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Theme

Development and Optimization of a Solar Tracking System for Solar Energy Harvesting

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In front of the jury composed of:

Dr. Hania ABOUB	UKMO	President
Dr. Chouaib AMMARI	UKMO	Examiner
Dr. Mohammed Chaker BOUTALBI	UKMO	Supervisor/ Director

Academic Year: 2023 /2024

Dedication:

I would like to dedicate this work:

To my large family, **BENHAMIED** and **AICHOUBI** .

To my dear parents, **Mohammed** and **AICHOUBI Khadija**.

To my beloved **sisters**.

To my **friends**.

And to everyone who helped me and extended a helping hand in completing this thesis.

BENHAMIED Abdelbari

Dedication:

Dedicated to my family, HADRAOUI and YOUSEFI, and to everyone connected to them.

Dedicated to my mother from the depths of my heart, she who welcomes me with a smile and bids me farewell with prayers.

Dedicated to my father, through whose support I have achieved what I am today, and all praise be to God.

Imad HADRAOUI

Acknowledgments

First of all, we would like to thank ALLAH, the Almighty, who has given us the courage and the will to carry out this work well. We thank our parents for everything they have done for us. We also thank our advisor,

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General Introduction

The depletion of non-renewable energy sources like oil, natural gas, and coal, coupled with their harmful environmental impact, has driven the scientific community to seek alternative solutions. Renewable energies, often referred to as clean energies, such as wind, water, and solar power, are increasingly being utilized. Technological advancements have enabled the conversion of sunlight, including its heat and light, into electrical energy.

Among the methods for converting solar energy into electricity is the photoelectric effect, This effect occurs in a photovoltaic cell light sensor, commonly known as photovoltaic (PV) panels. Here, photons of light interact with a semiconductor material, transferring their energy to electrons and thereby generating an electrical voltage [1]. However, to maximize the efficiency of these PV panels, they must be oriented perpendicularly to the sun, which requires the use of a solar tracking system.

Our work is part of the overall goal of improving the performance of photovoltaic systems by increasing the accuracy of the sensors LDR (Light Dependent Resistor) in the solar tracking system. Unlike, the common implementation of solar tracking systems and prototypes, ours aim to provide a higher precision of sun path tracking by avoiding the problems that exist when using LDRs fully or partially exposed to the sun light which makes hard to claim the the panel is really inclined toward the sun and not inclined toward what the non-precise LDRs are giving as signal. To the best of our knowledge, we are the first in Algeria or at least in the university of Ouargla to use and implement this model in real-life practice.

In the first chapter we present the different renewable energies by studying in a more in-depth way the production of electricity by the photovoltaic effect. The second chapter focuses on understanding solar trackers where we highlight their various types, techniques, and operating methods. The third chapter we introduce our solution proposition design and motivation hence explain the various important materials used in our experiment. We present the experiment algorithm and protocol followed with a conclusion in the last chapter.

Chapter 1

Renewable Energies

1.1 Introduction

Renewable energies are energy sources that regenerate naturally and quickly, without exhausting the planet's resources. The most used renewable energies today are wind energy and solar energy. In 2022, these two energy sources together accounted for around 12% of global electricity supply [2].

In this first chapter, we will discuss the different renewable energy sources and dedicate the study more broadly to the solar energy system (photovoltaic system) in terms of its components, and its different types of installations. Finally give its advantages and disadvantages.

1.2 Renewable energy

Renewable energy is called a source of energy whose natural renewal is immediate or very rapid, in such a way that it can be considered inexhaustible on a human time scale. Among renewable energies,the most famous ones that have already been exploited are solar, wind, hydropower, biomass and Geothermal energy [3]. As an example Figure 1.1 shows the renewable electricity capacity additions additions by technology and segment (2016-2028) [4]:

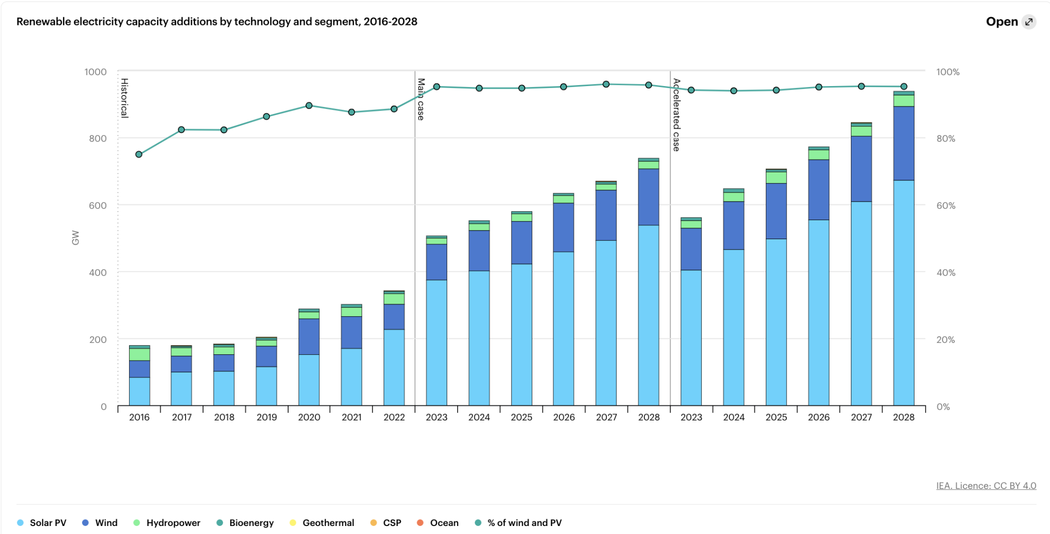

Figure 1.1: Renewable electricity capacity additions additions by technology and segment(2016-2028)

1.2.1 Evaluation of renewable energy in Algeria

Algeria has important potentials in terms of renewable energy, in particular in solar energy and wind energy. The country is one of the sunniest in the world, with an average of more than 3,000 hours of sunshine per year, which represents a huge potential for solar energy. Likewise, the country also has significant wind resources, especially in coastal regions. The Algerian government has put in place a favorable regulatory and legislative framework to encourage the use of renewable energies. The national program for renewable energies and energy efficiency, launched in 2011 [5], aims to develop the country's renewable energy production capacity to meet the growth in energy demand. Despite these efforts, the share of renewable energies in the Algerian energy mix still remains low. In 2019, the share of renewable energies in electricity production in Algeria represented only 0.3%. However, the country has launched several ambitious projects aimed at increasing its renewable energy production capacity, including wind farm and solar power plant projects.

In summary, Algeria has an important potential to develop renewable energies, in particular solar energy and wind energy. Although the government's efforts to encourage the use of these energy sources are underway, their use is still low. However, some ambitious projects are under development thus they can contribute to increase the share of renewable energies in the future. Table 1.1 gives the cumulative capacities of the REn program, by type and phase, over the period (2015 - 2030)[6] :

Table 1.1: The Cumulative capacities of the REn program, by type and phase, over the period (2015 - 2030) in Algeria

Unit: MW	1st Phase 2015-2020	2nd Phase 2021-2030	Total
Photovoltaic	3000	10575	13575
Wind energy	1010	4000	5010
Thermal (CSP)	-	2000	2000
Cogeneration	150	250	400
Biomass	360	640	1000
Geothermal energy	05	10	15
Total	4525	17475	22000

1.2.2 Types of renewable energies

- **Solar energy**

Solar energy is the most abundant source of energy on earth. It is considered to be the origin of the majority of renewable energies in the world, especially the sunniest ones. When solar radiation is used to produce electrical energy directly using photovoltaic semiconductors or solar thermal heat for heating or electricity generation. [7]. There are several types of solar energy such[8, 9] :

Photovoltaic solar energy It is produced from photovoltaic cells that directly convert sunlight (**sun radiations**) into electricity. Photovoltaic solar panels are often used to produce electricity for homes and companies.

Solar thermal energy It is produced from solar thermal panels that use the heat of the sun to heat a fluid that circulates in the system. This heat can be used to heat water or air for heating buildings or for electricity generation.

Concentrated solar energy It is produced from mirrors or lenses that concentrate sunlight on a point, thus generating heat. This heat is then used to produce electricity using a thermodynamic cycle.

Passive solar energy It is produced naturally using the design of buildings to maximize the use of sunlight for heating, air conditioning and natural lighting.

Figure 1.2: Photovoltaic energy source.

- **Wind energy**

It is the energy produced by the momentum of the wind's the blades of a wind turbine in wind farms. When the wind begins to blow, the forces that are applied to the blades of the propellers induce the rotation of the rotor. The electrical energy thus produced can be distributed on the electrical network thanks to a transformer [3, 7].

A wind farm is a set of several wind turbines planted on a site, connected to the electricity grid.Figure 1.3 represents a wind energy farm.

Figure 1.3: Wind energy park.

- **Hydropower**

Water is also a renewable source since it regenerates thanks to the cycle of evaporation and precipitation. Its strength has been known and exploited for thousands of years through dams, water mills and irrigation systems.

Several technologies make it possible to exploit the energy produced by the fall or movement of water. The impellers can transform it directly into mechanical energy (water mill), while turbines and electric generators transform it into electricity [8, 10], see Figure 1.4.

Figure 1.4: Hydropower electricity production example

- **Geothermal energy**

Geothermal energy refers to the energy created and stored in the earth in thermal form. It is sometimes released to the surface by volcanoes or geysers, but it can also be accessible at any time, as in hot springs. Geothermal energy can be used to produce electricity or to heat and cool. The energy is extracted from underground reservoirs buried very deeply and accessible thanks to drilling, or from reservoirs closer to the surface [8, 10].

Geothermal energy can also be used for domestic purposes, thanks to small heat pumps, for example.

Figure 1.5: Geothermal energy[10].

- **Biomass energy**

Biomass, as the Bio refer, it is related to organic matter of plant or animal origin.

The main forms of biomass energy are: biofuels for transport (produced mainly from cereals, sugar, oilseeds and used oils); domestic heating (powered by wood); and the combustion of wood and waste in power plants producing electricity, heat or both two [8].

