ÓBUDAI EGYETEM
ÓBUDA UNIVERSITY

KANDÓ KÁLMÁN FACULTY OF ELECTRICAL ENGINEERING
ELECTRONIC AND COMMUNICATION SYSTEMS INSTI TUTE
INSTRUMENTATION AND AUTOMATION DEPARTMENT

FINAL ESSAY

OE-KVK
2023.

Bándi Magdolna Anna
T009085/FI12904/K

ÓBUDAI EGYETEM
ÓBUDA UNIVERSITY

Óbuda University
Kandó Kálmán Faculty of Electrical Engineering

Institute of Instrumentation and Automation

THESIS ASSIGNMENT

Student's surname, forename (s): Magdolna Anna Bándi
Thesis number: SZD2309040923458608[redacted]
Registration number: T009085/FI12904/K **Neptun code:** [redacted]

Branch of study:
Specialization: Instrumentation and automation specialisation

Thesis title: Napraforgó napelem
Task description: Planning a flower shaped dual-axis solar panel, which follows the movement of the Sun. Automatization of its movement by an Arduino microcontroller and implementing a telecommunication device. Collecting data to prove its efficiency compared to other implementations.

Institutional consultant's name: Döníz Borsos

The limitation period of the theme issued: 31.12.2025.
Deadline for submission of Thesis: 15.12.2023.

The thesis is: Not secreted.

Issued: Budapest, 24.10.2023. P.H ....
Director of Institute

The Thesis is suitable for submission:

....
Institutional consultant External consultant

STUDENT STATEMENT

I hereby declare that the present final thesis paper is solely my own work and that the references (written and electronic literature and tools used during the process) have been acknowledged and fully cited. I hereby grant the university and the task assigning institution permission to use free of charge the final results of this paper for their own purposes, abiding by the pertaining rules of encryption.

Budapest, 2023. 12. 13.

Signature of student

Sunflower Solar Panel

TABLE OF CONTENTS

1 INTRODUCTION

In today's rapidly evolving world, solar panels have become a crucial and game changing technology. Their importance cannot be emphasized as they address numerous pressing global challenges.

As we delve deeper into these issues, it becomes evident that solar panels are crucial answer for the present as well as a technology of the future.

A central role in our effort of sustainability is occupied by solar panels. By harnessing the inexhaustible solar energy, they reduce our dependence on finite fossil fuels. This transition to renewable energy sources makes it possible to protect the ecosystems, preserves natural resources and minimizes environmental degradation.

Solar power represents a clean and green alternative by reducing harmful emissions and mitigating the negative impacts of climate change. By replacing fossil fuels with clean solar energy, we are able to significantly reduce greenhouse gas emissions.

Solar power is a critically important tool in our collective effort to limit the rising of global temperature and mitigate the impacts of culminate change on both natural environments and human societies.

Nowadays the solar industry is a formidable driver of economic growth. The installation, manufacturing, and maintenance of solar panels create jobs and stimulate local economies. Solar energy can lead to long-term cost savings for households and businesses, freeing up capital for other investments and upgrades in life.

With the help of solar panels, individuals, communities, and even entire countries can become more energy independent.

To promote economic stability and reduce the vulnerability to geopolitical tensions and fluctuations in fossil fuel prices, the dependence has to be minimalized. The more energy we can generate locally, the less need we have towards the centralized power grids.

This independence can be maximized by a little more complex solar systems, for example dual-axis solar trackers. Solar energy is being revolutionized by this kind of solar systems. Unlike static solar panels, these innovative systems are designed to continuously follow the sun, therefore it is able to maximize the energy capture by dynamically tracking the motion of the energy source in two dimensions, therefore it enhances the efficiency of solar panels.

In this dissertation, the focus will be on elucidating the theoretical underpinnings of a distinctive solar panel variant known as the Sunflower Solar Panel. The discussion will encompass the automation of its movement facilitated by a microcontroller, along with the practical aspects of its implementation.

The objective is to successfully execute the implementation, subsequently gathering data. The acquired information will then be utilized for analysis and evaluation.

The controlling system is designed with an ESP32 microcontroller, implementing sun tracking using photoresistors. The movement of the solar panels will be facilitated by servo motors, which are controlled based on the sensor values to track the sunlight. The automation process and the measurement of the energy generated by the panels will be described, and the analysis of the measurement process and final results will be conducted.

2 LITERATURE OVERVIEW

Solar flowers operation is based on the working principle of dual-axis solar trackers. In order to properly understand the topic and the goal of the comparison, we need a basic knowledge about solar panels.

2.1 Solar Panels Basic Working Principle

Solar panels, often referred to as photovoltaic (PV) panels, harness the power of sunlight to convert it into electricity, offering an environmentally friendly and renewable source of energy. Understanding the fundamental working principle of solar panels is essential in appreciating their role in our transition to clearer energy sources. In this section, we will explore the basic concept behind how solar panels capture sunlight and transform it into electrical energy.

The main component of a solar panel is a solar cell, which is a tiny semiconductor device responsible for capturing sunlight and transforming it into electrical power, usually made from silicon [1].

Other commonly used materials are thin film-materials (like cadmium telluride, derivatives of copper), organic materials and specialized materials, such as gallium arsenide. Thin-film panels are flexible and lightweight, which makes them suitable for various special applications.

Solar panels operate by capturing sunlight and converting it into electricity through a process called photovoltaic effect. This effect is initiated when the fundamental units of light, so called photons impact the substance, so they can energize electrons, creating a flow of electric current.

Electrons within the semiconductor are excited by the energy of the absorbed photons, which causes them to shift to a higher energy state.

When an electron moves from its original position, it forms "electron-hole pairs" that result in a positive "hole" where it once resided. An electric field is produced inside the semiconductor by this method.

While the holes move toward the rear side of the surface, electrons migrate towards the cell’s front surface. As the holes and electrons travel in opposite directions, they generate electrical current.

Electrical contacts are presented on the front and back surfaces of the solar cell, which collect the electrons and provide an external electrical channel for them to travel along. To effectively collect electrons, the front side of the cell is typically constructed of a conductive substance, such as metals.

This collected electrical current is in the form of direct current (DC), which passes through an inverter converting it into alternating current (AC). This conversion is necessary because alternating current is the standard for electricity distribution grids. Additionally, alternating current is the type of electricity that is used in the majority of households and appliances.

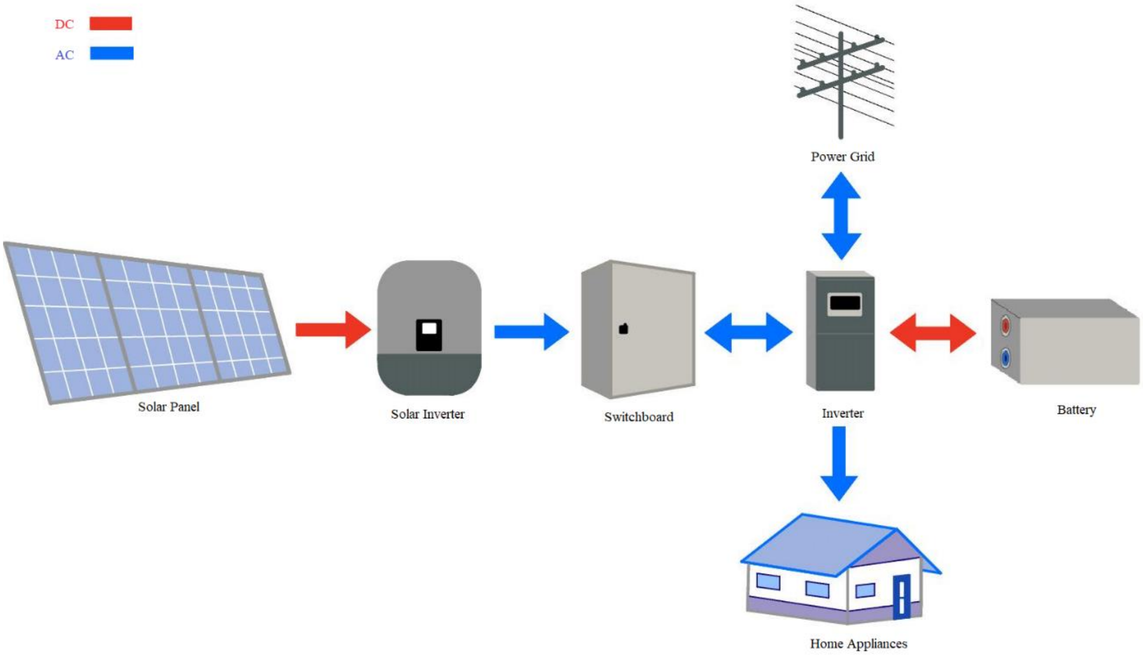

Figure 1. Path of Solar Energy to Power Users

Nonetheless, net metering systems give the possibility to homeowners to use the electricity from grid when their panels are not producing enough electricity – for example at night – and it also allows to send excess power back to the grid when their panels generate more electricity than they use and can store.

2.2 Dual-Axis Solar Tracker [2]

Dual-axis solar trackers are advanced devices designed to continuously change their orientation to follow the sun's apparent path throughout the day in order to maximize the efficiency of solar panels. Unlike fixed solar panels, which are stationary and receive sunlight at a fixed angle, this equipment can tilt and rotate in two directions, both vertically and horizontally. From sunrise to sunset, this dynamic movement allows solar panels to maintain the ideal angle and orientation to gather the most sunlight.

The basic idea is that with the help of photosensitive sensors the device is continuously adjusting the position of solar panels in two directions: azimuth and elevation (also known as altitude).

Azimuth is the direction of a celestial object from the observer, in this case the Sun, therefore this axis rotates the panels horizontally to follow the sun's movement from east to west. The elevation axis cambers the panels vertically to optimize the tilt angle, which is the space between the panels, and maximize sunlight exposure based on the sun's position in the sky.

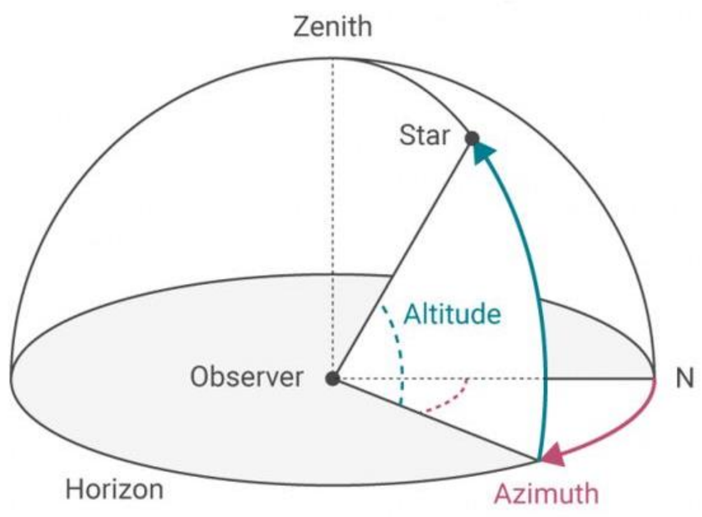

Figure 2. Azimuth and elevation angle [3]

These movements ensure that the solar panels are always perpendicular to the sun's rays, maximizing energy generation by capturing the maximum amount of sunlight.

