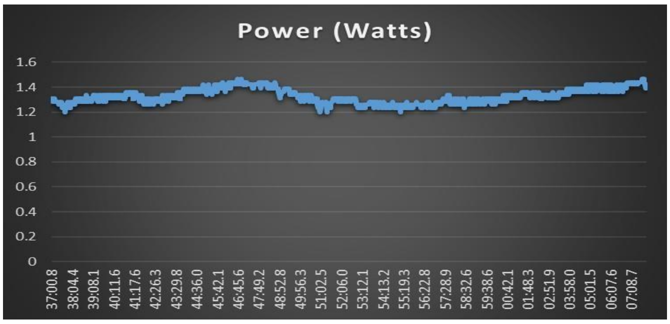

Fig.11: Environmental measurement (power)

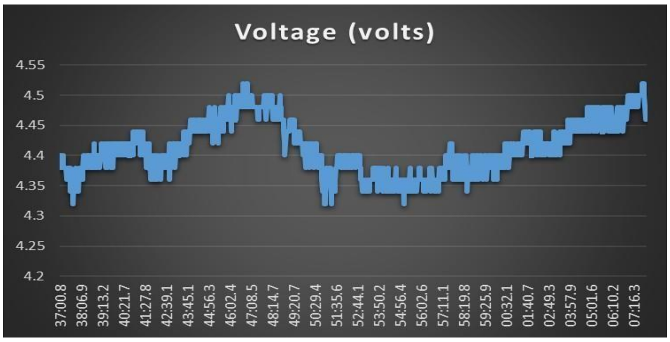

Fig. 12: Environmental measurements(Voltage)

In an IoT application, data samples are recorded in real time, trying to ensure that all environmental and electrical measurements are provided accurately. It has been developed to send an alert to test the monitoring application's reliability. When an event occurs, the user is notified. When the measured temperature hits 40°C, for example, an alert notification is sent to our mailbox at the same moment as can be seen in fig 10.

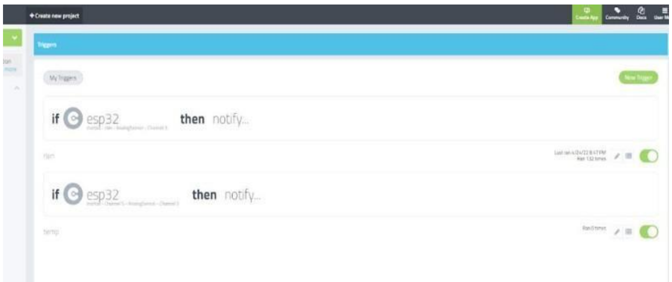

Fig13: Cayenne Dashboard

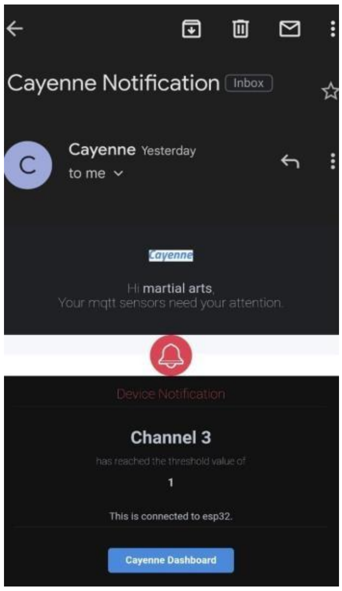

Fig 14: Cayenne Notification

Other alarms, such as a sensor and/or actuator fault and a sudden drop in PV power, can be added to the programme.

Similarly the rainfall is measured based on the the values - 0 or 1, with 1 indicating the clear weather and 0 indicating the rainy weather condition. Furthermore, testing has shown that the solar tracker implements commands from the monitoring platform correctly and quickly, with a response time of less than 2 seconds.In manual mode, the user can remotely position his device in an optimal direction based on the surrounding environment and device location. Furthermore, motor power consumption can be significantly reduced in this mode, or the user can intervene to direct the solar tracking system in only one direction for a particular season or period.

Fig 15: Dual axis solar tracker

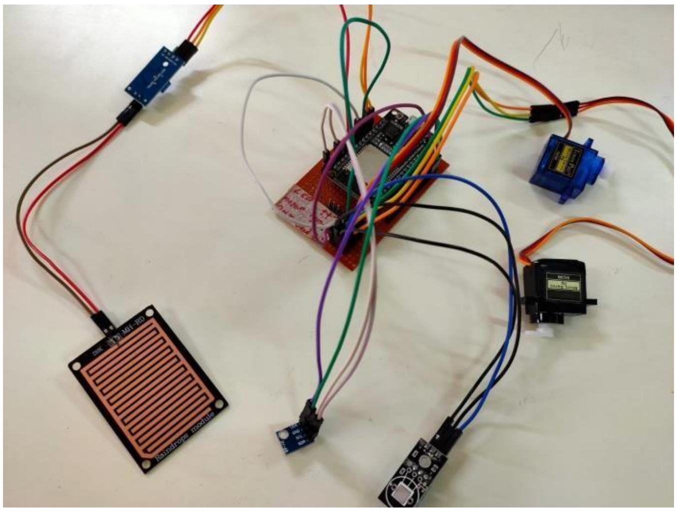

Fig 16: Weather station

6. CONCLUSIONS

The proposed project is aimed at an efficient solar panel system along with a mini weather station. To improve the efficiency of sun tracking, the AA algorithm is applied. Our tracker is dual axis, meaning it can track in both the X and Y axes. It moves left, right, up, and down, to put it even more simply. For accurate sun tracking, the AA Algorithm was utilised. This means that after you've set up your tracker, you'll never have to update or tweak anything because it will follow the sun wherever it goes. This use of algorithm saves up to 20- 30%

more power than regular LDR-based systems. Our smart prototype can be used to monitor as well as control the tracker. TThe system can also be expanded to test the solar tracker's flexibility in excessive pressure and high windy conditions. Due to its simplicity, reduced error rate, and cost- effectiveness the proposed IoT solutions can be used in a variety of settings, including at home, in neighbourhoods, and in businesses

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