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Development of solar tracker for low-cost Offset parabolic thermal concentrator

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ABSTRACT
The interest in exploiting solar energy has been steadily increasing as the world is aiming at sustainability. This work focused on making better use of solar energy through the manufacturing of a low-cost mechanism for solar tracking, with both horizontal and vertical rotating axes, to be coupled to a parabolic solar concentrator. For the electronic parts, it was employed a microcontroller Arduino UNO, power window regulator motors, a photoresistor sensor, a IBT-2 H-bridge, and a micro switch. On the other hand, the mechanical parts of the solar tracking system were fabricated using a 3D printer. Besides, this project introduced new concepts regarding the mechanical parts, which are not discussed in the literature of solar tracking systems, such as radial and straight oblong holes as well as the axial increase in the height of the motors. As a final result, we obtained an optimized setup for a parabolic solar concentrator equipped with a solar tracking system useful for water heating, which combines better efficiency in energy conversion with an affordable cost for needy people.

Keywords: Solar energy, Solar tracker, Heating.

1 INTRODUCTION

The sudden rise in energy occurred at the time of the beginning of the First Industrial Revolution with the creation of steam engines, the effectiveness of the use of electricity in industries, locomotives and ships. In this way, they discovered new forms of energy, such as oil, natural gas and hydroelectric power (ENERGIA E SOCIEDADE, 2014), thus increasing the need for the use of energy for society. However, many energies that are used can cause problems to the environment and this was seen by the population as something pejorative, because of this society began to think about ways to use technology bringing development and innovation of clean and sustainable energies already created - such as windmills - and new means of capturing clean and sustainable energy like wave energy.

Some of the negative points of clean and sustainable energy are that they may not be as efficient and their manufacture is based on high prices, that is, it is not feasible for needy families to acquire.

However, some of these energies can be innovated and developed to achieve high levels of efficiency in their capture and with low manufacturing costs, one of them being solar energy.

One of the great problems of solar energy is that with the rotation of the earth during the day, there are several incident positions of the light rays and when you have a fixed solar capture system there is only a maximum peak of performance of that capture. However, one of the ways to solve this problem is with solar trackers, as the maximum points can be reached at any time depending on the position of the sun, during the whole day the solar pickup will be facing it.

The work presented by Jacob Filho (2016) shows the performance of a parabolic solar concentrator coated with reflective palettes where, in his tests, he showed significant yields on days when solar radiation was around 1000 W/m² ± 10 % and 200 W/m² ± 10 %, with wind less than 2 m/s, ambient temperature in the sun between 29 ºC ± 2 ºC and 36 ºC ± 2 ºC and the results arrived, after 20 measurements, water values exceed 80 ºC. However, this design does not have automatic mechanisms for identifying the peaks of the sun's rays and, as an example, a solar tracker with two axes of rotation can obtain higher temperatures.

The use of design software such as SmoothDraw4 and more dynamic drawing software, such as Inventor, and for the drafting of the electronic part, Autodesk's Tinkercad, helped to have greater horizons to be able to identify possible execution errors, being able to solve them before going to the practical part and purchase components.

2 LITERATURE REVIEW

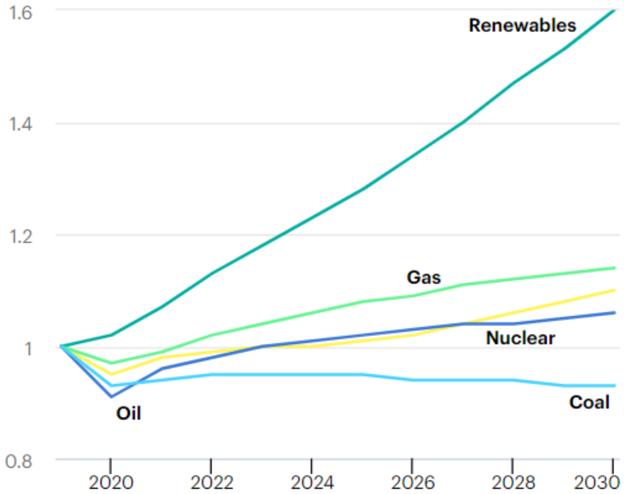
We know that in the early days the source of energy from fire was extremely important for cooking and heating hominids. As time went by, new ways of capturing energy sources were created, given that one of the first civilizations (Incas and Mayans) was only sustained due to the large irrigation of the planted cereals, the energy of the water courses and the animal traction for the transport and grinding of these grains (DECARVALHO, 2014).