Photoresistors can be used as sensors to determine the position of the sun related to the earth, also to maximize the energy generation. To gather more accurate data, we place four photoresistors in the same plane and separate them with a slab, which does not allow light to pass through.

If the plane is not perpendicular to the sunlight, the shadow of the slab will influence the resistance value of the photoresistors, so the position of solar panels has to be adjusted. The panel stops the tracking of sunlight if the four photoresistors in the margin of error have the same resistance. Shortly, the plane will be perpendicular to the sun’s rays, if the corresponding photoresistors have almost the same value of resistance.

To realize the solar tracking, the data measured by the photoresistors have to be sent to the controlling unit, which processes the data and forwards the information to other components. To position the panel into the right direction, two motors are required, one for horizontal and another for vertical positioning.

To achieve the best possible timing of movement, servomotors are used, which can be directed by a PWM (Pulse Width Modulation) signal. According to the sensor values the microcontroller can set the positioning of the servomotors.

A power meter is used to measure the system’s generated power in order to demonstrate the above claim. This procedure can be carried out either via telecommunication or it can be measured directly at the location of the solar panel.

To ensure a minimum of current available in the circuit, a load resistor is added to the circuit in parallel connection with the solar panel. This component is critically important, while it draws current away from the panel, improves output stability and therefore protects the elements of the circuit from current overflow.

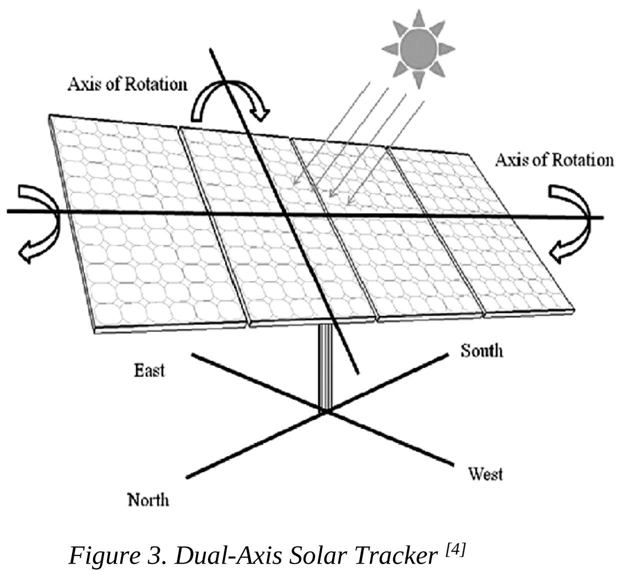

Figure 3. Dual-Axis Solar Tracker [4]

To achieve maximum power transfer, the load impedance has to be matched to the internal impedance of the solar panel, which is done by a load. In this case the load resistor is connected directly to the solar panel.

To sum up, understanding dual-axis solar trackers is essential to understanding the functionality of flower- flower shaped solar panels. The knowledge of these trackers highlights their ability to optimize solar panel orientation for optimal sunshine exposure. When applied to flower solar, this understanding enhances our grasp of how these unique designs can efficiently harness solar energy.

2.3 Solar Flower compared to Dual-Axes Solar Tracker

As opposed to traditional dual-axis solar systems, solar flowers can provide a number of advantages in several different situations. In the following paragraph I will list some of these advantages.

They are simpler in design and require fewer components, therefore the solar flowers have lower installation and maintenance cost. Also due to their simpler design solar flowers are generally more reliable.

When compared to a static slanted PV, a dual-axis tracking system offers an energy gain factor that is up to 40% higher.

Solar flowers provide an additional 10% efficiency [5] compared to dual-axis solar trackers, which results in thew conclusion, that flower solar increase in energy gain in contrast to not only a traditional solar system, but also to a dual-axes tracking system.

By continually adjusting its position to face the sun, the solar flower maximizes its energy production. Resembling a sunflower, it uses a biomimetic design to follow the sun's path across the sky.

This continuous adjusting gives the opportunity for them to capture more sunlight and produce more electricity than fixed dual-axis systems, which may not adjust as frequently.

Solar flowers are often more space-efficient, since they don't require as much clearance around them as dual-axis systems, which need more room to rotate. While a solar flower's panel are placed in a curricular format, the panels themself require less room than a panel system in which parts are placed next to each other.

Figure 4. Movement of Flower Solar during the day [6]

In a solar flower the panels are placed petallike around a point, which is the center of the flower (for example in case of a sunflower, this center would be the place of the seeds). The photoresistors are placed in this center which ensures a more accurate positioning to the solar panels, by avoiding shadow on the sensors.

Also, it is important to note that in this discussion I am mostly mentioning the advantages of flower solar, however a dual-axis solar tracker has advantages over the other implementation as well. The choice between these two implementations depends on the specific needs of the given project. The decision should be based on factors like budget, energy goals, climate conditions (because in changing weather dual-axis solar trackers are more suitable) and available space.

2.4 Classification of Solar Panel Installations [7] [8]

As mentioned in the section Solar Flower compared to Dual-Axis Solar Tracker, the choice between the implementations depends on several different aspects.

In this chapter the aspect of installation will be taken as the main standing point in order to gain a proper insight and understanding of the comparison.

Generally, based on installation, solar panels are categorized into six groups: residential, commercial, and industrial, grid-tied, off-grid, community, and hybrid solar panel installation.

Residential solar panel installations, as their name tells, are designed for homes and residential properties. Rooftop solar panel systems, that generate electricity for household consumption, typically belong to this group. Residential installations can assist homes in lowering their electricity costs and making a positive environmental impact.

Commercial and industrial solar panel installations are larger in scale and are designed for commercial buildings, industrial facilities, and businesses. These installations aim to offset a significant portion of the energy consumption of the respective buildings or facilities.

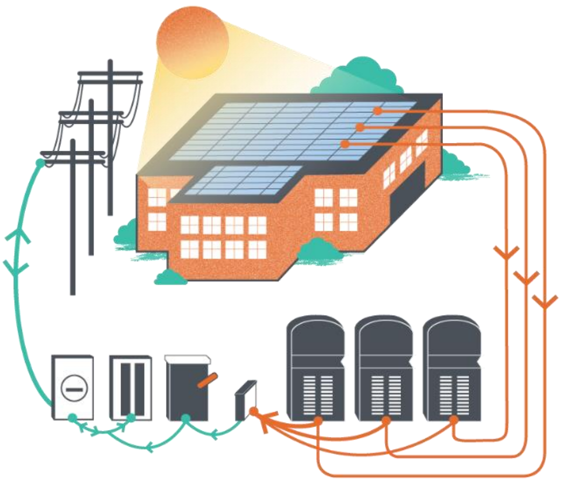

Figure 5. Commercial solar panel installation [9]

Grid-tied solar panel installations are connected to the local electrical grid. They allow the transfer of excess electricity generated by the solar panels back to the grid, which can be credited or used to offset electricity consumption during periods of low solar generation.

This type of installation is the most common type, and it can be found in both residential and commercial settings.

Off-grid solar panel installations are not connected to the power grid, also they typically can be found in remote areas where access to the grid is limited or not cost-effective. These installations require careful planning to ensure sufficient energy storage capacity. Off-grid solar panel installation is commonly used for instance in a standalone solar power system installed in a remote cabin, a vacation home or in disaster-relief efforts to provide immediate power.

Community solar panel installations, also known as solar gardens or shared solar, provide access to solar energy for those who may not have suitable rooftops or the ability to install solar panels on their own properties. Participants can subscribe to a portion of the solar energy generated and receive credits on their electricity bills. This type of installation is mostly operated in the United States.

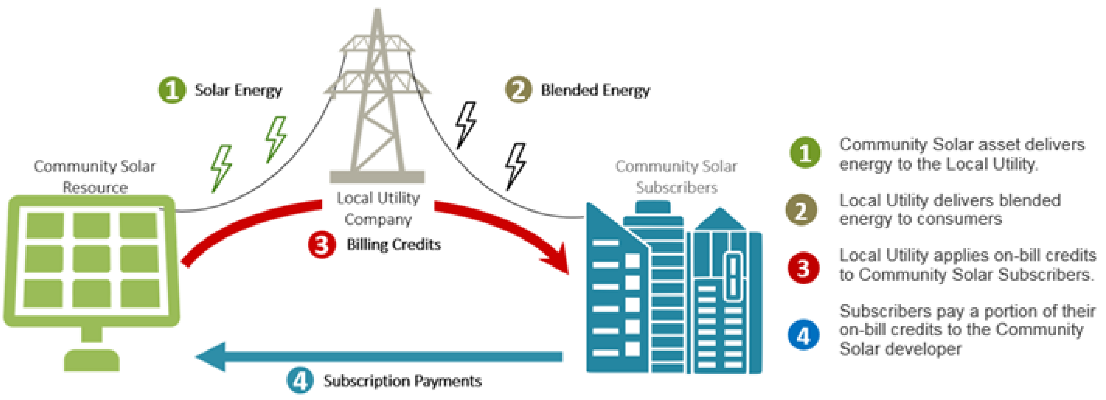

Figure 6. Community solar panel installation [10]

Hybrid solar panel installations combine solar panels with other sources of energy generation, such as wind turbines or diesel generators. These systems are designed to provide a more reliable and continuous power supply by utilizing multiple sources of energy. Hybrid installations are commonly used in areas with intermittent renewable energy resources or unreliable grid connections.

A common example for hybrid solar panel installations is combining photovoltaic panels with a solar thermal collector. The photovoltaic panels generate electricity for the homeowner, while the solar thermal collector captures the sun’s heat to provide hot water for domestic use. This system significantly reduces the homeowner’s electricity bills while also supplying hot water, making it a cost effective and sustainable solution.

Classification of solar panel installations is essential for understanding the diverse landscape of solar energy systems. This classification facilitates the wider shift to clean and sustainable energy sources as well as effective planning and management.

As we proceed to integrate solar energy as a major component of our energy production, having a well-defined classification system is a valuable tool for promoting growth, innovation, and environmental responsibility.

2.5 Communication [11]

In the realm of electronics and embedded systems, the seamless transfer of data from a microcontroller to a computer or server is a fundamental aspect of information exchange. In this project, this process facilitates the transmission of power measurements and other valuable data collected by the microcontroller to the computing system for further analysis.

One potential solution is to physically connect the computer to the device, thereby enabling the transmission and reception of data. However, in a project where the device is exposed to direct sunlight for an extended period, establishing a physical connection is not practical, as the heat generated wouldn't be beneficial for the computer.

Considering the above statement, the utilization of telecommunication becomes necessary. Telecommunication involves the transmission of information over a distance using electronic means and encompasses various technologies.