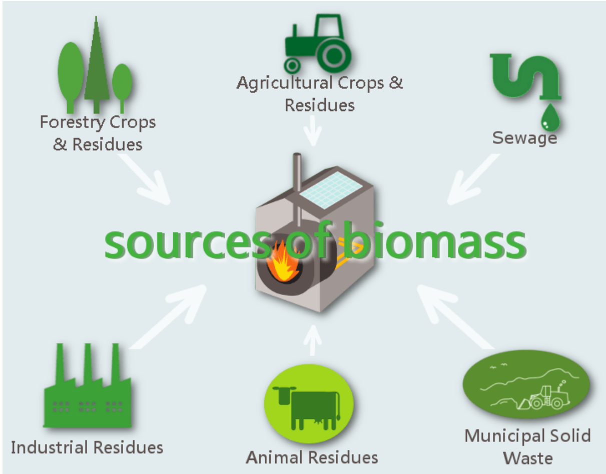

Figure 1.6: The sources of biomass

1.3 Photovoltaic Solar Energy

1.3.1 Definition and Principle of operation

The photovoltaic cell is the basic electronic component of the system. It uses the photoelectric effect to convert the electromagnetic waves (radiation) emitted by the Sun into electricity. Several cells connected together form a photovoltaic solar module or collector and these modules grouped together form a solar installation. Electricity is either consumed or stored on site, or transported by the distribution and electrical transmission network [12].

1.3.2 Photovoltaic cells

Photovoltaic cells are devices that directly convert sunlight into electricity [3, 13]. They are composed of several layers of semiconductor materials, such as silicon, which have the property of producing an electric current when exposed to sunlight.

When sunlight hits the surface of a photovoltaic cell, it is absorbed by the electrons in the upper layer of the semiconductor material. This light energy is then transferred to the electrons, which are released from their atomic bond and move in a specific direction through the cell. This circulation of electrons creates a direct electric current that can be used to power electrical appliances.

The following Figure 1.7 represent Structure of a photovoltaic cell

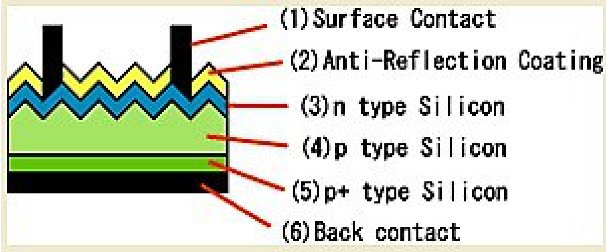

Figure 1.7: Structure of a photovoltaic cell

1.3.3 The different types of photovoltaic cells

a. Silicon photovoltaic cells

Monocrystalline silicon photovoltaic cells are one of the most common types of solar cells. They are made from monocrystalline silicon wafers, which gives them high efficiency and a long service life. Monocrystalline silicon is a very pure and homogeneous material, which makes it effective in converting light into electricity. See Figure 1.8.

Monocrystalline silicon solar cells have a uniform appearance, with a dark blue or black color. They are also known for their high efficiency, reaching up to 24% efficiency in converting light into electricity. However, the production of monocrystalline silicon is expensive and requires a large amount of energy, which can increase the cost of the solar cell. Despite their high cost, monocrystalline silicon photovoltaic cells are widely used in residential, commercial and industrial applications due to their high efficiency and long service life [14, 13].

Figure 1.8: PV cell based on monocrystalline silicon[9].

b. Crystalline silicon photovoltaic cells

Crystalline silicon is easily recognizable thanks to its blue crystals. These photovoltaic cells are composed of a single silicon wafer. They have a square shape. It is often found in domestic, agricultural or industrial installations .

The advantage of these cells compared to monocrystalline silicon is that they produce little cutting waste and that they require 2 to 3 times less energy for their manufacture. Estimated service life is 30 years [10, 14].

Figure 1.9: Poly-crystalline PV cell[9].

c. Amorphous cells

Amorphous silicon solar cells are made from non-crystalline silicon. They are cheaper than crystalline silicon cells, but they are also less efficient. The efficiency of panels composed of these cells is lower than polycrystalline or monocrystalline technologies [14] .

Figure 1.10: Amorphous cell.

d. Thin-film solar cells

Thin-film solar cells are made from materials such as cadmium telluride, copper-indium-gallium diselenide and amorphous silicon. They are cheaper to produce than crystalline silicon cells and can be manufactured in large quantities. However, their efficiency is also lower than that of crystalline silicon cells.

e. Organic solar cells

Organic solar cells are made from organic materials such as polymers. They are less expensive to produce than silicon cells, but their efficiency is still low.

f. Hybrid solar cells

Hybrid solar cells combine different types of photovoltaic cells to maximize efficiency. For example, a hybrid solar cell can use a thin layer of silicon combined with a thin layer of cadmium telluride.

1.3.4 Photovoltaic Modules

A photovoltaic module is a set of photovoltaic cells connected in serie and then encapsulated between a glass plate at the front and another waterproof material at the back.

The photovoltaic cells are thus protected from moisture and shocks. A cell produces less than 2 watts under approximately 0.5 Volts. That is why they are put into a module which then makes it possible to provide a satisfactory and more stable voltage and power. To do this, photovoltaic cells are assembled in two ways :

Serial association

An association of NS (The number of cells in serial) cells in series makes it possible to increase the voltage of the photovoltaic generator Gpv. The cells are crossed by the same current, the resulting voltage is obtained by adding the elementary voltages of each cell. This association is commonly used for commercial Gpvs. (See Figure 1.11)

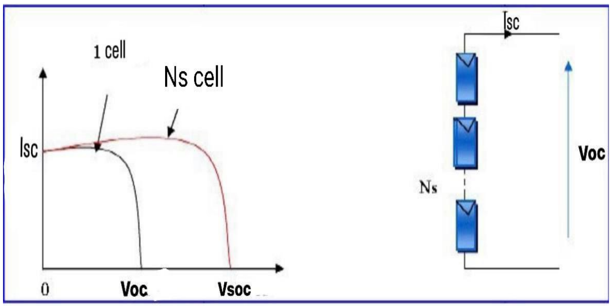

Figure 1.11: characteristic current voltage of (Ns) cell in series.

Parallel association

A parallel association of Np (The number of cells in parallel) cells makes it possible to increase the output current of the generator thus created. In a group of identical cells connected in parallel, the cells are subjected to the same voltage and the characteristic resulting from the group is obtained by addition of the currents.see Figure (I.14)

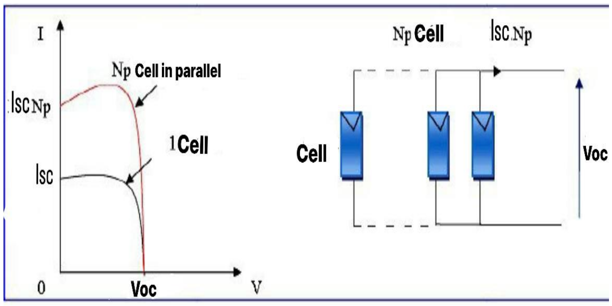

Figure 1.12: Characteristic current voltage of (Np) cells in parallel.

So, each photovoltaic panel consists of several models (series / parallel), and the latter consists of associated cells either (series or parallel) (see Figure 1.13)

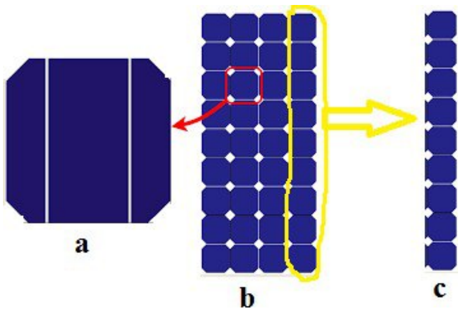

Figure 1.13: (a) Cell, (b) photovoltaic panels and (c) module

1.3.5 Photovoltaic systems installations and device systems

1.3.6 Photovoltaic systems installation types

There are generally three types of photovoltaic systems are :

- Autonomous systems
- Hybrid systems
- Systems connected to a network

The first two are independent of the electricity distribution system, often found in remote areas.

1.4 The advantages and disadvantages of a PV system

1.4.1 The main advantages of PV energy are :

1. Clean and Renewable energy: PV energy uses sunlight to generate electricity, making it a clean and renewable energy source. Unlike fossil fuels, PV energy does not produce greenhouse gases or other harmful pollutants for the environment.

2. Low operating costs: Once installed, solar panels have very low operating costs, as they do not require fuel or regular maintenance. This means that the long-term costs of PV energy can be lower than those of traditional energy sources.

3. Great flexibility: Solar panels can be installed practically anywhere there is sunlight, which makes them very flexible. They can be used to power residential and commercial buildings and industrial, as well as mobile devices such as electric vehicles.

4. Durability: Solar panels are usually very durable and have a long service life. Modern solar panels are designed to last up to 25 years or more with minimal maintenance.

5. Job Creation: The solar energy industry is expanding rapidly, creating jobs in the manufacture, installation and maintenance of panels solar.

1.4.2 The disadvantages of PV energy are :

Despite its many advantages, photovoltaic (PV) energy also has certain disadvantages that must be taken into account, in particular :

1. High initial costs: The initial installation costs of PV systems can be high, especially for large installations. However, these costs have decreased significantly over time, making solar energy more accessible for individuals and businesses.

2. Dependence on sunlight: PV energy can only be produced when the sun is shining, which means that electricity production can be variable depending on the weather and the season. Energy storage solutions, such as batteries, can help compensate for this variability.

3. Environmental impact of solar panel production: The production of solar panels can have an environmental impact, especially due to the use of certain toxic chemicals in their manufacture, such as cadmium and lead. However, solar panel manufacturers are working to minimize these environmental impacts and develop more sustainable production methods.

4. Land Occupancy: PV installations require large enough land areas to accommodate solar panels, which can cause land occupancy problems.

5. Need for energy storage: As mentioned earlier, PV energy is variable depending on the weather and the season, which may require the implementation of energy storage solutions to ensure a constant supply of electricity.

1.5 Conclusion

In this chapter, we have presented the different renewable energy sources, including solar energy, wind energy, hydroelectricity, biomass and geothermal energy. We then focused on the photovoltaic solar system, explaining its operating principle, the different components of the system, as well as the types of installations used. We also discussed the advantages and disadvantages of using photovoltaic energy.