Today, energy is one of the most precious commodities in the world. However, the world has been acquiring a new culture about energy resources, focusing more on the environment, on aspects of sustainability, lower greenhouse gas emissions, less aggression to the environment and the reduction of deforestation. In this way, the interest and use of renewable and clean energy sources has been growing for both developed and emerging countries, even if the economic factor is still a major determinant of which energies that country will use, but with the advancement of technology and new research on this field of developing techniques to capture clean and renewable energy, little by little, countries with lower purchasing power are adopting resources (MORAIS, 2015).

Not far from that, a great source of sustainable and clean energy that grew from 1996 to 2006 by 2000% in the world is solar energy, because this energy comes from an almost inexhaustible source and that all countries have access to. In Brazil, solar energy is being used more in large urban centers such as São Paulo, Rio de Janeiro and Santa Catarina, being converted either into electricity (using photovoltaic panels) or thermal energy (using thermal concentrators). There is a great tendency to adopt this energy resource in Brazil because it is located in a privileged region of solar rays, given that solar radiation strongly depends on latitude, atmosphere and the season of the year (MORAIS, 2015).

The world's energy use is continuously increasing, as shown in Figure 1. Growth is expected to be led by the use of solar PV and wind renewables (IEA, 2020) at the expense of the use of coal.

Figure 1 – Projection of primary energy demand.

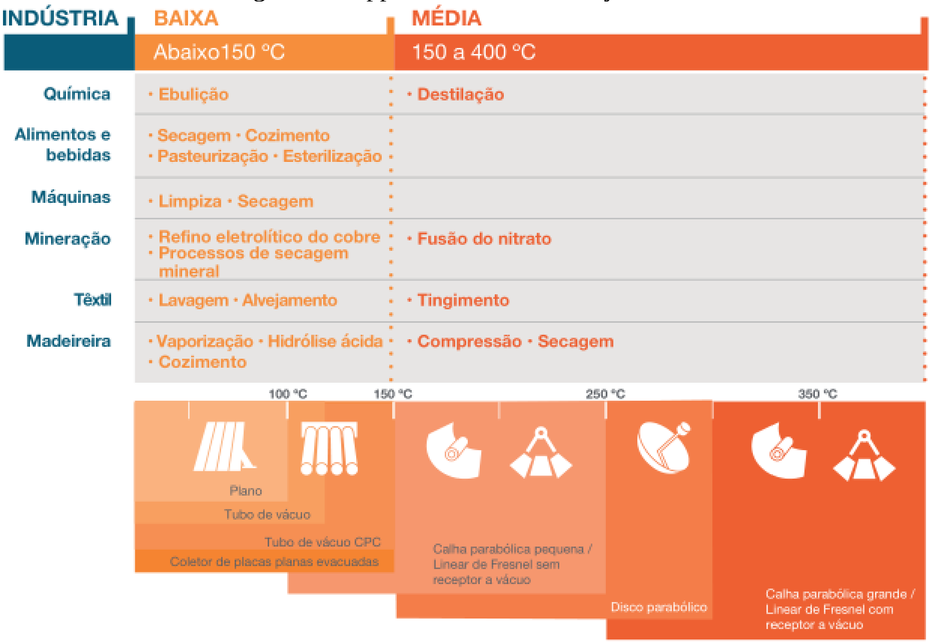


Source: IEA, 2020

The use of energy takes place mainly in two processes, which are thermal and photovoltaic, the latter being the one that has increased the most in use in recent years. Until 2017 thermal collectors were the most used, especially in the residential heating sector, after that they were displaced by photovoltaic technology (IEA-SCH, 2020). Solar heating for industrial processes ranges from small-scale demonstration plants to large systems in the order of 100 MWh (IEA-SHC, 2020). The only plant with a solar concentrator currently installed in Brazil is a demonstration plant and is of the parabolic cylinder type, installed in the CEFET-MG laboratory (Neto *et al*., 2019).

Figure 2 schematically shows some possible applications of solar heating systems for industrial use.

Figure 2 – Applications of SHIPs systems.