In telecommunications and networking, baud rate is a measure of the speed of data transmission. It represents the number of signal or symbol changes that occur per second in a channel.

The selected microcontroller, which will be specified in the "Component Selection" section, supports two types of telecommunications: Bluetooth and Wi-Fi.

Bluetooth, as a wireless communication standard, facilitates the exchange of data over short distances between devices, typically working within the 2.4 GHz frequency band with an approximate range of 10 meters, depending on the class. It employs Frequency-Hopping Spread Spectrum (FHSS) to minimize interference. The integration of Bluetooth Low Energy (BLE) enhances its energy efficiency, making it particularly suitable for Internet of Things (IoT) applications.

What distinguishes Bluetooth is its straightforward device pairing and the convenience of automatic reconnection. It employs radio frequency signals to transmit digital data between devices, classifying it as a digital wireless communication technology.

Wi-Fi, an abbreviation for Wireless Fidelity, facilitates seamless device connectivity to networks, spanning both 2.4 GHz and 5 GHz frequency bands (the selected microcontroller typically covers 2.4 GHz). It provides versatility and adapts to diverse environments. Wi-Fi routers typically provide an effective range of around 100 to 150 meters.

It is noteworthy that these telecommunications methods can be employed in conjunction. An example of the synergy between Bluetooth and Wi-Fi is seen in smart homes, where Bluetooth-enabled devices communicate locally, while Wi-Fi connects these devices to the broader internet.

In the context of this project the section of Bluetooth over Wi-Fi for data transmission in this solar tracking system is driven by specific environmental conditions and requirements. Given the extended exposure to direct sunlight and impracticality of a physical connection, Bluetooth emerges as the more suitable choice. Its short-range communication capabilities, energy efficiency, and user-friendly features align seamlessly with the solar tracker's needs.

This decision ensures a practical and efficient wireless communication solution, tailored precisely to the demands of the solar tracking system.

3 LOGICAL ARCHITECTURE

Active daylight tracking is essential in a flower solar because it allows the solar panels to be continuously adjusted to face the sun. This increases energy output, adapts to changing conditions, and improves the return on investments while reducing the carbon footprint, making solar systems more efficient and environmentally friendly.

The most common technologies for this include light sensors, motorized blinds, or shades, building management systems, daylight harvesting systems, smart glass or electrochromic windows, sun tracking mirrors and IoT technology for data collection. [12]

In this project photoresistors, as light sensors, are employed. This approach involves positioning photoresistors on a plane and elevating a plate made of non-transparent material between the components, which serves to divide the parts.

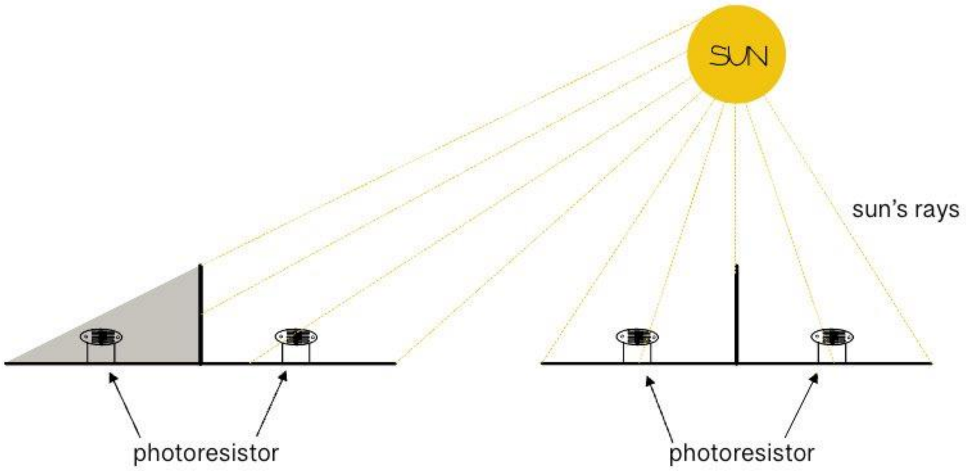

Figure 7. Active daylight tracking with photoresistors

If the incidence angle of the sunlight is perpendicular to the plane defined by the sensors, the separating plate has no effect on the resistance values of the photoresistors, and they take on identical values within the margin of error.

Nonetheless, if the incidence direction deviates from perpendicular, the separating plate casts a shadow in the opposite direction of the sun, which affects the resistance values. The photoresistors resistance values decrease with increasing light exposure.

In order to detect changes in light levels and follow the passage of the sun throughout the day, this kind of system makes use of the capabilities of photoresistors. By utilizing photoresistors in an active daylight tracking system, it is possible to monitor the direction of sunlight.

By observing the direction of sunlight, the system gains the ability to “know” in which direction it needs to move, and by doing so, it ensures that the solar panels are consistently aligned to face the sun directly.

This moving activity is carried out by two motors that move the panels to follow the sun’s movement. These are the tools for precise directional adjustment at specific times. To move the panels and maintain their alignment with the sun’s current position, the control algorithms transmit signals to the motors.

Since the system makes use of control algorithms, a controlling unit is definitely required. In this instance a microcontroller will satisfy this requirement and serve as the intellect of the whole system.

Its primary duty is to process data from sun position sensors, calculate the optimal orientation for the solar panels, and send control signals to servo motors for precise tracking, ensuring maximum solar energy capture.

The major objective of this project is to demonstrate flower solar’s superior power efficiency and systems’ effectiveness over alternative implementations. To measure the electricity generated by the solar panels a power meter is added to the system. In addition to the measurement, the goal of this device is to provide data on energy production and system performance.

In order to access the provided data remotely in such a system, telecommunication is necessary. This communication allows remote monitoring of the solar tracker.

It enables the collection and storage of historical data related to the system’s performance, that can be valuable for assessing efficiency, diagnosing errors, and making adjustments to optimize energy production or develop the system itself.

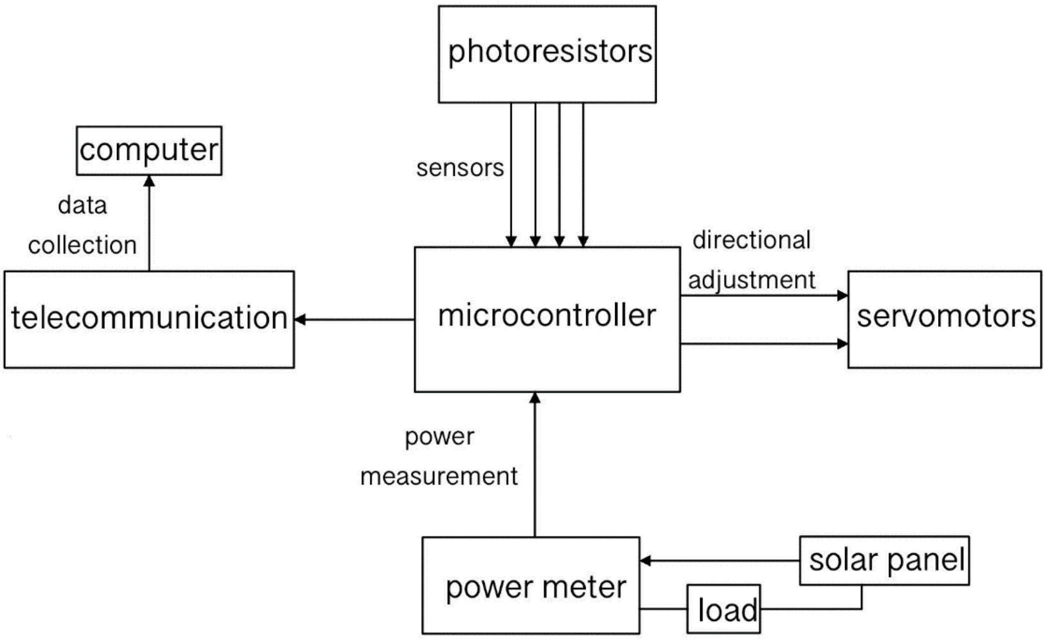

Figure 8. Logical diagram

In conclusion, the photoresistors are employed as sensors, whose output data is received by the analogue input of the controlling unit. Based on the results from the photoresistors, the microcontroller performs computations and generates output signals to the servo motors, which align the solar panels in the appropriate direction. The controlling unit also receives data about the power generated by the solar panels and transmits it via a telecommunication device to a computer.

4 TECHNICAL OVERVIEW

4.1 Design Requirements

Designing an efficient and reliable solar system is a complex process that demands careful attention to a number of essential design requirements. These specifications encompass factors such as precision tracking mechanisms, energy efficiency, and environmental considerations.

In this section, the essential design requirements that support the creation of solar tracking systems will be discussed, highlighting their critical role in maximizing solar energy capture and sustainability.

One of the fundamental requirements in designing a solar tracker is the integration of precise tracking mechanisms. These mechanisms encompass high precision actuators and motors that facilitate the accurate adjustment of solar panels in two dimensions.

To support precise tracking mechanisms, integral to the operation of the equipment are light sensors, in this case photoresistors (photodiodes are commonly used for this purpose as well). These sensors have an important role in detecting the position of the sun. As sunlight hits them, the sensors transmit data to the controller, enabling real-time adjustments.

Selecting the appropriate controlling unit is essential because every step on the above procedure depends on the calculations and instructions it provides. An efficient microcontroller ensures optimal performance, while energy efficiency is vital for sustainability.

4.2 Component selection

After identifying the design requirements, a vital stage in the design process is the selection of components. The panel's efficiency, durability, and overall functionality will be determined by these components.

4.2.1 Microcontroller [13] [14]

As the center and control of the project a NodeMCU esp-wroom-32 development board has been selected. It has integrated Wi-Fi and Bluetooth capabilities and supports Arduino IDE programming.

The main component of the board is an ESP32 microcontroller, which has high-performance and low power consumption. Nonetheless, it is based on the Harvard architecture (uses separate memory spaces for instructions and data), features 4 megabytes of flash memory and a range of peripherals, making it suitable for a wide variety of embedded applications.

The board also contains two oscillators, an external RC oscillator with a frequency of about 240 MHz, and an internal 80 MHz oscillator, which are used by the microcontroller as its primary clock source. This oscillator provides precise timing for the controller's operation.

The device requires a power supply voltage of 3.6 volts, which can be sourced through a micro-USB connector, even from an external battery. It provides dual voltage outputs of 5 volts and 3.3 volts for various applications. In this accomplishment the 5V output facilitates the propulsion of servomotors, sensor systems and the performance monitoring unit. The 3.3V output is dedicated to powering the telecommunication module.

It consists of 38 pins – 25 of them are PWM capable, 15 analogue channels of 12-bit SAR ADC (Analog-to-Digital Converter), two 8-bit DAC (Digital-to-Analog Converter) channels, and various power and ground pins. Digital pins are General-Purpose Input/Output (GPIO), which means they can be used for both input and output, while analogue pins are primarily used for analogue input.