Chapter 2

Solar Tracking System

2.1 Introduction

To generate the maximum amount of energy, a solar panel must be perpendicular to the light source[16]. Since the sun moves both daily and annually, a solar panel must be able to follow the sun's movement to produce the maximum possible power. The solution is to use a tracking system that maintains the panel's orthogonal position with the light source.

Solar tracking is a mechanized system that tracks the sun's position to increase power output by 30% to 60% compared to stationary systems[17, 18]. It is a more cost-effective solution than purchasing additional solar panels.

2.1.1 Sun path

The amount of solar energy reaching a surface outside the Earth's atmosphere is determined exclusively by astronomical and geometrical laws. These laws are influenced by the latitude of the location, solar declination, time of day, and the orientation of the receiving surface. The position of the sun is dependent on solar time and the specific day of the year, and it is represented by various angles [19].

The altitude angle or the solar elevation

Is defined as the angle between the central ray of the sun and the horizontal plane 2.1 : It is given by the following equation :

$$\alpha = \text{Arcsin}(\sin\varphi * \sin\delta + \cos\varphi * \cos\delta * \cos\omega). \tag{2.1}$$

with: φ :Latitude of the place. δ :Solar declination. ω: Time angle. or:

The latitude is denoted by an angular value, which signifies the inclination angle of the half-line that passes through the center of the Earth and the geographical location under consideration, relative to the equatorial plane. This angle ranges from 0° at the equator to 90° at the poles.

Longitude is another angular value that represents the east-west positioning of a location on Earth, with the Greenwich Meridian serving as the reference point. It spans a range of -180° (180° West) to +180° (180° East).

Figure 2.1: Latitude and longitude representation.

The solar declination

The solar declination is the angle created by the vector connecting the Earth's center to the sun and the equatorial plane of the Earth. It fluctuates from approximately +23.45° (in decimal degrees) at the summer solstice (June 21) to around -23.45° at the winter solstice (December 21), with the value of 0° observed at the equinoxes (March 21 and September

23). This variation is caused by the inclination of the Earth's axis relative to the ecliptic plane, leading to the distinct seasons experienced on Earth.

Azimuth angle

This angle is measured on the horizontal plane from the south to the horizontal projection of the direct rays of the sun. It is also defined as the angle between the local meridian and the projection of the line of sight to the sun on the horizontal plane, as shown in Figure 2.2. The solar azimuth angle is calculated using the following relation:

$$\mathrm{Az} = \mathrm{Arcsin}(\sin\omega * \cos\delta \div \cos\alpha) \tag{2.2}$$

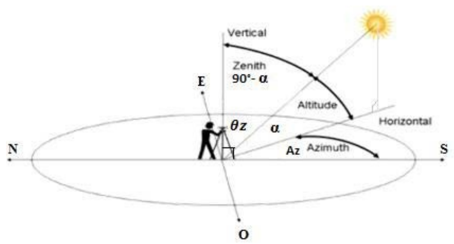

Figure 2.2: Representation of the solar Zenith, Azimuth and altitude angles.

2.2 Solar Tracking System

2.2.1 Definition

A solar tracking system is designed to align a solar photovoltaic panel with the direction of the sun's rays, crucial for applications needing precise orientation to ensure concentrated sunlight reaches the powered device efficiently. This system, whether electrical or mechanical, aims to optimize solar power output by maximizing exposure to sunlight [20].

2.2.2 Classification of Solar Tracking System

There are two categories of solar tracking system are :

Classification Based on Nature of Motion

This can be further subdivided into passive and active solar tracking systems:

Passive (Mechanical/Chemical) Solar Tracking System: Passive (Mechanical/Chemical) Solar Tracking System: This system operates by utilizing the concept of thermal expansion in materials or a low boiling point compressed gas fluid that shifts to one side or the other to enable tracking. Typically, a chloro-fluoro-carbon (CFC) or a shape memory alloy is positioned on each side of the solar panel. When the panel aligns perpendicularly with the sun, both sides reach equilibrium. As the sun moves, one side heats up, causing expansion on one side and contraction on the other, leading to the rotation of the solar panel.

Passive systems have the potential to enhance efficiency by up to 23% and are more cost-effective than active systems [21], although they are not widely adopted commercially [22]. Additionally, these systems incorporate viscous dampers to prevent excessive movement in response to wind gusts[20].

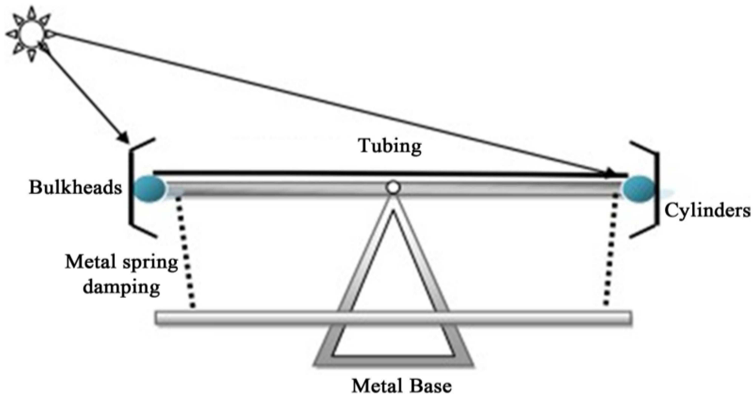

Figure 2.3: A tracking system using two identical cylinders, connected by a tube, filled with a fluid under pressure [23].

Active (Electrical) Solar Tracking System: These systems utilize motors and gear trains to orient the tracker according to commands from the controller, which tracks the solar direction. The sun's position is continuously monitored during daylight hours. When the tracker is in darkness, it either enters a sleep mode or halts, depending on its design. Light-sensitive sensors like LDRs are employed for this purpose. The sensors' voltage output is fed into a micro controller, which then controls actuators to adjust the solar panel's position. Active tracker systems consist of three primary types: auxiliary bifacial solar cell system, electro-optical system, and microprocessor/computer system [20] .

Classification Based on Freedom of Motion

This class is also subdivided into two viz:

Single Axis Tracking System: These trackers possess one degree of freedom, functioning as the axis of rotation. The axis of rotation in single-axis trackers is aligned along the meridian of true North. With advanced tracking algorithms, they can be aligned in any cardinal direction. Common implementations of single-axis trackers include horizontal single-axis trackers (HSAT), horizontal tilted single-axis trackers (HTSAT), vertical single-axis trackers (VSAT), tilted single-axis trackers (TSAT), and polar-aligned single-axis trackers (PSAT)[24] .

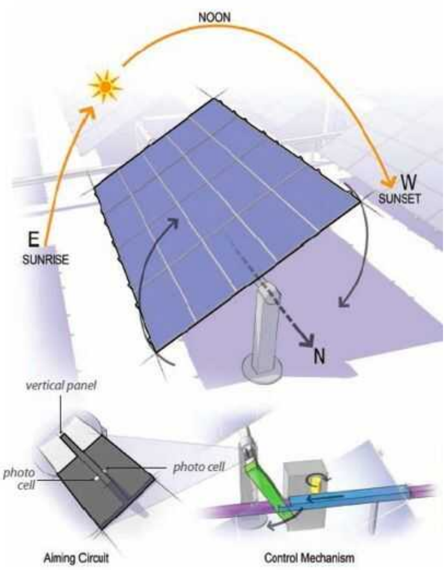

Figure 2.4: Solar panels with Single Axis Tracking System

Dual Axis Tracking System: These systems feature two degrees of freedom serving as axes of rotation, usually perpendicular to each other. The main axis remains fixed concerning the ground, while the secondary axis is oriented in relation to the primary axis. Dual trackers come in different common implementations, categorized based on the orientation of their primary axes relative to the ground[17]. Among these, azimuth-altitude and tilt-roll (or polar) solar trackers stand out as the most widely used two-axis solar tracking systems across diverse solar energy applications.

Below is Figure 2.6, illustrating the broad classification of solar tracker systems.

Figure 2.5: Solar panels with Dual Axis Tracking System

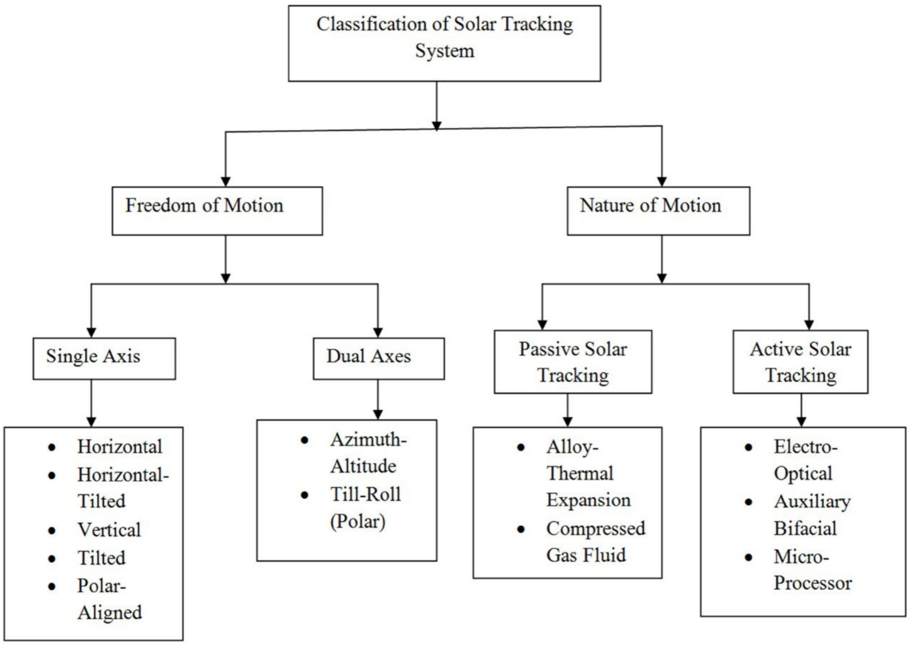

Figure 2.6: Classifications of Solar Tracking System [20].

2.2.3 Components of Solar Tracking Systems

The primary elements of a solar tracking system include the tracking device, the tracking algorithm (or thermal or electro-optical alternatives for non-algorithmic tracking), the control unit, the positioning system, the driving mechanism, and the sensing devices.