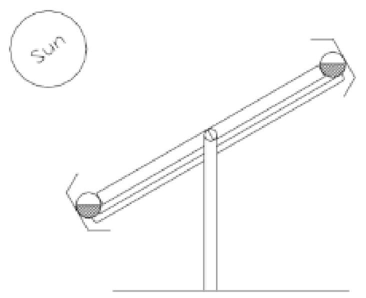
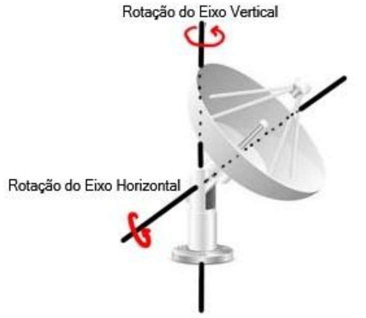


Fonte: SOLAR PAYBACK, 2017

Solar collectors can be classified according to their use as low (< 100 °C), medium (100 – 400 °C) and high temperatures (> 400 °C) (KENEDY, 2002), for medium and high temperatures the solar collector must have a concentrator. Among the technologies available for solar use at < temperature of 400 °C are stationary collectors (flat, evacuated tube), compound parabolic concentrator (CPC), and with tracking systems there is the cylinder-parabolic collector, Fresnel, parabolic disk and Scheffler (DUFFIE and BECKMAN, 2013). All the collectors mentioned, except for the flat collector and evacuated tube, are concentrators, i.e., they have an opening area larger than the area of reception (absorption) of radiation, thus achieving high temperatures in the receiver. Thus, the receiver must withstand high radiation fluxes and temperatures of little more than 400 °C in SHIP applications. Most solar collectors that can be used in the industrial sector work with direct solar radiation, due to this it is necessary solar tracking systems to direct the collector's reflector towards the sun and thus concentrate the direct radiation in small areas of absorption thus reaching high temperatures. It is possible to classify solar trackers according to the number of rotating axes, and a single-axis solar tracker will cause the absorption of solar radiation to be lower than in the case of two-axis tracking, usually the rotation axes are positioned one horizontally and the other vertically, with the two-axis tracker it is possible to always have the maximum capture of direct solar radiation throughout the day during the day. every day of the year. They can also be classified if it is passive or active. Some types of solar trackers are described below.

The *passive tracker* does not use any electrical and electronic equipment for its movement as shown in Figure 3. In this one, there is a mechanism of movement by liquids that make evaporation and condensation. This figure shows a single-axis solar tracker.

In *the Active Tracker*, electrical and electronic equipment is used to rotate the axes and maintain greater efficiency throughout the day. Tracking can be on one or two axes. Figure 4 shows the tracking on an axis, positioned horizontally. Figure 5 shows a two-axis tracking scheme.

Figure 3 – Passive liquid tracker.	Figure 4 – Solar tracker with a drive axis.	Figure 5 – Solar tracker with two axes of movement.
		
Source: (QUEIROZ et al., 2018)	Source: Adapted from (LIFE, 2021).	Source: Adapted from (LIFE, 2021).

Solar tracking is required for solar thermal concentration systems. In Brazil there are no companies that work with tracking systems, so this work intends to develop a proposal for a solar tracking system.

One of the most important parts of the solar concentrator is the parabolic, as it will serve as the equipment that will concentrate the sun's rays in a region where it will contain some fluid, and the parabolic form is usually used in the means of capturing signal for televisions, that is, from satellite signals it is emitted to the satellite dishes, capturing the image on television. This is because the parabolic is a paraboloid and every signal that enters parallel to its axis is reflected (in a concentrated way) - when it hits its surface of that paraboloid - in a region called the focus.

3 OBJECTIVES

The objectives of this project were to build a device that can capture the best positions of the sun's rays automatically, and from the sun's rays, these would be concentrated in a region heating some fluid.

The work was carried out at Unesp - Institute of Science and Engineering (ICE), Itapeva Campus, with the following objectives:

- Develop a proposal for an automatic solar tracker in two axes for a solar collector offset parabolic reflector;
- Use low-cost materials;
- Encourage more use of solar energy by underserved populations.

4 MATERIALS AND METHODS

For the development of the initial theoretical concepts, it was necessary to design possible ways of movement of the solar tracker and to select which low-cost parts would compose this project, so the SmoothDraw4 software was used [Figure 6]. Once the first concept tests of the follower were carried out, the drawings were carried out in Autodesk Inventor which allowed the simulation of all the constituent parts of the follower in its digital twin, such as the fixing bracket of the base of the structure [Figure 7], the parabolic offset, the absorber support [Figure 8], and the complete conceptual structure [Figure 9].