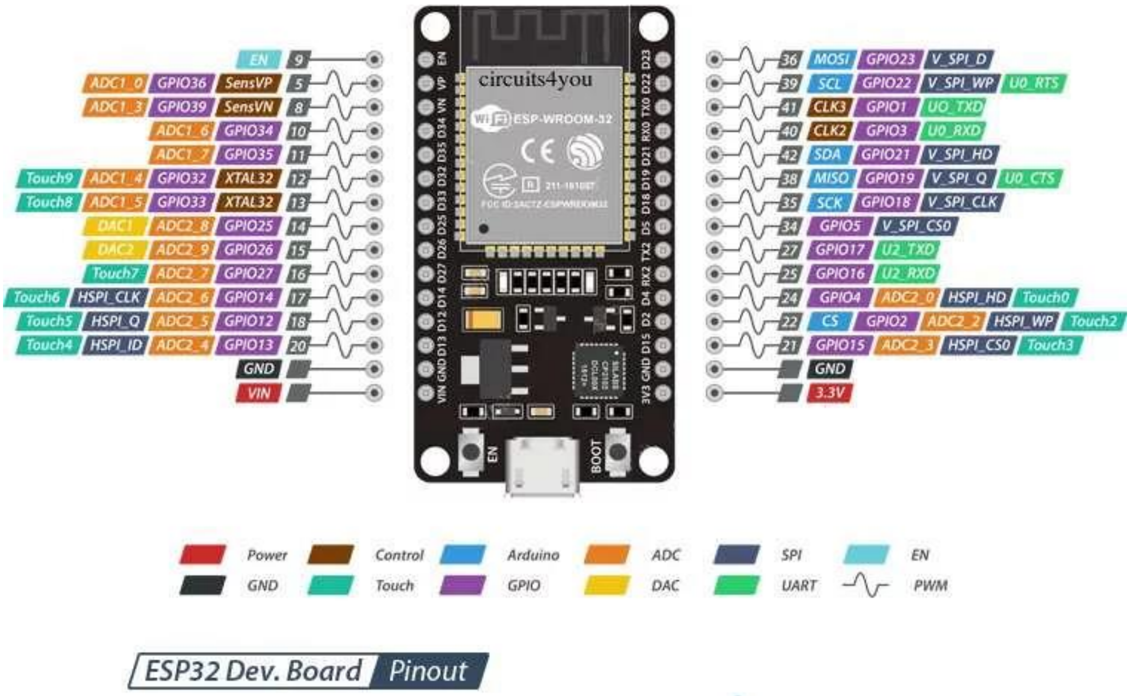

Figure 9. Microcontroller PIN layout

During the selection of a microcontroller, a critical criterion was the capability to generate Pulse-Width Modulation (PWM) signals on distinct output pins. On the above figure these pins are identifiable by the '~' symbol.

PWM is a technique used to generate variable analogue-like signals by rapidly switching a digital signal on and off (high and low). The key parameters in PWM are the signal's frequency and duty cycle, which determines the percentage of time the signal is in the high state. It controls the average voltage supplied to a device, allowing precise control of components like LEDs, motors, and servos.

In the course of this project, PWM signals were harnessed for the precise control of servo motors. The motor's shaft could be positioned to the required orientation by varying the duty cycle within a range.

Another crucial consideration during the selection process was the availability of suitable communication channels. The chosen power meter uses a so called I2C communication.

The I2C (Inter-Integrated Circuit) protocol is a synchronous serial communication standard, that enables integrated circuits to communicate with each other using a shared bus, consisting of two wires for SDA (Serial Data Line) and SCL (Serial Clock Line). SDA is the lane used for sending and receiving data between devices, SCL is responsible for synchronizing the data transfer between devices on the I2C bus and it serves as a clock signal for the data being transferred. Each device connected to these lines is uniquely addressable, by default INA219 has an address of 0x40.

The ESP32 microcontroller boasts integrated Wi-Fi and Bluetooth functionalities, offering indispensable capabilities for tasks related to the collection and analysis of data. These built-in features empower the microcontroller to seamlessly engage in wireless communication and data exchange, providing a robust foundation for a wide array of applications that demand connectivity and information processing.

4.2.2 Light Sensors

A variable resistor is an electronic component, whose resistance changes in response to different circumstances. In case of photoresistors, this condition is the amount of light it is exposed to. Lead sulphide and cadmium sulphide (used in CdS type photoresistors) are two examples of the extremely resistant semiconductor materials used in the fabrication of these components.

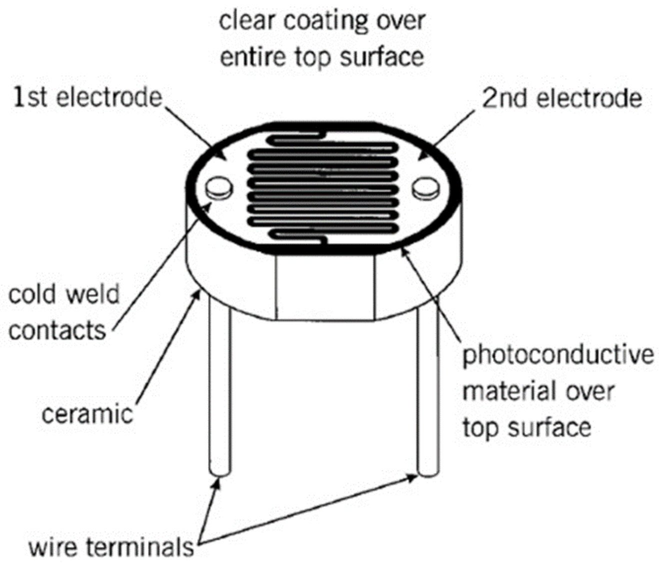

Figure 10. Photoresistors structure [15]

The fundamental idea behind how photoconductive cells operate is that the more light illuminates its electrodes, the less resistance the components have. The primary attributes of photoresistors can be categorized into two groups based on the quantity of light that strikes the component.

In the event of radiation two quantities must be mentioned: photocurrent, or the current that flows when the sensor is exposed to radiation, and bright resistance, which is the possibly lowest amount of resistance can be measured.

However, in total dark condition, important quantities include dark current, or the electric current flowing through the photosensitive device in the absence of light, and dark resistance, which is the possibly highest resistance value on a the photoresistor.

These quantities are measured in Lux, which is a unit of measurement for illuminance, representing the amount of luminous flux per unit area.

The values for the pieces I applied are as follows [16]:

- Light resistance at 10 Lux: 8～20 KΩ
- Dark resistance at 0 Lux: minimum of 1.0 MΩ

The implementation of this type of sensor requires an additional resistor, which serves as a fixed reference point. The resistor can be used to calculate what value of resistance the photoresistor has. In this case I used a resistor of 1k ohms for each photoresistors.

4.2.3 Servo Motors

To adjust the orientation of the solar panel and its attached sensors (photoresistors), servo motors must be employed. For the two directions, two servomotors are utilized for horizontal and vertical positioning, respectively. This equipment represents an electromechanical device, combining electrical and mechanical components to execute specific functions or tasks.

The term “servo” refers to a system that uses feedback to control the position of speed of a mechanism. A servo motor is a rotary of linear actuator that allows for precise control of angular or linear position, velocity, and acceleration.

Figure 11. Servo motor [17]

Servomotors can be divided into three main components: a DC motor, a control circuit, and a feedback mechanism.

The DC motor generates the rotational force necessary for positioning.

The control circuit, typically in the form of an integrated chip, receives information from an external controller (in this case the Arduino microcontroller) and adjusts the motor’s position based on these signals.

The feedback mechanism provides information about the actual position or speed, ensuring precise control and positioning. A common feedback device is a potentiometer, which sets the position of the motor's shaft, and as the shaft rotates, the resistance of the potentiometer changes. The change in resistance in the potentiometer generates a PWM (Pulse Width Modulation) pulse of varying length. This change in resistance also provides feedback to the control circuit, allowing it to determine the current position of the motor shaft.

The control circuit expects an update in every 20 ms, with a pulse width between 1 ms and 2 ms. In the case of the minimum duty cycle (5%), the shaft's position is typically at one extreme, for example, -90°. In the case of the maximum duty cycle (10%), the shaft's position is typically at the opposite extreme, for example, +90°. Positions between these extremes can be linearly interpolated base on the duty cycle.

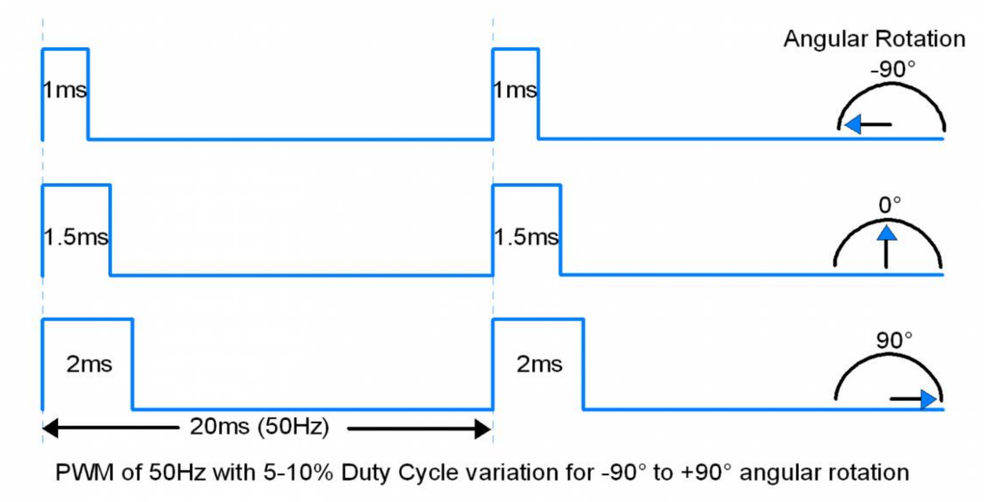

Figure 12. Servo Motors Duty Cycle [18]

Servo motors typically have three pins. As the figure "Servo motor" shows, the device usually has a brown, a red and an orange wire. The brown wire is connected to the common ground (GND) of the system, serving as the reference point for electrical potential. The red wire is connected to the Power Supply (Vcc), providing necessary voltage to operate the motor, usually 5 volts. The last, orange wire is employed for the signal, which receives the control signal from the microcontroller.

The maximum extent of the models I use is 22 x 11.5 x 27 millimetres, their weight is 13 grams. When choosing the components, a crucial criterion was that the internal gears are constructed from metal, ensuring durability, strength, precision, temperature resistance, and overall reliability in various applications.

4.2.4 Performance Measurement

A power meter that can connect to the microcontroller and transmit data to it is required to measure the power output of the solar panel. The INA219 chip is suitable for current and voltage measurement, in addition it also features an internal multiplier unit.