The algorithm functions as a tracking control system that computes angles for positioning the solar tracker. It encompasses two categories of algorithms: astronomical algorithms and real-time light intensity algorithms. The astronomical algorithm relies on mathematical calculations using astronomical references to determine the solar angles.

The non-algorithm thermal control system utilizes the differential thermal expansion of a working fluid to generate torque for tracker movement. On the other hand, the non-algorithm electro-optical control system employs differential optical signals to apply torque on the tracking mechanism for solar tracking purposes [25].

The positioning system is responsible for orienting the tracking device towards the sun based on the calculated angles. This system can operate using either electrical or hydraulic mechanisms.

The driving mechanism is the component tasked with adjusting the tracking device to the position set by the positioning system.

The sensing devices The sensing devices consist of sensors that gauge environmental factors like temperature, humidity, rainfall, and other ambient parameters, as well as light intensity for real-time light intensity algorithms, and the tilt angle of the tracker. Determining the tilt angle is achieved using an inclinometer or a blend of limit switches and motor encoder counts [26].

2.3 Comparison of solar trackers with sun position sensors and solar trackers using the sun trajectory algorithm (chronological solar tracker)

In the realm of control strategy for solar trackers, three primary types are recognized: passive, open-loop, and closed-loop controlled trackers [27, 28, 29].

Table 2.1: Comparison of solar trackers with sun position sensors and solar trackers using the sun trajectory algorithm

Control Strategy	Advantages	Disadvantages
Passive Trackers	- Reliable and straightforward design. - Nearly maintenance-free. - No need for electronic controls or motors.	- Do not achieve precise solar position measurements. - Cannot adjust for daily temperature variations. - Unpredictable movement, especially on cloudy days. - Challenging real-time implementation due to calibration requirements.
Open-Loop Systems	- Use microprocessors and sun position algorithms. - Do not require physical measurements. - Simpler and more cost-effective than closed-loop systems.	- Cannot account for temperature variations from day to day. - Unpredictable movement due to mechanical factors, especially on overcast days. - Challenging real-time implementation due to calibration needs. - Cannot correct errors or compensate for disturbances.
Closed-Loop Systems (Electrooptic Sensors)	- Enhance efficiency on sunny days. - Utilize various sensors (e.g., CCD cameras, photocells) for better accuracy.	- Complex due to the use of multiple sensors. - Require precise installation. - Struggle to measure solar positions accurately during cloudy or intermittently sunny conditions. - More expensive than open-loop systems.

2.4 Conclusion

Developing solar photovoltaic systems is relatively straightforward, although they generate less energy and power without tracking mechanisms. The implementation of solar tracking systems can enhance the collected solar energy by 10% to 100% at varying times of the year and under distinct geographical conditions [25] .

From this chapter we conclude that: The solar tracking system can be categorized as either passive or active, with the active system capable of tracking the sun's trajectory in either a single or dual axis. Research indicates that solar systems with tracking outperform fixed solar systems, and within active systems, dual-axis tracking proves more efficient than single-axis due to its ability to track solar irradiance on both axes. It is advised against using solar trackers with small PV arrays due to the energy consumption of the driving systems, which can range from 2% to 3% of the energy increase provided by the solar trackers [22, 30, 31].

Chapter 3

Material descrption

3.1 Introduction

After what we compared between 'solar trackers with sun position sensors ' and 'solar trackers using the sun trajectory algorithm' in the previous chapter , in this one, we elaborate our solution proposition and talk about the used materials for its design and programming.

Solution proposition As we talked about before, the use of each type of solar tracker has its own requirements, advantages and disadvantages. Based on the available materials the we have in order to make our experiment, in which we decided to work with an Arduino board and provide a high precise tracking of the sun path. This makes the implementation of the solar tracker the follows the sun path blindly by just relaying on the polar positions is impossible due to the big amount of calculations, so we are going to rely on using sensor based solar tracker. This latter also has serious problems when in comes to real life practice. The famous problem is LDRs equilibrium. Not all LDRs deliver the same signal when they are subjected to the sun light. The common solution of this problem as it is widely implemented is using a trimmer to converge to the same outputs of the LDRs. We believe that this is not an efficient solution with regards to the non-linearity between the output signal and the light intensity.

In this work, we are not going to discuss or compare the accuracy when using a solar tracker and not. We just focus on tracking the sun path. Therefore, we didn't use a real solar panel because it has been already proven that a solar panel with a solar tracker is better than a fixed one [18]. So, when we mention a solar tracker we mean by that just the tracking system (just our prototype) without the solar panel.

Our main goal in this work is to eliminate the mentioned problems of using the sun path algorithm and the non-exactitude of the common solar tracker. What we propose is a design of dual axes solar tracker where we cover the LDRs in a way that it eliminates LDRs dis-equilibrium and at the same time delivers a reliable sun tracking mechanism the same as done in [32]. In the next sections, we present the main parts we used in our prototype.

3.2 Arduino

Arduino is an open-source platform [33] utilized for building and programming electronics. It can communicate with various devices and even control specific electronic devices via the internet. Arduino utilizes a hardware component called the Arduino Uno circuit board and programming software (based on Simplified C++) to program the board.

3.2.1 Arduino Board

An Arduino Board can be divided into two main components:

Hardware: The Arduino board [34] hardware comprises multiple components that work together to enable its functionality.but, we will focus on the main component :

- **USB Plug:** This is the initial component of the Arduino as it facilitates program uploading to the microcontroller[4] [35] and provides a regulated 5-volt power supply to the Arduino board.
- **Reset Button:** This button resets the Arduino when pressed, allowing you to upload a new command or program for the Arduino to execute.
- **External Power Supply:** This is solely utilized to power the board and operates at a regulated voltage range of 9 to 12 volts, typically employed when the USB plug cannot deliver adequate power for the programmed tasks.

- **Microcontroller:** This device processes and exchanges information or commands with the corresponding circuit.
- **Analog Pins (A0-A5):** These are analog input pins labeled from A0 to A5.
- **Digital I/O Pins:** This are the digital input, output Pins 2 tol3.
- **Digital and analog Ground pins**
- **Power Pins :** we have 3.3 and 5 volts power pins e.t.c .. To write code using a

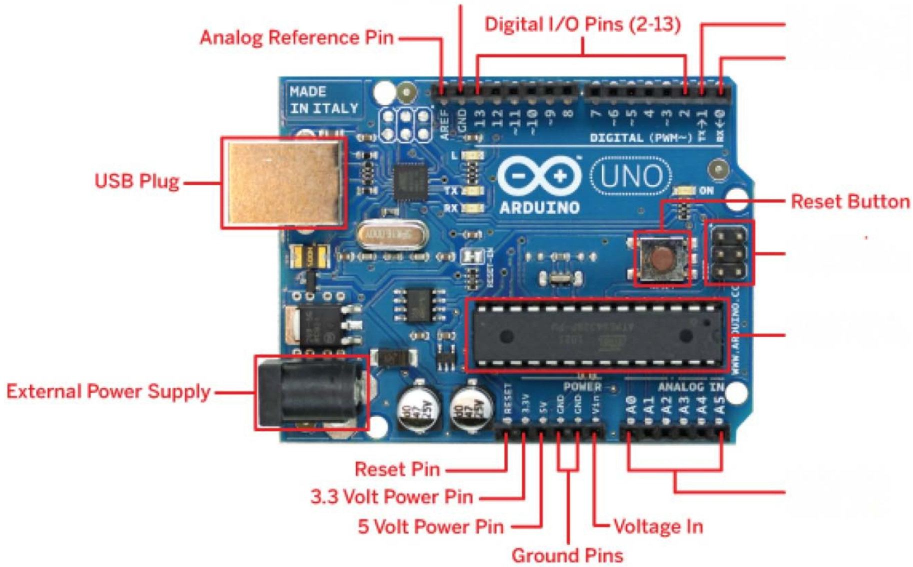

Figure 3.1: Labelled Arduino Board .

simplified version of the C++ programming language, which makes it easier to create a program.

3.3 Servo motor

3.3.1 Definition

A servo motor is a specialized type of electric motor designed to provide precise control of angular or linear position, velocity, and acceleration. Servo motors are widely used in various applications requiring accurate and controlled movement, such as robotics, CNC machines, 3D printers, and industrial automation systems [36].

3.3.2 Structure and functioning

In standard hobby servo motor, you will almost always find three core components: a DC motor, a controller circuit, and a potentiometer or similar feedback mechanism.The DC motor is coupled with a gearbox and output/drive shaft to amplify the motor's speed and torque. The DC motor propels the output shaft. The controller circuit interprets signals from the controller, while the potentiometer provides feedback to the controller circuit, enabling monitoring of the output shaft's position. Most hobby servos feature a standard three-pin, 0.1-inch-spaced connector for powering and controlling the servo. While color coding may vary between brands, the pins arrangement is generally consistent. By connecting these components, you can effectively manage the direction, speed, and position of the output shaft using just three wires [37].

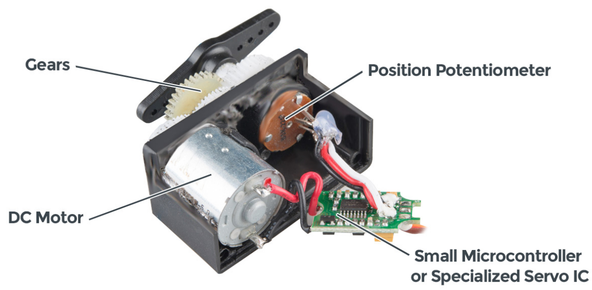

Figure 3.2: Inside a standard hobby servo

we used a two SG90 360 Degrees 9G Micro Servo Motor Tower

Servo Motor 9g SG90 features:

- **Operating voltage: 3.0-7.2V**
- **Speed (4.8V without load): 0.12sec / 60 degrees**
- **Strength: 1.2kg / 42.3oz (4.8V); 1.6 kg / 56.4oz (6.0V)**
- **Working temperature: -30 to +60 degrees C**
- **Cable length: approx. 23cm**
- **Dimensions: 22x11.5x27mm**

Figure 3.3: SG90 360 Degrees 9G Micro Servo Motor Tower

3.3.3 Controlling servo motors

To control the movement of a servo to a specific position within its range of motion, or for continuous rotation servos, to control the motor's speed and direction, the controller must transmit a precisely timed signal that the servo can interpret. Standard hobby servos typically require a pulse signal every 20 milliseconds (ms), where the width of this pulse determines the servo's position. This pulse width typically ranges between one and two milliseconds (ms). This method of signal control is commonly known as Pulse Width Modulation (PWM).