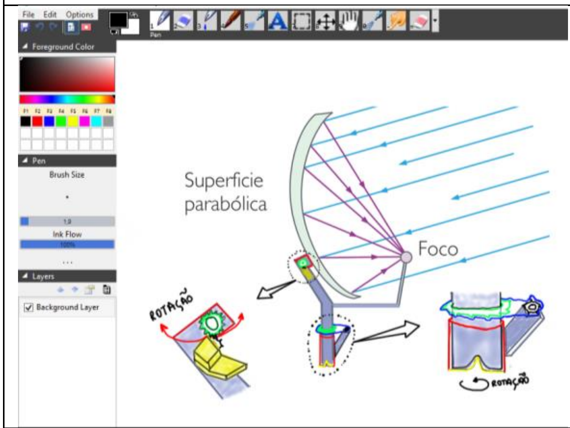
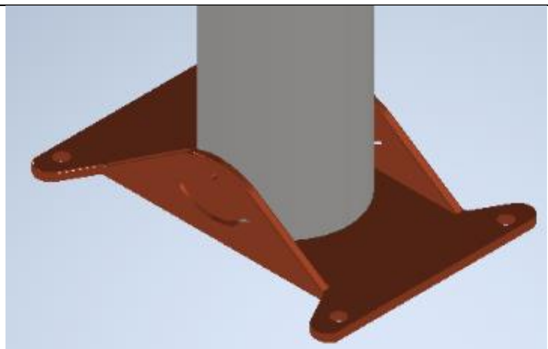
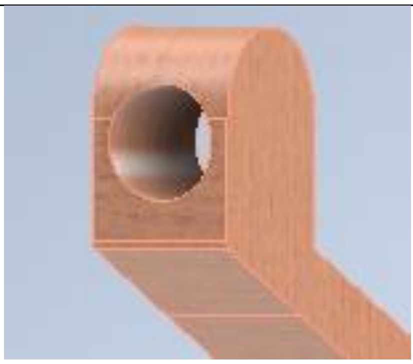
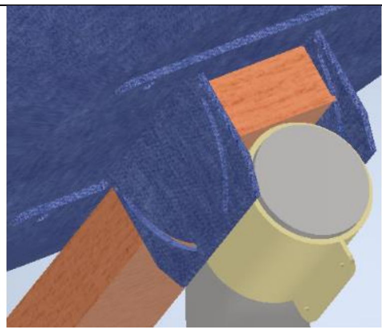
Figure 6 – Primary ideas in the SmoothDraw software4.	Figure 7 – Initial structure of attachment of the tracker base.
	
Source: Author's own.	Source: Author's own.

Figure 8 – Absorber support.	Figure 9 – Complete initial structure.	Figure 10 – Fixation structure between the satellite dish and the support structure of the solar tracker.
		
Source: Author's own.	Source: Author's own.	Source: Author's own.

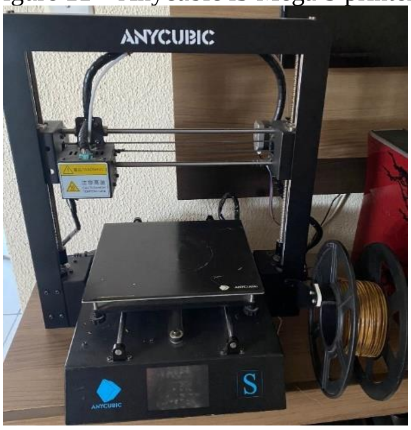
The vertical axis should rotate around a pin mounted on the base of the frame. An initial idea was to weld a semi-spherical surface to the bottom of the vertical structure, with this surface rotating around the stud. Table 1 shows the materials required for the mechanical part of the solar tracker.

In order to achieve a lower rotational speed of the frame shafts, a speed reduction between the motor shaft and the frame shaft is required. This reduction is provided by gears which were manufactured on an Anycubic I3 Mega S 3D printer [Figure 11]

Table 1 – Mechanical components of the structure.

Items	Qty.	Pcs. (R$)	Detail
Ø80MM X 500MM STEEL TUBE	1	20,00	Recycling
STEEL PLATE	1	30,00	Recycling
REDUCTION GEAR	4	12,00	Plastic in 3D printer
ALUMINUM ABSORBER	5 m	49,00	3/8" (9.52 mm)
ABSORBER HOLDER (ALUMINUM PAN)	1	30,00	Bought in the city
SCREWS	22	16,50	Bought in the city
LIGHT SENSOR SUPPORT	1	5,00	Plastic in 3D printer

Figure 11 – Anycubic i3 Mega S printer.



Source: Author's own.

The solar tracker must have a two-axis rotation, which are provided by motors. Table 2 shows some electric motor alternatives that can be used.

Table 2 – Characteristics of the motors used.