INA219 is an integrated circuit designed for accurate and convenient power monitoring in electronic systems. The device enables precise measurement of both voltage and current with a focus on ease of integration, therefore it allows quick determination of delivered power without the need to separately read current and voltage values. [19]

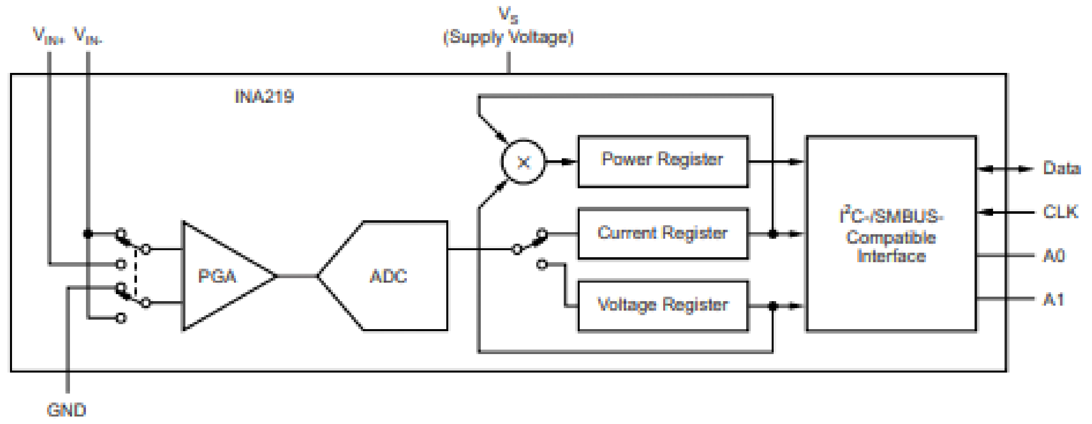

Figure 13. Simplified Schematic of INA219 [19]

The INA219 integrates an ADC with 12 bites as part of its design, which enhances the precision. This supports the easier work with digital systems and the microcontroller by simplifying data processing and analysis.

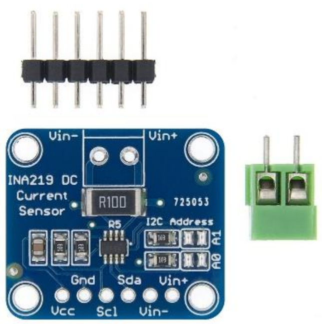

Figure 14. Pin Layout of INA219 Module [20]

The INA219 is equipped with six pins, serving distinct functions within its operation. One pin is designated for the power supply voltage, requiring a 5 V supply due to the sensor's operational range of 3.3 V to 5 V. Another pin establishes the ground reference.

Two pins are dedicated to I2C communication, with SDA facilitating serial data communication and SCL managing the clock signal line for synchronization.

The remaining two pins are pivotal for the measurement process, linking to both the loas and the panel components. This pin configuration ensures a comprehensive and accurate power measurement functionality.

4.2.5 Solar Panel

The arrangement of the solar panels in a flower-like solar configuration involves strategically placing the panels in a radial pattern, mimicking the petals of a flower. This design aims to optimize exposure to sunlight from various angles throughout the day, enhancing energy capture efficiency.

When choosing solar panels, a critical emphasis was placed on minimizing both mass and physical dimensions. This priority arises to enable the servo motors to operate efficiently, facilitating the precise movement and alignment required for optimal functionality. This consideration is crucial because the weight and size of the solar panels directly impact the effectiveness of the servo motors in making necessary adjustments and directional positioning.

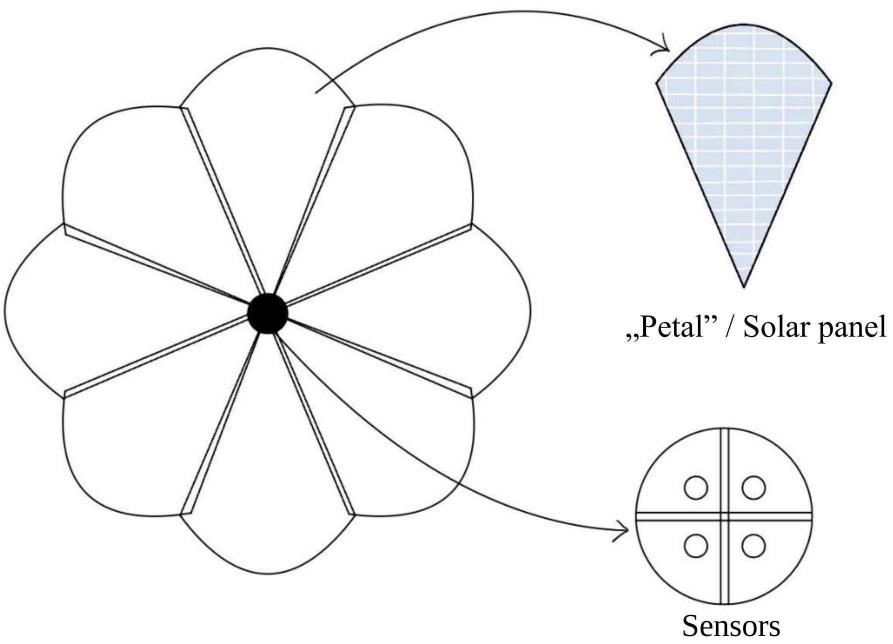

Figure 15. "Petal" layout

In the context of this project, it is essential to note that square-shaped solar panels have been chosen for implementation, for the sake of cost efficiency. It is noteworthy that these panels deviate from the circular arrangement depicted in the Petal layout image, where solar panels are typically positioned in a more radial fashion.

The chosen solar panels are of polycrystalline type, featuring a nominal power output of 1 W, a maximum voltage of 3 V, and physical dimensions measuring 64x31 mm. [21]

4.2.6 Resistors

In the course of this project, supplementary resistors are essential for facilitating the functionalities of light sensors and power measurement operations.

Connecting resistors in series to photoresistors in a solar panel implementation serves specific purposes related to adjusting the resistance and response characteristics of the photoresistors. By adjusting the value of the series resistor, the resistance of the photoresistor can be modified, affecting its sensitivity to light.

Through adjustments in sensor sensitivity, it can be ensured that the system remains unresponsive to subtle changes in light, effectively avoiding unnecessary responses of moving components. To accomplish this task, I opted for 1 kOhm resistors, linking one resistor in series with each photoresistor.

The maximum power output of the solar panels can be achieved with an appropriate load. The load resistor helps optimize the power output of the solar panels by matching the impedance of the solar panels with that of the load. This matching maximizes power transfer efficiency. For this assignment, I selected a 3.3 kOhm resistor.

4.3 Schematic Diagram

The diagram illustrates the electrical connections and components used to control the solar panels orientation in both the horizontal and vertical axes.

The diagram includes the microcontroller, photoresistors as light sensors, servo motors, solar panel, power meter and the additional resistors. The schematic also incorporates power supply connections and serves as a guide for assembling and understanding the electrical infrastructure of the project.

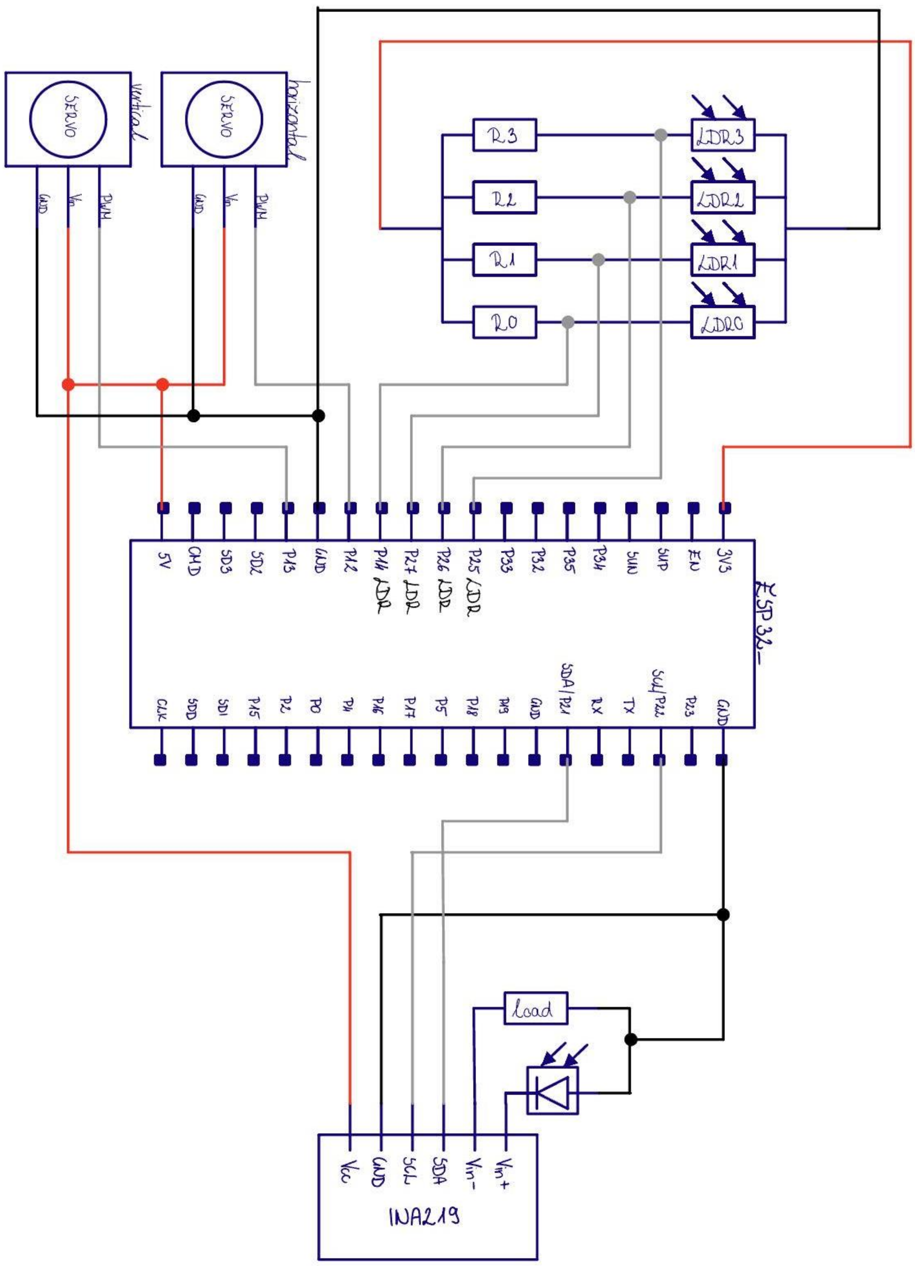

Figure 16. Schematic diagram of the project

5 IMPLEMENTATION

The implementation of this project begins by conducting separate tests for various models. The purpose of individually examining each module was to ensure the cohesion and functionality of the system. The isolated testing of modules allowed me to ensure a high level of overall functionality for the project.