A servo controller is typically a specialized hardware device designed to generate the control signal for the servo based on inputs from other components such as a joystick, potentiometer, or sensor feedback. Alternatively, PWM-capable pins on a microcontroller can directly transmit the PWM signal to control the servo [37].

Pulse Width Modulation (PWM)

Pulse Width Modulation (PWM), also known as Pulse Duration Modulation (PDM) or Pulse Time Modulation (PTM), is an analog modulation technique where the duration or width of the pulse carrier varies proportionally to the instantaneous amplitude of the message signal. In PWM, the width of the pulse changes while keeping the amplitude of the signal constant. Amplitude limiters are employed to maintain a consistent signal amplitude by clipping off the excess, thereby limiting noise. The following figures illustrate different types of Pulse Width Modulation waves: Figure 3.5 (a), (b), (c) depict various Pulse Width Modulated waveforms with different time slots. There are three different

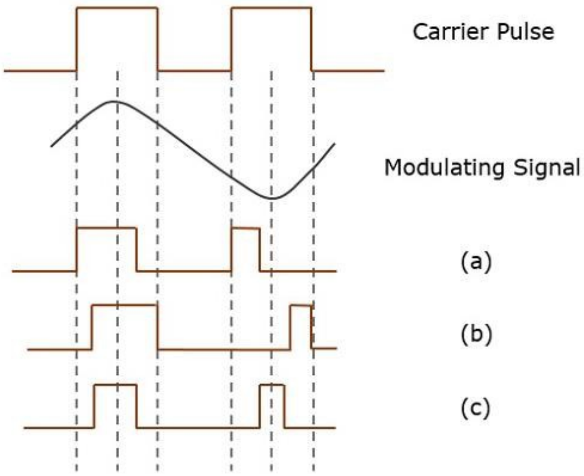

Figure 3.4: Pulse Width Modulated Waves with different time slots

types of PWM:

The first type of PWM keeps the leading edge of the pulse constant while varying the trailing edge according to the message signal. In the second type, the trailing edge of the pulse remains constant while the leading edge varies with the message signal. The third type maintains a constant center of the pulse while allowing both the leading edge and trailing edge to vary according to the message signal. These three types are illustrated in the provided figure, demonstrating different timing configurations [38].

3.3.4 Servo motors problems

Ordinary servo motors can be prone to inaccuracies in moving to the required angle due to various reasons. One common issue is the lack of precise calibration, which can lead to deviations from the intended position. This can be caused by factors such as incorrect settings in the controller software or damaged components within the motor, or even environmental factors like temperature fluctuations. Additionally, some servo motors may not be designed to operate within specific load limits, which can result in reduced accuracy and precision. Furthermore, the use of low-quality or generic servo motors can also contribute to these inaccuracies, as they might not be optimized for precise control. As a result, it is crucial to carefully select and configure servo motors for specific applications, ensuring that they are properly calibrated and maintained to achieve the desired level of accuracy and precision [39, 40].

3.4 LDR

The Light Dependent Resistor (LDR), also known as a light sensor, is a type of resistor that undergoes changes in resistance based on variations in light intensity [41].

Typically, LDRs are fabricated using cadmium sulfide, a semiconductor material whose resistance changes with the intensity of incident light. When used in a circuit, an LDR is installed similarly to a standard resistor, following the conventional resistor installation method [42].

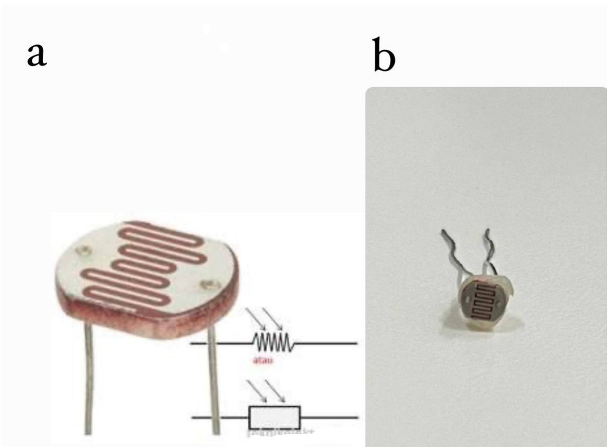

Figure 3.5: (a)LDR Sensors and Symbols ,(b) A picture of the LDR We used.

3.4.1 Characteristics

The Light Dependent Resistor (LDR) is a type of component that exhibits a change in resistance based on the intensity of light. The characteristics of an LDR can be categorized into two types: Recovery Rate and Spectral Response [42].

3.4.2 Working principle

The operation of an LDR light sensor varies based on the surrounding light intensity. In darkness, the LDR exhibits a high resistance of about $10M\Omega$, whereas in light conditions, the resistance decreases to $1K\Omega$ or less. LDRs are constructed from semiconductor materials like cadmium sulfide, where incident light energy generates additional charge or electrical current, leading to a decrease in material resistance [42].

LDR Technical problems

When ordinary light-dependent resistors (LDRs) receive the same intensity of light but do not output the same intensity of current, it Indicates that common issue with LDRs known as inconsistency in their response to light. This inconsistency can stem from variations in the manufacturing process of LDRs, leading to differences in their sensitivity to light even when exposed to the same illumination levels. Factors like the quality of materials used in the LDR's construction, variations in the semiconductor properties, or even environmental conditions can contribute to this discrepancy. As a result, when multiple LDRs are used in a system, these differences in sensitivity can lead to inaccuracies in light detection and affect the overall performance of light-sensitive circuits or devices. Calibration and careful selection of LDRs with consistent characteristics are essential to mitigate this problem and ensure reliable light sensing capabilities in electronic applications [43, 44].

3.5 ADC

3.5.1 Definition

An analog-to-digital converter (ADC), also referred to as A/D converter, is an electronic device designed to capture and convert real-world signals (like temperature, pressure, acceleration, and speed) into a digital format [45].

3.5.2 Working principle

In practical terms, analog signals exhibit a continuous sequence of values (often infinite, but sometimes finite) and can originate from sources like sound, light, temperature, and motion. On the other hand, digital signals are characterized by discrete values organized in sequences determined by sampling rates or time intervals. To illustrate this concept visually, Figure 3.6 provides a clear depiction of analog and digital signal representations [46].

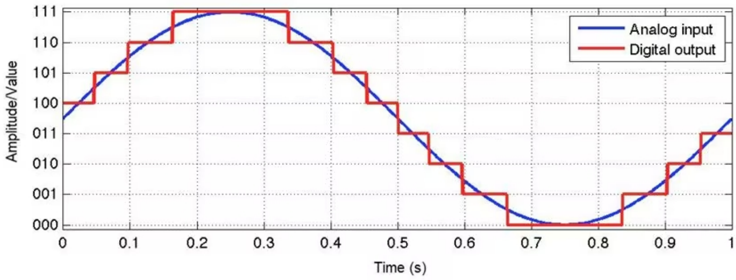

Figure 3.6: A continuous signal (analog) turning into a digital signal

Microcontrollers are unable to directly interpret analog values; they require digital data for processing. This limitation stems from the fact that microcontrollers can only discern voltage "levels" determined by the ADC resolution and system voltage.

ADCs follow a defined sequence to convert analog signals into digital form. They begin by sampling the analog signal, then quantifying it to establish signal resolution, and finally encoding the result into binary values for transmission to the system as digital data to be read [46].

3.6 Design and used material of our prototype solar tracker

Our proposed prototype of the solar tracker is given as follows: First, we used nylon tubes to seal the LDRs from the sunlight. All tubes are of the same length, which is 20 cm, as shown in Figure. 3.7.

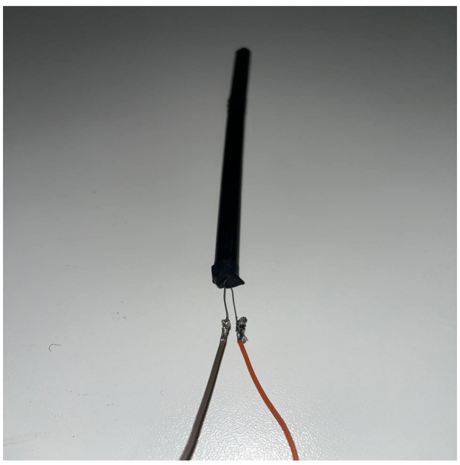

Figure 3.7: Black nylon tube

The LDR is put and in the edge of each one, covered and fixed. In order to make many tests in our solution, we fixed an LDR tub and made the other adjustable to play with the angle difference between the two in both axes (See Figure 3.8).

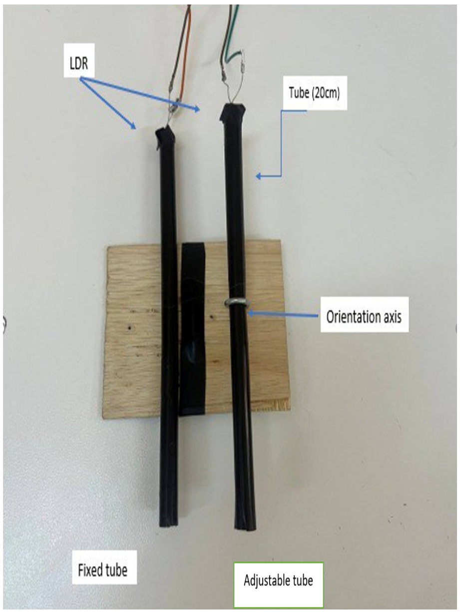

Figure 3.8: The fixed LDR tub and the adjustable one

Description and dimensions of the used holder are :

On the base, we install a vertical stump with a length of 22 cm. The horizontal stump, with a length of 10 cm, is installed on it. After that, we install the first servo motor (north/south) on the horizontal stump, and then we install the second servo motor (east/west) on it, where we have installed the LDRs, as shown in the figure. 3.8. The used holder, basis, and wiring are all shown in Figure 3.9.