Feature	Glass (Mabuchi)	Windshield (truck)	Windshield (car)
Tension	12Vdc	12 Vdc	15 V DC
Gear	8 cloves	0 teeth	0 teeth
Torque	3 Nm	100 kg/cm	100 kg/cm
Rated speed	65 +/- 15 rpm	High and Low	37 (Low) to 58 (High) rpm
No-load speed	80 rpm		
Price	R$ 53,80	R$ 756,24	R$ 92,15
Maximum Current	7.5A	10A	10A

Among these three possibilities, the automotive glass engine was selected because it has a lower cost. Figure 12 shows the selected engine.

Figure 12: Car glass engine.

Source: Author's own.

To follow the sun, the mechanism must have light sensors, motors and a drive controller. An Arduino board was used to control the drive motors, a full list of components that were used is given in Table 3.

Table 3 – Electronic components.

	Items	Qtde.	Units. (R$)	Total
1	Arduino uno R3 - ATmega328	1	39,51	39,51
2	H Bridge L298 5th	1	24,00	24,00
3	MxM Jumpers 110-240 mm	25	2,10	11,88
4	LDR 5mm	4	0,70	2,80
5	Protoboard 830 Points MB-102	1	15,00	15,00
6	Resistor 10kΩ – 1/4 W	10	0,15	1,50
7	Resistor 150 Ω - 1/4W	10	0,27	2,78
8	Pot	4	3,15	12,60
9	Switching power supply 12V, 10A	1	49,78	49,78
10	Electric Window Motor	2	35,00	70,00
11	Wires	1	19,40	19,40
12	End-of-Course	2	3,29	6,58

Due to the exposure to sun and rain that the electronic components will be exposed to, it was necessary to manufacture a galvanized steel box.

Figure 13 - Galvanized steel box for the electronic part of 40x30x10 cm


.

Source: Author's own.

Conceptually, the solar tracker will heat water or oil and to be able to use the converted energy it will be necessary to use a heat exchanger, so a low-cost car radiator was used. The components used were a 40 mm diameter hose, radiator water reservoir, 1/2" x 1/2" seatpost, PVC short reduction bushing, 1/4 nuts and bolts, 40 mm diameter clamps. It was necessary to fabricate an extra structure to be able to fix the radiator in the main structure using steel angles and aluminum profile, shown in figure 14.

Figure 14 - Components of the heat exchanger part.	Figure 15 – Radiator mounted.
	
Source: Author's own.	Source: Author's own.

After the completion of the conceptual ideas made in the Inventor and SmoothDraw4 software, the assembly of the solar tracker structure began. The development of the structure to fix the offset dish [Figure 16] shown in the blue part of Figure 10 began. This piece was made with angles and 1020 steel plates, which were welded.

Figure 16 – Fixing structure of the offset dish.

Source: Author's own.

The vertical support of the frame consists of a circular tube that is slightly curved at the top. This part was welded to a square profile and tube, for this it was necessary to make a reduction, the detail of which is shown in Fig. 17.

Figure 17 – Circle and square reduction.

Source: Author's own.

The lower part of the vertical support of the structure has an M6 screw with a tip that has been ground [Figure 18], to allow the rotation of the vertical support and at the end, the rotation of the entire structure.

Figure 18 – Screw responsible for the rotation of the solar tracker structure.

Source: Author's own.

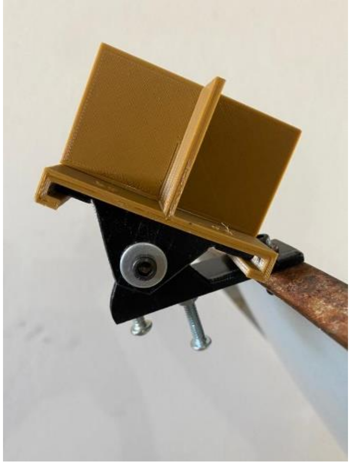
The base of the structure can be fixed in a place permanently, for this it was made in the development by a welded square plate anchored to a concrete mass. Four vertical M10 x 150 mm screws were welded to this plate to fix the base of the square structure (Fig. 19). At the base of the structure, four French hands and a central tube were welded, which is where the circular tube of the vertical support rotates.

Figure 19 – First steel plate.

Source: Author's own.

Obviously, the axis of the offset dish should point to the sun at all times, so a support was developed that should always be perpendicular to the axis of the dish. It is in this bracket where the LDR (*Light Dependent Resistor*) luminosity sensors were attached. The developed bracket is fixed to the dish by means of an M6 screw and allows adjustments of its inclination, as shown in figure 20.