The application of this strategic approach significantly contributed to the seamless and efficient progression of the project, ensuring that each module operated harmoniously within the broader framework of the project objectives.

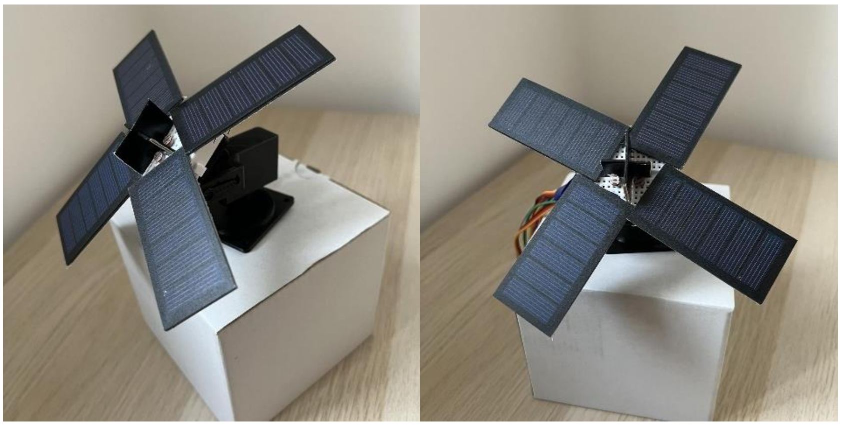

Figure 17. Implementation and instrument box

5.1 Implementation of Sun Tracking Unit

The solar tracking unit is a multifaceted system comprising several essential components. First is the implementation of photoresistors designed to detect variations in light intensity, by which provide real-time data on the sun’s position. Moreover, the microcontroller directs the solar tracking operation, using data from the sensors to accurately guide the servo motors. These servo motors, integral to the unit, dynamically adjust the orientation of solar panels, ensuring they consistently face the sun for optimal energy capture.

To achieve the appropriate adjustment of light intensity values in the code, a resistor (1 kOhm) was initially connected in series with the photoresistor, and the circuit endpoints were subsequently connected to the ESP32 3.3 V and GND outputs. An integer value is defined to store the measured value, and P14 is designated as the input port. The serial port is activated at a baud rate of 9600 bit/sec to facilitate the reading of values.

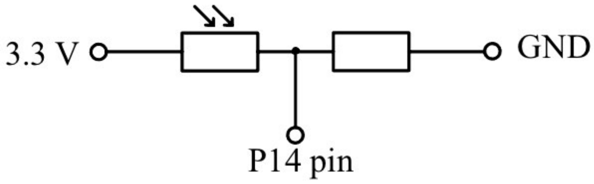

Figure 18. Schematic of the voltage divider

The received value is not the actual resistance of the photoresistor, but a measure of light intensity. A value of 40 Lux was observed in total dark condition, while a value of 950 Lux was recorded in full illumination using the Serial Monitor of the Arduino Ide application. By this value the sensitivity of the photoresistor detection has been fine-tuned.

In pursuit of achieving maximum accuracy for solar tracking, it is essential to incorporate four identical photoresistors into the sensor board. The sensors are named LDR0, LDR1, LDR2 and LDR3 in sequential clockwise order, starting with the top-left sensor.

The measurement operates effectively by comparing the values of the upper two sensors (LDR0 and LDR1), followed by performing the same comparison with the lower sensors. By setting in opposition the results of these two comparisons, the sensor board is adjusted, thereby equalizing the resistance values of all photoresistors. Based on these comparative measurements, a nonius signal is achieved, providing precise linear measurements.

To ensure that the measured values equalled only under perfectly perpendicular illumination, a non-transparent plate is employed. To mitigate excessive sensitivity and prevent unnecessary repositioning of servo motors, a threshold value for the difference in resistance values between the photoresistors needs to be specified.

The photoresistors, along with the resistors connected in series, were soldered onto a panel. To the common point of the resistors a zero-reference point (GND) was soldered, and the 3.3 V wire was soldered to the collective junctions of the photoresistors, establishing the connection to the outputs of the ESP32 board.

After the light sensors perfectly track the movement of the sun, the solar panels were fixed onto the panel following the “Petal” layout figure (Figure 15).

The panels are aligned with the assistance of the servo motors, described in the "Component Selection" section. To test this movement, a servo motor has been added to the existing circuit. The appropriate pins have been connected: red wired pin to the voltage source (5 V), brown wired pin to the zero-reference point (GND) and the third pin, which receives the control signal, has been attached to pin P12.

In order to store the current position of the motor shaft, an integer variable named 'shaftposition' has been instantiated. The 'shaftposition' value is adjusted according to which photoresistor corresponds to the lower voltage value, signifying the direction from which the sunlight is incoming. This behavior was achieved through the utilization of a loop structure, wherein, in each iteration, an examination was conducted on the values of light resistors.

For more precise movement in tracking the Sun, dual-axis motion of the solar panel is necessary. The execution of this involves the utilization of two servo motors, where one ensures horizontal movement while the other manages the vertical aspect.

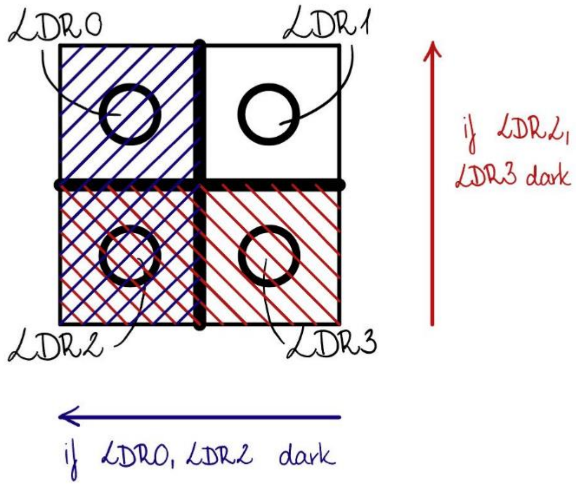

Figure 19. Motion of servo motors according to the shadows cast by resistors

Ideally, the servo motors would be capable of a 180-degree movement, however due to fixation of the axes, the dimensions of the motor, and the routing of cables, achieving this is challenging. In order to determine the maximum range of motion, the values of resistors were altered, allowing the observation of the minimum and maximum angles of rotation. This test was conducted after the integration of the model to be discussed later.

To implement the motors, a publicly available 3D-printable model [22] for the motor support structure was utilized. This model consists of three parts:

A base platform, in size of 4.5 x 4.5 centimeters with four holes at its corners for fixation. In the center of the base plate, there is a cross-shaped recess matching the four-winged shaft head of the servo motor.

The middle element comprises a box of a size suitable for inserting the lower servo motor, allowing vertical axis rotation. This component also includes two supporting arms, to which the upper motor can be affixed.

The third component can be attached to the motors shaft, thus performing vertical movement. As it is designed parallel to the plate of the solar panel and sensor unit, it allows for the mounting of the components.

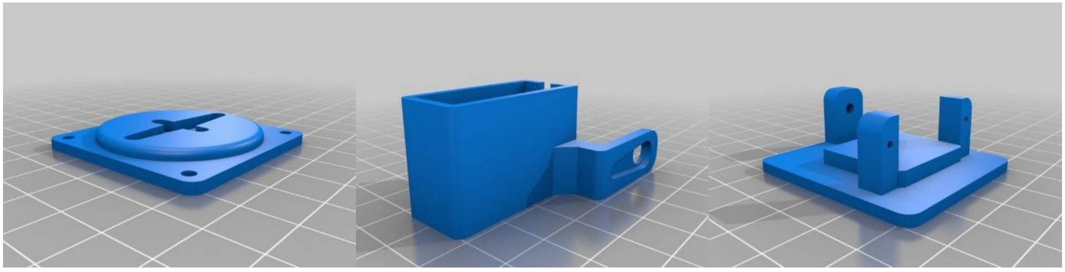

Figure 20. Supporting elements

After the motors were inserted, the appropriate cables were attached to the 5 V pin and GND pins. The servo motor handling the horizontal movement was linked to the P12 pin, while the servo responsible for vertical movement was connected to the P13 pin.

Ideally, the servo motors would be capable of a 180-degree movement, however due to fixation of the axes, the dimensions of the motor, and the routing of cables, achieving this is challenging. In order to determine the maximum range of motion, the values of resistors were altered, allowing the observation of the minimum and maximum angles of rotation. The lower motor demonstrated a range from 30 degrees to 130 degrees, while the upper motor spanned from 70 degrees to 170 degrees.

After the sun tracking module was assembled, the code incorporating the four photoresistors as sensors and two servo motors was complied. The code facilitates ongoing sensor value readings, enabling the servo to respond to any fluctuations in environmental light.

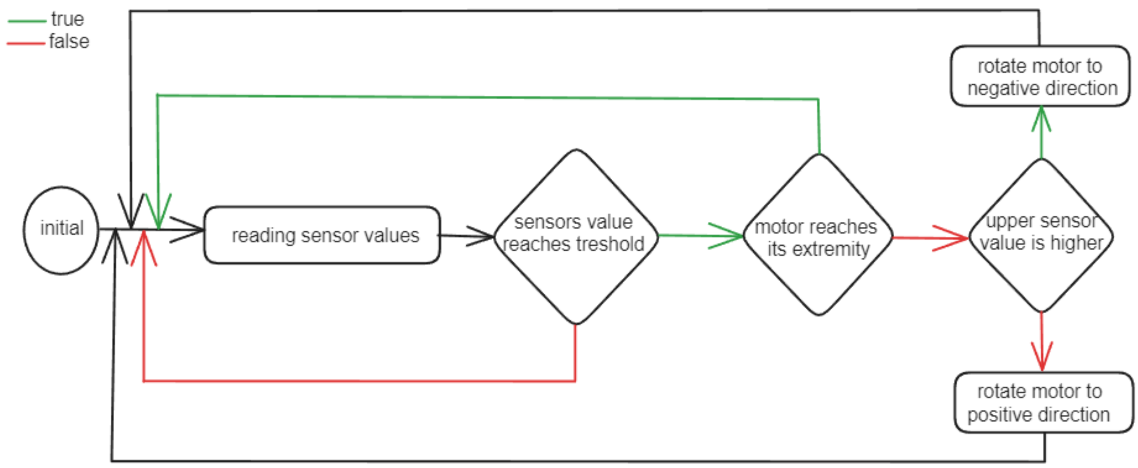

Figure 21. Flowchart of the vertical motor

Following the initial setup of motor positions, the code proceeds to read sensor values. The evaluation revolves around whether the difference between these values surpasses a predetermined threshold, if it does, it triggers motor movement. If not, the system remains motionless, and the code returns to reading sensor values.

In the affirmative case, the next condition checks whether the specific motor has reached its extremity. In case of reaching the position, the following step involves determining the rotation direction of the motor, then executing the movement itself.