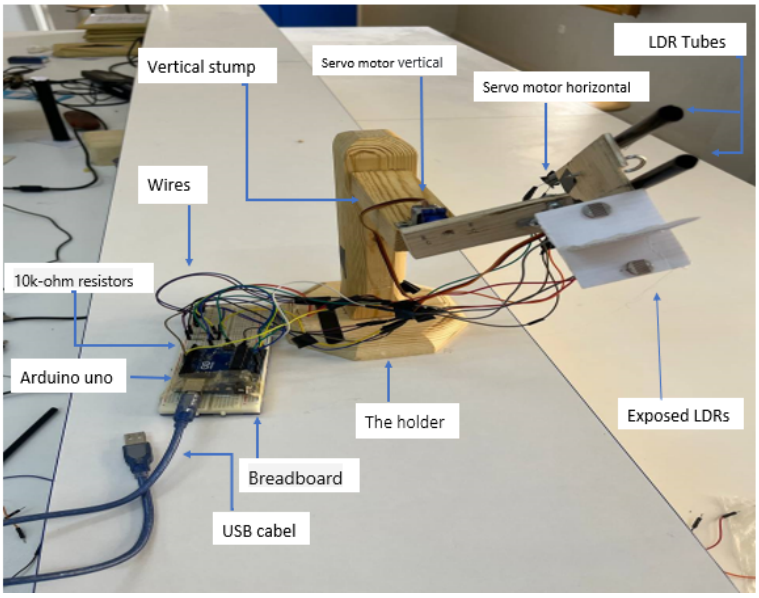

Figure 3.9: Solar tracker prototype

3.7 Conclusion

Throughout this chapter, we introduced our prototype idea, motivation, and design. We provided an explanation of the important materials used in our experiment and mentioned the most significant problems and malfunctions we faced, such as the LDRs not outputting the same current intensity when exposed to the same light intensity, and inaccuracies in moving to the required angle relative to the servo motor.

Chapter 4

Results and discussion

4.1 Introduction

This chapter contains the main parts of our experiment including the experiment protocol, the movement algorithm, the control interface. In the end, the acquired data of the LDR signal history and the relevant angles will be shown to reveal the success of our prototype of tracking the sun path.

4.2 Algorithm

In our work, there are two parts, the automatic control of the solar tracker in the arduino board, and data acquisition & visualization in the control interface. In addition to the communication algorithm that is shared between the two systems, Figure 4.1 shows the flow chart of the control algorithm existing in the arduino board.

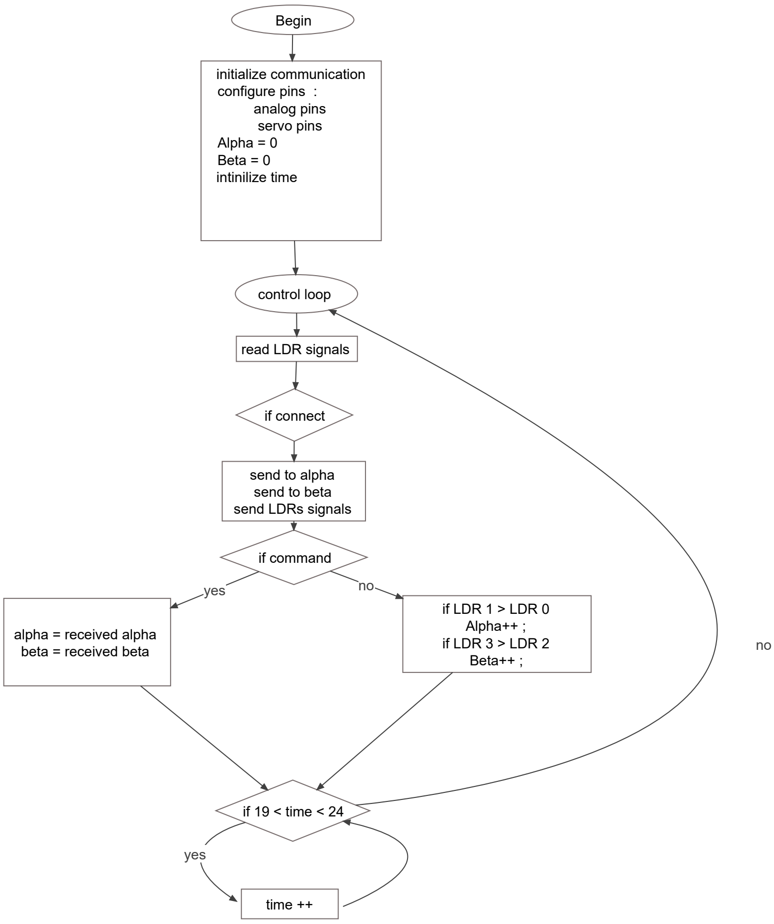

Figure 4.1: Flowchart

4.3 Control interface

In order to better visualize LDRs signals and the servo motors as well, we used the control interface shown in Figure 4.2 which has been developed by our supervisor Dr. Boutalbi. The used software for developing the interface is called Processing . Processing is an open source software used mainly for digital art, educational purposes and animation. It is based on Java programming language, lacks of libraries compared to the other programming languages like Python, C sharp, C++ but give the programmer more flexibility to develop graphical user interfaces.

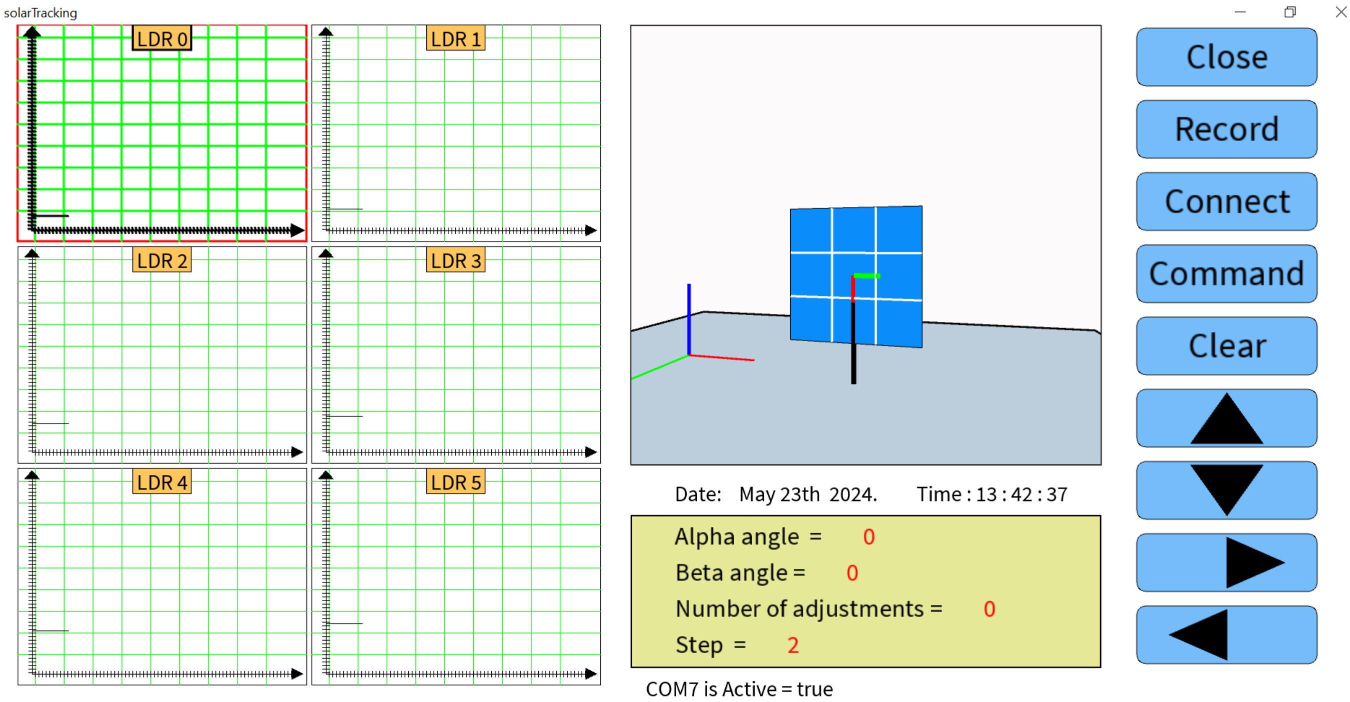

Figure 4.2: Control interface

- **Close :** Leave the system.
- **Record:** Recording data obtained from the arduino board (servo motors angles and LDRs signals).
- **Connect:** Connect to the Arduino board.
- **Command:** Manual Command of the servo motors angles (only works when the computer interface has been successfully connected with the Arduino).
- **Clear:** Clear data or reset to zero state.
- **LDR 0-5:** A graph showing the percentage of sensory resistance (LDR) exposure to light (sunlight).
- **Direction :** Angle control for inclination.
- **Alpha angle :** Horizontal (elevation) angle.
- **Beta angle :** Vertical (azimuth) angle.
- **Number of adjustments:** Number of servo motors movements.

- **Step :** Degree of change in tilt angle.
- **Date and time :** Date and time (hour, minute, and second) obtained from the computer system.
- **Figure :** A three-dimensional (3D) model reflecting the movement of a solar panel while capturing light.

4.4 Protocol and experiment

4.4.1 Protocol

In this section we talk about the followed protocol we made to achieve the aimed results when it comes to the implementation phase. The protocol comes respectively with the following steps:

First step, we fixed our solar tracker in the position where each angle of the servo motors fits with its real corresponding angle. In order to do so, we used the compass in the smart phone as pictured in Figure 4.3.

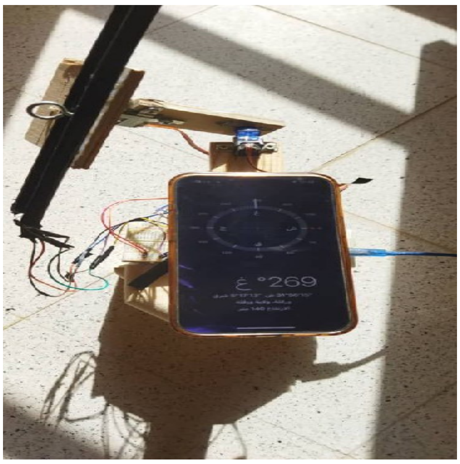

Figure 4.3: The compass of the smart phone

Second step: we used the Command control to manually adjust the angles of the servo motors, visualize LDRs signals to have an idea on how it works in real life implementation.