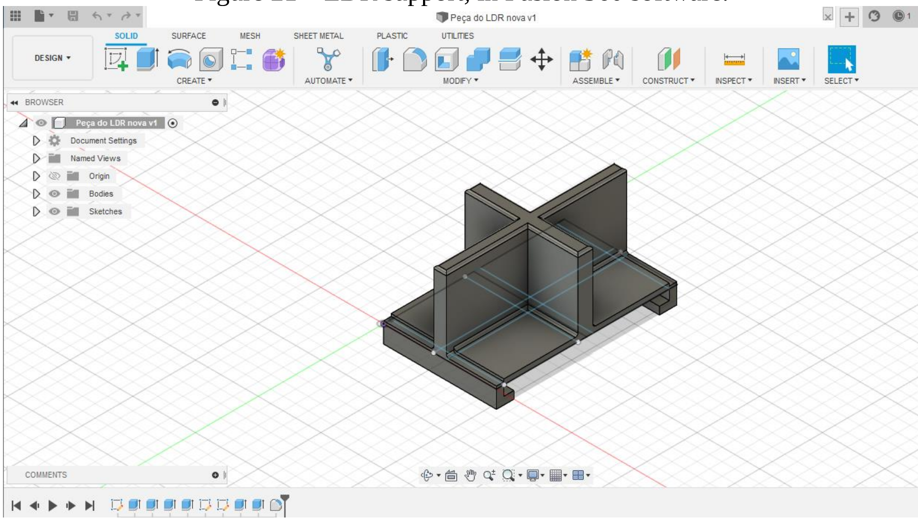
Figure 20 – LDR sensor support.



Source: Author's own.

It can be noticed that on the black metal structure there is a brown shader. This shader causes different luminosities that are read by the LDR sensors, which send signals to the Arduino board to move the motors. The shader was manufactured on the 3D printer, the model of which was made in the Fusion 360 software. A photo of this drawing is shown in figure 21.

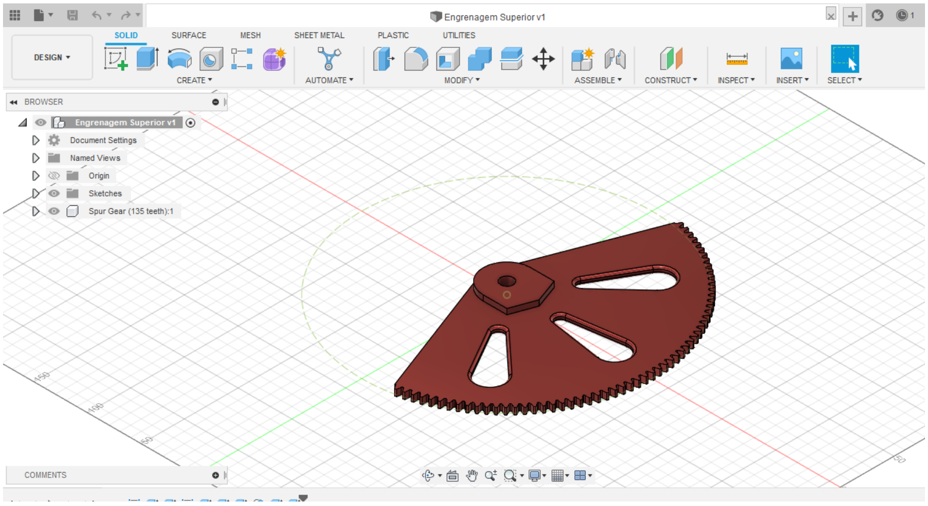
Figure 21 – LDR support, in Fusion 360 software.



Source: Author's own.

Other parts that were made in the Fusion 360 software were the gears [Figure 22], centering tube, and pins.

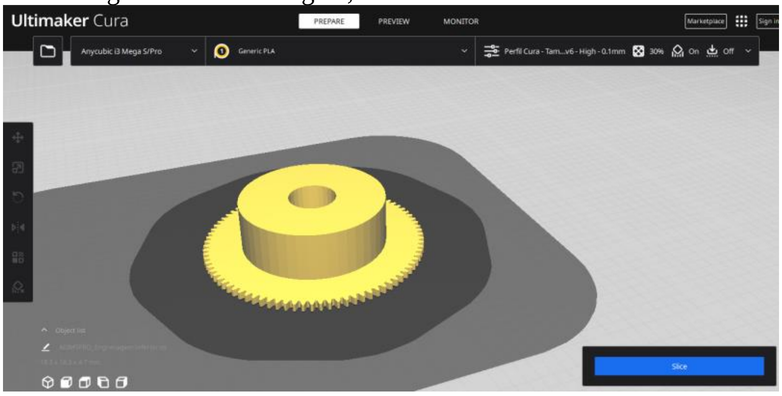
Figure 22 – Top gear, in Fusion 360 software.