Upon reaching the last step of the process following the motor movement, the loop initiates anew, and the assessment is reiterated. This iterative cycle persists as long as the sensors are able to read values, signifying that the system remains in ON mode.

5.2 Implementation of Power Measurement

As highlighted in the component selection segment, the chosen power meter is the INA219 module. It is a high-side current and voltage sensor, which provides an accurate and efficient means of measuring current and voltage in electronic systems.

As depicted in Figure 19, the module arrived with two accompanying pin rows, of which only the six-pin one was utilized.

As a first step, it was soldered onto the module. The six adjacent pins correspond to the Vcc for power, GND for zero reference point, the SCL and SDA lines for I2C communication, and the V- and V+ lines to be connected for measurement.

Following this, I connected these pins to the appropriate pins of the ESP32. The Vcc pin was connected to the 5 V pin of the microcontroller, and the GND pin was connected to the microcontrollers pin with a matching name, GND.

The SDA pin was assigned to the P21 pin, which is a communication line used for bidirectional data transfer and the SCL pin was attached to the P22 pin, which is used for synchronizing data transfer.

The V+ pin was connected to the positive terminal of the solar panels, while the V- pin was attached to one end of the load resistor. The other end of the resistor has been connected to the negative terminal of the solar panel and zero-reference point.

Having implemented multiple solar panels into the system, the positive and negative terminals of these panels were soldered together. It is crucial for this step to be executed that they have identical voltage ratings, thus avoiding inefficient power generation and preventing potential damage to the panels.

It is noteworthy, that when connecting solar panels in parallel, their voltages remain the same, but the current capacity adds up. According to this, a larger load resistance - namely 3.3 kOhm - has to be used, because it can indeed reduce the current capacity flowing through the circuit.

The operation of the module involved utilizing the Adafruit_INA219 library, and creating the object ina219, which serves as an instance of the library. For data storage, an integer variable named ‘power_measured’ was initialized with a value of 0. This variable stores the value, which is provided by the ‘getPower_mW’ function for measuring power directly.

5.3 Implementation of Telecommunication

To enable wireless data transfer seamlessly, the monitoring process is aimed to be integrated, with a simultaneous presentation of power values on the Serial Monitor and their transmission via Bluetooth Serial communication.

The utilization of the Bluetooth serial library is deemed crucial as it streamlines Bluetooth communication on the ESP32 platform. Subsequently, a BluetoothSerial object, named SerialBT, is instantiated, serving as the conduit for the wireless transmission of data. The initiation of Bluetooth Serial, achieved through the command 'SerialBT.begin()', entails the assignment of a device name, simplifying identification during the pairing process.

The measured power values are relayed to the Bluetooth Serial interface through the function 'SerialBT.print(power_measured)'. To facilitate the reception of this data on a computer, the associated Bluetooth Serial Port COM Port needs to be identified.

For data reception, reliance on a serial terminal program becomes necessary. Several options are available, contingent upon the operating system, with PuTTY being the chosen solution in this instance.

While PuTTY itself lacks a direct mechanism for the exportation of received data to a file, it encompasses logging capabilities. The commencement of a session enables the reception of data, which can be simultaneously logged into a file. This functionality proves invaluable for the observation and analysis of the efficiency of the solar system.

The functionality of this was tested with the applied light resistance shown in the Figure 18. Measured data have been written every 10 seconds and elapsed time was indicated every 30 seconds:

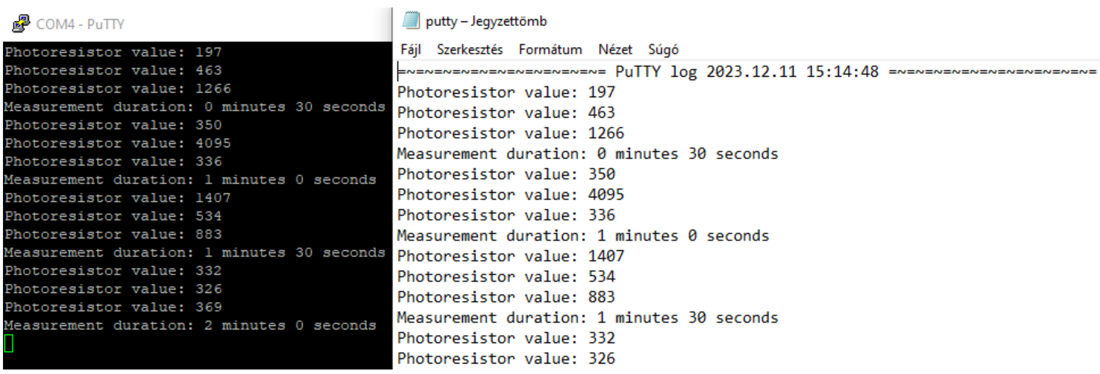

Figure 22. Logging by PuTTY

In practice, apart from power measurement, the conversion of the analogue signal to a digital one is the task of the INA219 as well. The voltage across the shunt resistor and the shunt resistor’s voltage drop, which is directly proportional to the current flowing through it are converted into a digital value by the internal ADC.

The device internally calculates power as the product of the digitally converted values. The formula for power is typically given as:

$P = V \cdot I$, where P is power in watts, V is voltage in volts, and I is current in amperes.

The output values of the INA219 are standard electrical measurement units, and it represents the actual power being produced by the connected device, in this case the solar panels. When the output of the INA219 is sent through Bluetooth to a logging software and the logged into a file, the unit of the logged data remains consistent with the original units.

6 TESTING

6.1 Condition Specification

The testing of the project took place in December, which influences the operation and results of the solar panel system from various perspectives. As a consequence, the following considerations need to be taken into account.

Winter introduces unique challenges to solar energy systems, marked by shorter days, a lower sun angle, and frequent cloud cover. The Earth's axial tilt results in reduced daylight hours, limiting solar panels' exposure to sunlight and hindering energy production.

Overcast skies diffuse sunlight, diminishing its intensity, and further impacting efficiency. While lower temperatures generally benefit solar panels, excessively cold conditions can pose challenges, such as reduced solar panel efficiency, reduced capacity of battery and icing and freezing of the moving components.

For example, during the summer in Mid-Latitude Regions, such as Europe, an average of five hours of sunlight per day is received, resulting in the production of approximately 750 watt-hours of electricity for a solar panel with an output rating of 200 watts. [23]

This can be calculated according to the following equation:

$$t \cdot P \cdot x = 5[h] \cdot 200[W] \cdot 0.75 = 750 \text{ watt hours}, \qquad (1)$$

where t stands for time in hours, P stands for power in watts and x is the deration factor, accounts for several variables, such as dust, pollution, and different weather conditions.

In contrast, solar panels generally produce about 40-60% less energy during the months of December and January than they do during the months of July and August. [24] According to this it can be inferred that approximately 300 to 450 watt-hours of electrical energy would be generated by the same solar panel during winter season.

During the winter season, an average of four hours of sunlight per day is received. Based on this, it can be calculated, that during winter, the percentage representation of the above-mentioned other variables, noted as x, decreases to 36-56%.

6.2 Indoor Testing

After assembling the equipment, its proper functioning was initially tested under indoor conditions with a flashlight, aiming to prevent unnecessary time spending with outdoor measurements, which would be useless in case of faulty operation.

After uploading the code, the following technical errors were experienced:

The structure responded to light movements too quickly, endangering the components. Consequently, the baud rate has been decreased, but even with a baud rate of 9600 bit/sec, the structure was considered overly sensitive. Therefore, the threshold of the photoresistors were increased until a reaction was not triggered by the shadow of an object quickly passing in front of the lamp’s light.

As a consequence of excessive movement, faulty solder joints in the solar panel and power meter components were exposed to light. The solar panels had already been affixed to the panel, rendering the execution of the resoldering quite challenging.

The device’s response to the use of sensor spacers of various heights was tested. The higher the separator wall, the more the need for light perpendicular to the panel increased. Excessively high divider would have led to the system’s repeated oversensitivity, therefore a height of 1 centimetre was chosen.

For the sake of enhanced traceability, diagnostic messages were incorporated into the coda at specific phases, displaying them on the serial monitor.

Alongside the results of power measurement, the values of the photoresistors were displayed on the serial monitor which values assisted in setting the appropriate threshold value. For the identification of the correct load resistor value, the current measured by the INA219 was also displayed.

6.3 Outdoor Testing

The implementation of the outdoor testing proved challenging due to the difficulty in selecting a suitable time and unpredictable weather conditions. Due to time constrains, the anticipation of direct sunlight was abandoned, so the measurement was carried out on December 9, 2023.

A measurement site was chosen with the primary consideration being a location of low pollution to maximize the potential amount of sunlight that could be captured.

Prior the chosen time, the weather forecast [25] was consistently monitored, preparing for potential precipitation, the avoidance of which was crucial given that my solar panel system was not waterproof. Despite the forecast suggesting no precipitation, constant attention was necessitated while the equipment was outdoors.

Figure 23. Testing Site

The sunrise occurred at 7:20, with sunset at 15:54 Consequently, the measurement was conducted between 8 and 16 hours. During this time frame, the minimum temperature was

-1 degrees Celsius, the maximum was 1 degree Celsius, and humidity remained relatively constant, ranging between 93% and 95%.

The structure was placed at the specific location before 8:00, followed by a brief inspection, and the code was then uploaded onto it. The Bluetooth signal was received on a laptop, and using this device, the data was output through the Putty application, later exported into an Excel spreadsheet. The measurement concluded at 15:18. because precipitation started, preventing the possibility of continuation. In order to avoid an overcrowded diagram, in the code, I predefined that the microcontroller transmits the measured values over the Bluetooth channel only at every sixth minute.

The results of this export are visible on the following diagram, illustrating the measured power values over time:

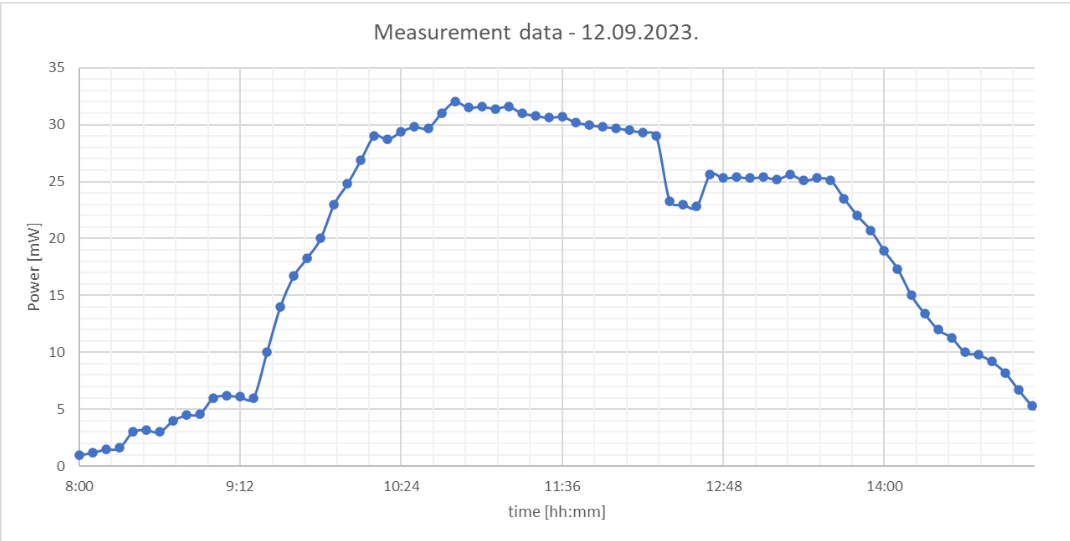

Figure 24. Measurement result

The following observations can be deduced from the time functions. From the measured power values, it can be inferred that the solar panel first received sufficient radiation at 8:42, which triggered measurable output. Before this time, the solar panel did not receive direct sunlight, therefore the power output of the solar panel was low.