Third step: we compare the signals of the two corresponding LDRs (LDR0 & LDR1 (East & West) and LDR2 & LDR3 (North & South)) to see if they are equivalent or not.

We put them all together aligned at the same angle (we eliminated the angular differences created by the tubs thanks to the flexible setting that we mentioned in Chapter 3 Section 3.6) to receive the same light intensity. We found that LDR0 delivers higher signla then LDR1, and LDR3 is higher than LDR2. Without adding a trimmer to the wiring of our solor tracker. We just tried to converge them by multiplying the LDR0 and LDR3 by 0.9 to approximate their peer LDRs.

In this particular point, our solution obviously outperform the common utilizing of LDR based solar tracker in which our prototype guarantees a considerable differences between the LDRs signals.

In the fourth step: We manually inclined the solar tracker toward the elevation angle by tracking the highest signal delivered by the LDRs to make sure that it follows the corresponding seasonal angle. Now, it left just the direct implementation of the solar tracker.

Note : The servo motors angles do not reflect the real angles (azimuth and elevation). It just tell about the servo angles hence can not be precise nor stable. It requires the use of professional servo motors with high torque and precision along side with the use of a GPS sensor.

4.4.2 Experiment and results discussion

We enabled our solar tracker, we connected it to the control interface. Because of some technical problems concerning the servo motor that controls the elevation angle, we used the manual control to set our solar tracker to the best inclination angle (also we were observing the resulting shadow of the frame where the est/west LDRs are mounted to facilitate the tuning of the elevation angel).
After doing so, it turns out that the best elevation angle we've got is 10. This returns to the servo motor default angle in which the available ones do not offer a high precision resolution when in comes to fixing the est/west frame on it.

The historical record of our experiment is saved using the record command during our experiment. Figures 4.4 show a set of obtained results.

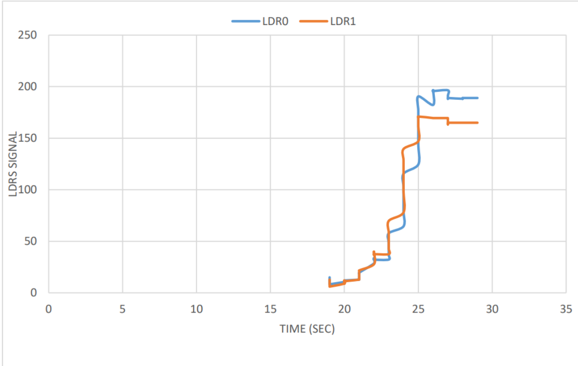

Figure 4.4: LDRs signals

Discussion As we see in Figure 4.2, the number of adjustments reflects the number of times the solar tracker changes the angle of the panel (supposedly mounted perpendicularly to the LDRs of the east/west frame).

Thanks to the control interface, we managed to record signals every 3 seconds (see Appendix A where we put the Data of the whole experiment). Figure 4.5 highlights the obtained peaks where the tracker adjusts the angle. We see a drop of the LDR signals after each adjustment, then signal goes back to the LDR that receives the highest sun light. We currently don't have a precise explanation of this phenomena in which we believe that the LDR of the highest signal conserves it until it loses the best inclination angle. We believe that this is caused by the LDR latency and disturbance of sun light reflections that happens inside the LDR tub. However, it goes be to the normal stat after few seconds where it has the highers signal.

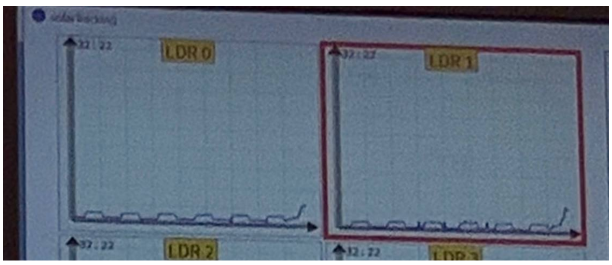

Figure 4.5: The peak

Something we noticed during our experiment is the insatiability of LDR signals even when the tracker doesn't adjust. Figure 4.6 shows a register of that. We believe the reason of this can be whether the manufacturing of the LDRs or some phenomena that occur inside the LDRs tubs that we couldn't arrive to an explanation for it.

Figure 4.6: The insatiability of LDR signals

In order to validate our prototype, we intended to compare it with the conventional prototype of solar trackers that use two fully exposed LDRS to the sun light. The model didn't work. I was because of the LDR signals are not equivalent. What happened is the solar tracker kept turning without stopping at all. Figure 4.7 shows the historical record of the experience.

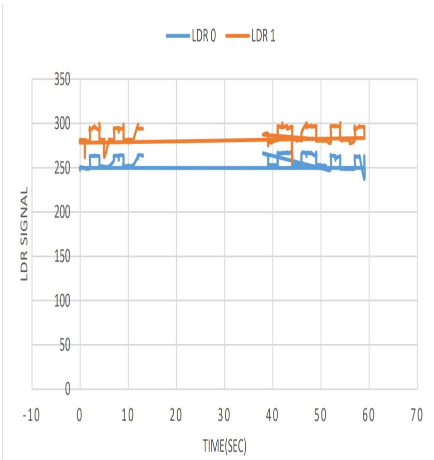

Figure 4.7: Expesd LDRs signals

4.5 Conclusion

In this chapter, we introduced the main parts of our experiment, including the experiment protocol, the motion algorithm, and the control interface. We presented and discussed the results obtained from LDR signals, which proved the success of our prototype.

General Conclusion

The solar tracking system plays an important role in increasing the efficiency of solar panels. The main objective of our work is to eliminate the problems of the use of the sun path algorithm and inaccuracies in tracking the sun, so we proposed this prototype of a two-axis solar tracker where we cover the LDRs in certain way to eliminate the imbalance of the LDRs. After comparing the obtained results from our first model and the results obtained from the usual model (LDRs exposed), we proved the efficiency and accuracy of our prototype.

In this thesis, we presented our prototype, including its concept, motivation, and design. We explained the key materials used in our experiment and discussed the major issues and malfunctions we encountered. These issues included the inconsistent current output when the same light intensity was applied to a set of LDRs and the inaccuracy in positioning relative to the servo motor.

We covered the basic components of our experiment, including the experimental protocol, the movement algorithm and the control interface. In the end, we presented the data collected from the signals of the tube-covered LDRs and the corresponding angles and the data collected from the exposed LDRs, after comparing the obtained results we found that the results obtained from the covered LDRs are better and more accurate than the results obtained from the exposed LDRs, which indicates the success of our bi-axial solar tracker model.

For future perspectives, we plan to use professional servo motors that enable us to fully implement the intended prototype. Furthermore, at that stage, the angles of the servo motors can reflect the real angles of the Azimuth and the elevation in which we can generate data and compare it to the algorithm based solar trackers that happens to be more expansive and depending mostly on high cost computational micro controllers and high precision GPS sensor. Doing so, we reveal the full potential of our proposed solution hence it can be commercialized as well and be independent, reliable and low cost.

Appendix A

Appendix 1

second	LDR0	LDR1
19	15	12.75
19	15	12.75
19	9	6.750001
19	8.25	6
19	8.25	6
20	10.5	9
20	10.5	12
20	10.5	9
20	12	12
20	12	11.25
21	12.75	12.75
21	12.75	12.75
21	12.75	12.75
21	18	21
21	19.5	21.75
22	28.5	27.75
22	32.25	39.75
22	32.25	37.5
22	33.75	36.75
22	32.25	37.5
23	32.25	37.5
23	36.75	42.75
23	42.75	50.25
23	48.75	58.5
23	57.75	69.75
24	64.5	78
24	78.75	98.24999
24	87.75	110.25
24	102.75	128.25
24	115.5	139.5
25	124.5	147
25	143.25	161.25
25	156	165.75
25	176.25	169.5
25	190.5	171
26	182.25	169.5
26	196.5	169.5
26	195	169.5
26	196.5	169.5
26	195.75	169.5
27	196.5	169.5
27	191.25	169.5
27	188.25	163.5
27	189	165
27	189	165
28	188.25	165

Figure A.1: The data of experiment

Bibliography

[1] BARA Meriem et al. “Etude et conception d’un suiveur solaire pour application photovoltaı¨que”. PhD thesis. Abdelhafid boussouf university Centre mila, 2020.

[2] Renewable Energy Statistics. “International Renewable Energy Agency: Abu Dhabi”. In: *United Arab Emirates* (2019), pp. 1–64.

[3] HAMZA BOUZERIA. “Modélisation et commande d’une chaine de conversion photovoltaı¨que”. PhD thesis. Université de Batna 2, 2016.

[4] International Energy Agency. *In 2025, RES will become the largest source of energy in the world: IEA Report.* `https://expro.com.ua/en/tidings/in-2025-res-will-become-the-largest-source-of-energy-in-the-world-iea-report`. Accessed: 2024-06-25. 2023.

[5] Ministry of Energy & Mines. *Ministry of Energy & Mines, Algeria.* 2011. URL: `http://www.mem-algeria.org` (visited on 05/03/2024).

[6] Tahar HAMAZ. “Journal of Business Administration and Economic Studies”. In: ().

[7] Ali Bouhafs. “Photovoltaic system, control, analysis and fault diagnosis”. PhD thesis. Université Kasdi Merbah Ouargla, 2022.

[8] Cuong hung Tran et al. “Améliorations d’une chaıˆne de conversion de l’énergie solaire en électricité autonome en vue d’application dans les pays en voie de développement”. PhD thesis. Reims, 2019.

[9] Salim Makhloufi. “Contribution à l’optimisation des installations photovoltaı¨ques par des commandes intelligentes”. PhD thesis. Université de Batna 2, 2013.

[10] Dris Mida. "Contribution à la Modélisation d'un Système de Production d'Energie Electrique Hybride «Eolien–Photovoltaı¨que»". PhD thesis. Université Mohamed Khider-Biskra, 2019.

[11] Mohamed Arrouf and Nour-Eddine Boughechal. "Optimisation de l'ensemble onduleur, moteur et pompe branché sur un générateur photovoltaique". In: (2007).