Source: Author's own.

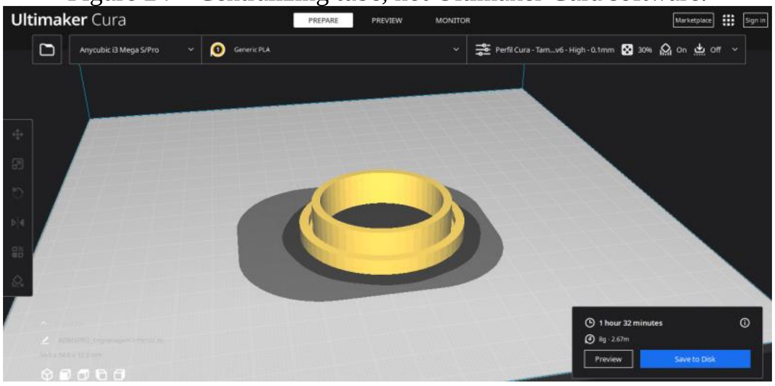
For all the pieces, a slicing process was carried out in the Ultimaker Cura software, where it is defined how many layers this piece will have, what will be the thickness of the line that the printer will print, the printing speed, among other parameters. Figures 23, 24 and 25 show pictures of the slicing program of the lower gear, the centering tube and the casing pin of the lower gear bore, respectively.

Figure 23 – Bottom gear, in the Ultimaker Cura software.



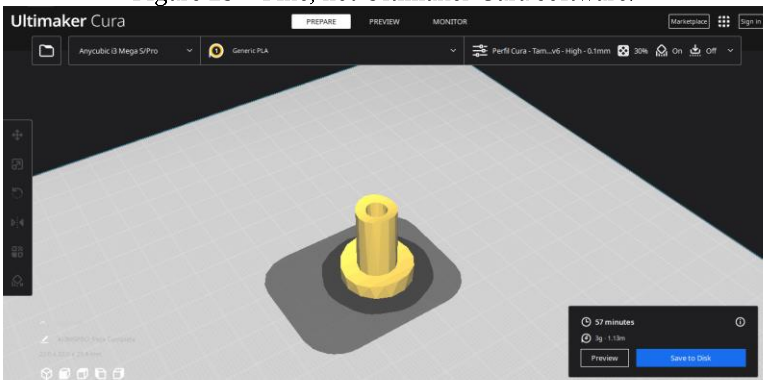
Source: Author's own.

Figure 24 – Centralizing tube, not Ultimaker Cura software.



Source: Author's own.

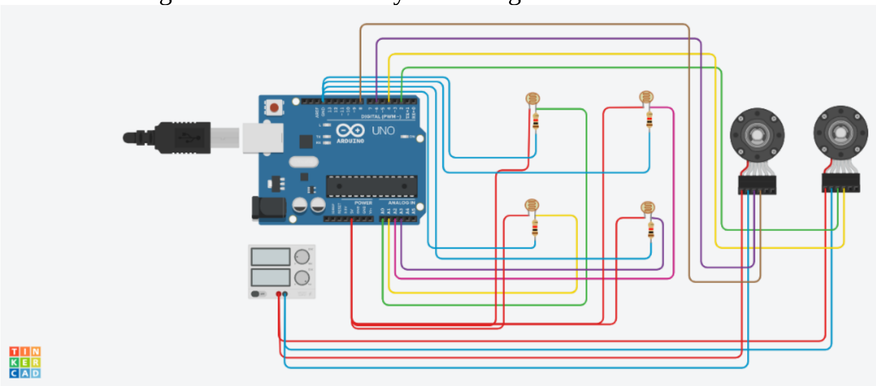
Figure 25 – Pine, not Ultimaker Cura software.



Source: Author's own.

When the mechanical part of the parts was finalized, the development of the electronic part began using the components in table 3. Initially, a virtual prototype was carried out. Thus, he used Autodesk's Tinkercad software to sketch the electronic system [Figure 26]. This figure shows the Arduino board, direct current source, LDR, motors and resistors, where these components are in charge of controlling the entire rotation part of the solar tracker.