Due to the cloudy weather, sunlight reaches the solar panel in a scattered form. As a result, after the initial direct sunlight, the power level harshly increases, reaching 32 mW at 10:48.

Following this, until 12:18, the measured data remains around 30,5 mW (29-31 mW), but it steadily decreases compared to the measurement taken at 11:43. Since in December the sun’s rays reach the Earth most significantly around noon, the measured data continues to decline thereafter. The sudden decrease between 12:18 and 12:42, essentially a “gap” in the diagram, perfectly illustrates the impact of a darker cloud than usual on the solar panels’ production.

After the mentioned “gap”, the power level remains around 25 mW for a period. However, starting from 13:42 the power level consistently decreases, and this decline is faster compared to the morning increase.

From these data, the power production of the system within the given time period can be easily calculated. For this execution, the following formula can be utilized:

$$E_{total} = \sum_{i=1}^{n} P_i \cdot \Delta t_i, \qquad (2)$$

where E_{total} is the total energy generated, P_i os the power at a specific time interval i, and Δt_i is the time duration of the i-th interval.

Based on this, the system’s power production during the measured time interval is 509,51 Ws. This value may be considered low compared to the energy generated by a solar panel park, but for a project of this size, it is adequate. Taking into account the size of the solar panels, their nominal power, and the weather conditions, the end results can be regarded as particularly high.

7 DEVELOPMENT OPTIONS

Certainly, the success of the project could have been enhanced with a more suitable choice of measurement location and by selecting a sunnier time period. However, even after these considerations, there are numerous development opportunities for the project.

The primary development opportunity was to make the system waterproof. A waterproof solar system is essential for safeguarding against damage caused by weather elements like rain and snow. preventing water ingress protects electrical components, ensures system safety, and maintains efficiency.

This could have been achieved by using a transparent material for the enclosure. However, this option would have compromised the systems' efficiency. Waterproofing in a solar system can be achieved through encapsulating panels in water-resistant material, securely sealing connections, and using watertight conduits for wiring.

During the measurements, a 6-minute sampling interval was chosen to prevent a significant increase in the equipment's consumption, ensuring sufficient data for reliable evaluation and analysis. The sampling interval could be increased to one hour; however, in this case, it would be necessary to let the instrument operate for days to obtain realistic data regarding its performance and generated energy.

Another development opportunity could be the mobility of solar panels, which would help prevent the accumulation of contaminants on the panels. Several industrial solutions, including those employed by similar flower solar technologies, utilize this approach. As a result, dust and snow are less likely to adhere to the panels, reducing the chance of the panels being covered and obstructed from the sunlight.

Other development opportunity would be the scale of the project. This includes increasing the size of the solar panels, allowing them to generate more energy due to their larger surface area. However, for this, the other components of the system would need to be larger as well, or at least their load-bearing capacity would need to be increased.

8 SUMMARY

In the first part of the project, the principles of solar panel operation and the method of transmitting the generated energy to households were briefly overviewed. Following this, the operational principles of the dual-axis solar system were taken as a basis, and with its elaboration, an explanation for the operation of the system was provided.

Additionally, a brief description was given of the dynamic movement method of solar panels and the logic behind solar tracking. Subsequently, the classification of solar panel systems was presented to gain better insight into why specific designs are advantageous for various applications.

Next, the telecommunication options supported by the microcontroller I chose were introduced, their operational principles were explained, and my selection was justified. Following this, a brief description was made of the solar tracking logic I chose, and the logical diagram of the planned system was realized.

After completing the above, the implementation of the project was initiated. This included the description of components, which was necessary to connect the elements in an understandable way during the implementation and was also essential for writing the program code. The practical steps of the implementation were described, making the project reproducible even for a layperson. The application of the printed 3D model and its necessity were presented, followed by a description of how solar tracking can be implemented in practice with servo motors and light resistors.

Next, the performance measurement procedure was presented, including its initialization in the code, the unit of measurement for the chosen module's output, and its calculation method. After that, the application of telecommunication was demonstrated, including its main steps, challenges, and solutions to these challenges.

Corrections were made during the indoor testing process, drawing attention to the need for proper soldering and program code, and the system was assembled. During outdoor testing, measurements were performed, and explanations were provided for any discrepancies, followed by an explanation of the calculation of the final result, and a discussion of its adequacy.

Subsequently, development opportunities were recommended for the project, and possible solutions were suggested for these opportunities.

9 REFERENCES

[1] (n.d.) *Solar Photovoltaic Cell Basics*. energy.gov. retrieved October 26. 2023, from Solar Photovoltaic Cell Basics | Department of Energy

[2] (n.d.) *Dual_Axis Tracking*. sciencedirect.com. retrieved October 23. 2023, from https://www.sciencedirect.com/topics/engineering/dual-axis-tracking

[3] (n.d.) *Altitude & Azimuth: The Horizontal Coordinate System* by Konstantin Bikos. timeanddate.com. retrieved October 23. 2023, from The Horizontal Coordinate System (timeanddate.com)

[4] (n.d.) Figure by Kazi M. Harman. researchgate.net. retrieved October 23. 2023, from Dual-axis tracking system. | Download Scientific Diagram (researchgate.net)

[5] (2022, May 06). *Are Smart Solar Flower Worth the Recent Hype?* by April Miller. earth.org. retrieved October 23. 2023, from https://earth.org/smart-solar-flowers/

[6] (2023, April 19). *SmartFlower Solar Review: The True Cost of a Solar Flower*. by Isaac Ost. solar.com. retrieved October 23. 2023, from https://www.solar.com/learn/smartflower-solar-comprehensive-review/

[7] (2023, March 24) *Types of solar panel installations*. by Spencer Fields. retrieved October 23. 2023, from Types Of Solar Panel Installations | EnergySage

[8] (n.d.) *The 3 Types of Residential & Commercial Solar Power Systems*. ilumsolar.com. retrieved October 23. 2023, from The 3 Types of Residential & Commercial Solar Power Systems - Ilum Solar

[9] (n.d.) *What is Commercial Solar?* straightupsolar.com. retrieved October 23. 2023, from Commercial Solar Installers | StraightUp Solar

[10] (2023, September 18) *Community Solar*. wilmette.com. retrieved October 23. 2023, from Community Solar - Wilmette

[11] (2020, February 24) *Bluetooth vs. Wi-Fi: What's the Difference?* by Jeremy Laukkonen. lifewire.com. retrieved November 25. 2023, from The Difference Between Bluetooth and Wi-Fi (lifewire.com)

[12] (2018, January) *Smart Technology used for active daylight techniques mainly based on smart windows, artificial lighting and daylight harvesting.* by Nikitha Raj. researchgate.net. retrieved November 4. 2023, from https://www.researchgate.net/publication/323696756_Smart_Technology_used_for_active_daylighting_techniques_mainly_based_on_smart_windows_artificial_lighting_and_daylight_harvesting

[13] (n.d.) *ESP32 Pinout Reference*. lastminuteengineers.com. retrieved November 25. 2023, from ESP32 Pinout Reference - Last Minute Engineers

[14] (n.d.) *ESP32 Series Datasheet*. espressif.com. retrieved December 1. 2023, from esp32_datasheet_en.pdf (espressif.com)

[15] (2009, May 21) *Photocells a.k.a. CdS cells, photoresistors, LDR (light dependent resistor)…* blog.adafruit.com. retrieved November 25. 2023, from Photocells a.k.a CdS cells, photoresistors, LDR (light dependent resistor)… « Adafruit Industries – Makers, hackers, artists, designers and engineers!

[16] (n.d.) *CdS Photoconductive Cells – Datasheet*. hestore.hu. retrieved November 25. 2023, from prod_getfile.php (hestore.hu)

[17] (n.d.) *MG90S Micro Servo, fém mechanika.* rpibolt.hu. retrieved November 12. 2023, from MG90S Micro Servo, fém mechanika - "rPI Bolt" - El

[18] (n.d.) *Servo Motor Basics, Working principle & interfacing with Arduino*. electronicwings.com. retrieved November 12. 2023, from Servo Motor Basics, Working principle & interfacing with Arduino ... (electronicwings.com)

[19] (n.d.) *INA219 Zero-Drift, Bidirectional Current/Power Monitor With I²C Interface*. hestore.hu. retrieved November 25. 2023, from INA219 Zero-Drift, Bidirectional Current/Power Monitor With I2C Interface datasheet (Rev. G) (hestore.hu)

[20] (n.d.) *INA219 – INA219 Kétirányú Egyenáramú Tápegység Érzékelő Kitörési Modul DIY 3V-%V IIC I2C.* mikroeletronik.hu. retrieved October 16. 2023, from Szín: INA219 - INA219 kétirányú egyenáramú tápegység érzékelő kitörési modul DIY 3V-5V IIC I2C (mikroelektronik.hu)

[21] (n.d.) *Solar Panel 64x31mm.* lomex.hu. retreived November 25. 2023, from lomex.hu/hu/webshop/?fbclid=IwAR0g5XRQvL8Hi2tYFTF2sLrLzdgEpbWOHI8lVZS1hKCcV1nrL7N1T39gBFA#/search,51-06-84/stype,1

[22] (2015, March 04) *Mini Pan Tilt – Servo G9*. by fbuenonet. thingiverse.com. retreived December 2. 2023, from Mini Pan Tilt - Servo G9 by fbuenonet - Thingiverse

[23] (2023, July 15) *How to Do Solar Panel Calculations? (Complete Guide).* anker.com. retrieved December 7. 2023, from A Complete Guide on Solar Panel Calculations (2023 Update) - Anker US

[24] (2017, February 08) *The Seasonality of Solar Energy Production*. lighthousesolarny.com. retrieved December 7. 2023, from Solar Power Generation in Summer vs. Winter | Lighthouse Solar (lighthousesolarny.com)

[25] (2023, December 10) *Agárd – Mai időjárás óránként 2023.12.09.* freemeteo.hu. retrieved December 9. 2023, from Időjárás Agárd Ma óránként | freemeteo.hu