[12] France Lasnier. *Photovoltaic engineering handbook*. Routledge, 2017.

[13] Abdelhakim Belkaid. "onception et implémentation d'une commande MPPT de haute performance pour une chaine de conversion photovoltaı¨que autonome". PhD thesis. 2018.

[14] Anne Labouret and Michel Villoz. *Energie solaire photovoltaı¨que*. Vol. 3. Dunod Paris, 2006.

[15] M Serhan and L El-Chaar. "Two axes sun tracking system: comparison with a fixed system". In: *International Conference on Renewable Energies and Power Quality, ICREPQ*. Vol. 10. 2010.

[16] Adolf Goetzberger, Christopher Hebling, and Hans-Werner Schock. "Photovoltaic materials, history, status and outlook". In: *Materials science and engineering: R: Reports* 40.1 (2003), pp. 1–46.

[17] Oloka Reagan Otieno. "Solar tracker for solar panel". In: *University of Nairobi, Dept. of Electrical and Electronic Engineering, 24th August* (2015).

[18] P Madhu and V Viswanadha. "Design of real time embedded solar tracking system". In: *International Journal of Emerging Trends in Engineering Research (IJETER)* 3.6 (2015), pp. 180–185.

[19] Belkebir Katia and Chaabi Siham. "Conception et réalisation d'un suiveur de soleil à base d'une carte Arduino UNO". PhD thesis. Université Mouloud Mammeri, 2017.

[20] J Ya'u Muhammad et al. "A review on solar tracking system: A technique of solar power output enhancement". In: *Engineering Science* 4.1 (2019), pp. 1–11.

[21] Adrian Catarius and Mario Christiner. "Azimuth-altitude dual axis solar tracker". In: *Worcester Polytechnic Institute* 80 (2010).

[22] Hossein Mousazadeh et al. “A review of principle and sun-tracking methods for maximizing solar systems output”. In: *Renewable and sustainable energy reviews* 13.8 (2009), pp. 1800–1818.

[23] MJ Clifford and D Eastwood. “Design of a novel passive solar tracker”. In: *Solar Energy* 77.3 (2004), pp. 269–280.

[24] David Cooke. “Single vs”. In: *Dual Axis Solar Tracking, Alternate Energy eMagazine* (2011).

[25] Muhammad Sami Sabry, Katherine Harper Hall, and Brian W Raichle. “Determining the accuracy of solar trackers”. PhD thesis. Appalachian State University, 2013.

[26] Rockwell Automation. *Solar tracking application [White Paper]. Marion, NC: Rockwell Automation.* 2009.

[27] Narendrasinh J Parmar, Ankit N Parmar, and Vinod S Gautam. “Passive solar tracking system”. In: *International Journal of Emerging Technology and Advanced Engineering* 5.1 (2015), pp. 138–145.

[28] Zhe Mi et al. “Open-loop solar tracking strategy for high concentrating photovoltaic systems using variable tracking frequency”. In: *Energy Conversion and Management* 117 (2016), pp. 142–149.

[29] Aurélio Gouvêa Melo et al. “Development of a closed and open loop solar tracker technology”. In: *Acta Scientiarum. Technology* 39.2 (2017), pp. 177–183.

[30] Seung Jin Oh et al. “A study on the development of high accuracy solar tracking systems”. In: *8thrwa International Conference on Sustainable energy Technologies.* 2009.

[31] JV Patil, JK Nayak, and VP Sundersingh. “Design, fabrication and preliminary testing of a two-axes solar tracking system”. In: *International Energy Journal* 19.1 (1997).

[32] Lizbeth Salgado-Conrado. “A review on sun position sensors used in solar applications”. In: *Renewable and Sustainable Energy Reviews* 82 (2018), pp. 2128–2146.

[33] Yusuf Abdullahi Badamasi. “The working principle of an Arduino”. In: *2014 11th international conference on electronics, computer and computation (ICECCO)*. IEEE. 2014, pp. 1–4.

[34] AU ARDUINO UNO. "Front. arduino uno board". In: (2012).

[35] Alicia M Gibb. "New media art, design, and the Arduino microcontroller: A malleable tool". In: *Pratt Institute* (2010).

[36] Darren Sawicz. "Hobby servo fundamentals". In: *Acesso em* 12 (2001), pp. 292–302.

[37] *Servos Explained - SparkFun Electronics*. `https://www.sparkfun.com/servos`.

[38] Diagram Source Brain Kart. "Pulse width modulation". In: (2001).

[39] Inc. Mitchell Electronics. "8 Tips for Troubleshooting Servo Motor Problems". In: *mitchell-electronics.com* (Year). URL: `https://www.mitchell-electronics.com/8-tips-for-troubleshooting-servo-motor-problems`.

[40] Global Electronic Services. *3 Common Servo Motor Problems and How They Can Be Resolved*. 2024. URL: `https://gesrepair.com/3-common-servo-motor-problems-and-how-they-can-be-resolved/` (visited on 05/07/2024).

[41] V Tipsuwanporn et al. "9-level inverter for induction motor control". In: *ICCAS 2010*. IEEE. 2010, pp. 2462–2466.

[42] Maharani Putri and Solly Aryza. "Design of security tools using sensor Light Dependent Resistor (LDR) through mobile phone". In: *Int. J. Innov. Res. in Comp. and Comm. Eng* 4.10 (2018), pp. 168–173.

[43] NCERT. "lelm312.pdf". In: *ncert.nic.in* (Year). URL: `https://ncert.nic.in/pdf/publication/sciencelaboratorymanuals/classXII/physics/lelm312.pdf`.

[44] NCBI. "Light Dependent Resistance as a Sensor in Spectroscopy Setups". In: *ncbi.nlm.nih.gov* (2013). URL: `https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3872342/`.

[45] Analog Devices. *Analog Devices Glossary: ADC*. 2024. URL: `https://www.analog.com/en/resources/glossary/adc.html` (visited on 05/07/2024).

[46] Arrow Electronics. *Basics of Analog to Digital Converters*. 2024. URL: `https://www.arrow.com/en/research-and-events/articles/engineering-resource-basics-of-analog-to-digital-converters` (visited on 05/07/2024).

Abstract

Putting a solar tracker in a solar panel is non-questionably a better option. It has been proved in various studies that solar trackers based solar panels deliver way higher efficiency. When it comes to real life implementation of solar trackers, there are several problems each one has its particularity depending on the type of the tracker. Our concern in this work is the implementation of a dual axes solar tracker. The common implementation of this model is using two LDRs fully exposed to the sun light. This causes many problems especially when using low cost commercial LDRs. These LDRs do not deliver the same signal when exposed to the same light intensity. Even when trying to make them deliver the same signal using a trimmer, we believe that it is not the best solution. Therefore, in this thesis we propose a prototype of a solar tracking system that solves this problem and guarantee a sun tracking mechanism which is more reliable than the conventional ones. The success of our implementation and the results validate our prototype in which it shows that it adjusts itself with the minimum energy where we used the number of adjustments (Located in the interface control) as a metric to measure it.

Key words: renewable energy ,solar tracker ,sun path sensor , sun sensor, Solar tracker prototype

Résumé

Mettre un traquer solaire dans un panneau solaire est sans aucun doute une meilleure option. Il a été prouvé dans diverses études que les panneaux solaires basés sur des traqueurs solaires offrent une efficacité bien supérieure. Lorsqu'il s'agit de mise en œuvre réelle de traqueurs solaires, il existe plusieurs problèmes, chacun ayant sa particularité en fonction du type de traquer. Notre préoccupation dans ce travail est la mise en œuvre d'un traquer solaire double axe. La mise en œuvre courante de ce modèle consiste à utiliser deux LDR entièrement exposés à la lumière du soleil. Cela pose de nombreux problèmes, en particulier lors de l'utilisation de LDR commerciaux à faible coût. Ces derniers ne délivrent pas le même signal lorsqu'ils sont exposés à la même intensité lumineuse. Même en essayant de leur faire délivrer le même signal à l'aide d'un trimmer, nous pensons que ce n'est pas la meilleure solution. Par conséquent, dans cette thèse, nous proposons un prototype de système de suivi solaire qui résout ce problème et garantit un mécanisme de suivi solaire plus fiable que les mécanismes conventionnels. Le succès de notre mise en œuvre et les résultats valident notre prototype dans lequel il montre qu'il s'ajuste avec le minimum d'énergie là où nous avons utilisé le nombre d'ajustements comme métrique pour le mesurer.

Mots-clés : énergies renouvelables, traqueur solaire, capteur de trajectoire solaire, capture solaire, prototype de traqueur solaire

الملخص

ان وضع نظام تتبع شمسي للوح كهروضوئي هو من غير شك افضل خيار. أثبتت العديد من الدراسات ان الالواح الشمسية القائمة على أجهزة التتبع الشمسي توفر كفاءة أعلى . عند تنفيذ متتبع شمسي في الحياة الواقعية ، هناك العديد من المشاكل التي تواجهنا اعتمادا على نوع المتعقب المراد إنجازه لان لكل واحد من هم خصوصياته . عملنا في هذه المذكرة هو انجاز جهاز تعقب شمسي ثنائي المحور اكثر اعتمادية ودقة من اجهز التعقب الشائعة ، التي يتمثل تنفيذها في استخدام اثنين من المقاومات الضوئية ،، لا تقدم هاته الأخيرة نفس الإشارة عند تعرضها لنفس شدة الضوء . حتى باستخدام أداة تشذيب ، التي نعتقد انها ليست الحل الأمثل ،لذلك اقترحنا في هذه المذكرة نموذجا اوليا لنظام تتبع شمسي الذي يحل هاته المشكلة ويضمن آلية تتبع الشمس تكون اكثر موثوقية من تلك التقليدية . نجاح تجربتنا والنتائج المتحصل عليها من نموذجنا الاولي تكمن في انه يضبط نفسه تلقائيا وباستهلاك اقل للطاقة حيث استنتجنا ذلك من عدد التعديلات (الموجودة في واجهة التحكم) التي استخدمناها كمقايس لقياس ذلك .

الكلمات المفتاحية : الطاقات المتجددة ، متتبع شمسي ، مستشعر مسار الشمس ، مستشعر الشمس ، نموذج أولي للمتعقب الشمسي