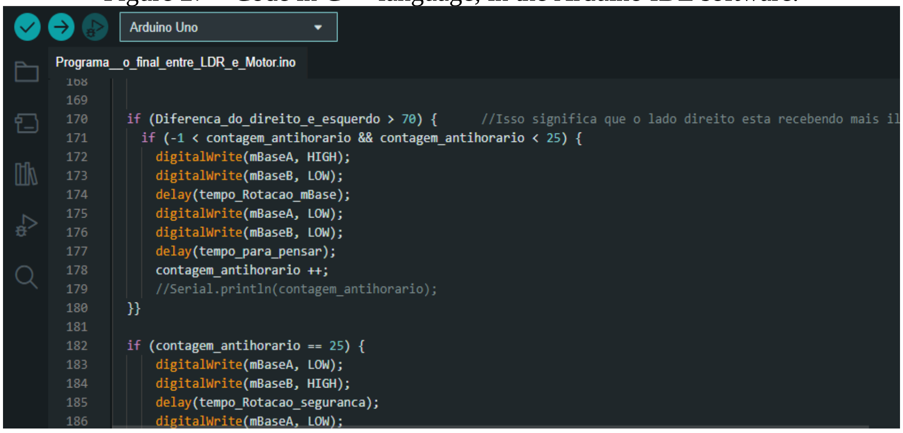
Figure 26 – Electronic system using Tinkercad software.



Source: Author's own.

After the electronic simulation, the code was developed in C++ language, which is responsible for the command of the solar tracker. This code was performed in the Arduino IDE software. In this way, functions such as "#define", "int", "pinMode", and "delay" were used to start the engines according to the signals coming from the LDR sensors. Figure 27 shows a portion of the code.

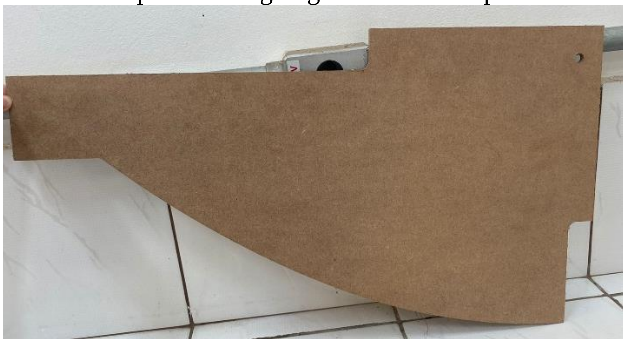
Figure 27 – Code in C++ language, in the Arduino IDE software.



Source: Author's own.

Another piece of equipment needed for the project was the CNC machine. In this, a part was machined that served as a template to align the LDR sensor holder to the parabolic axis. In addition, the jig has a parabolic profile to ensure the correct geometry and focal length of the parabola.

Figure 28 – Photo of the template for aligning the axis of the parabola to the LDR support.



Source: Author's own.

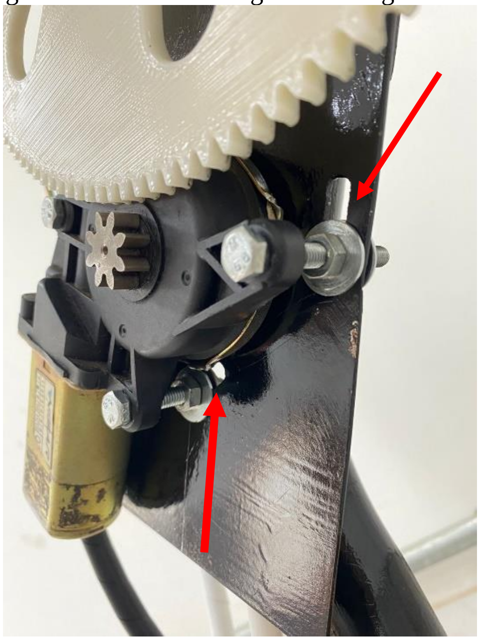
4.1 TWO-COMPONENT ADJUSTMENTS

Various parts of the structure allow adjustments to be made to achieve a better position, for example the LDR bracket allows you to adjust the correct ninety-degree angle between the axis of symmetry of the parabolic dish and the LDR bracket plate. Other adjustments are in the fixation of the motors to the support plates, where oblongs were made aligned with the motor holes [Figure 30] in order to fit the printed gear and the motor gear in a more practical way. You can also vary the height of the motor relative to the plate to align the motor gear faces and the printed component [Figure 31]. This variation is done with nuts and bolts.

Figure 29 – Adjusting the LDR bracket.

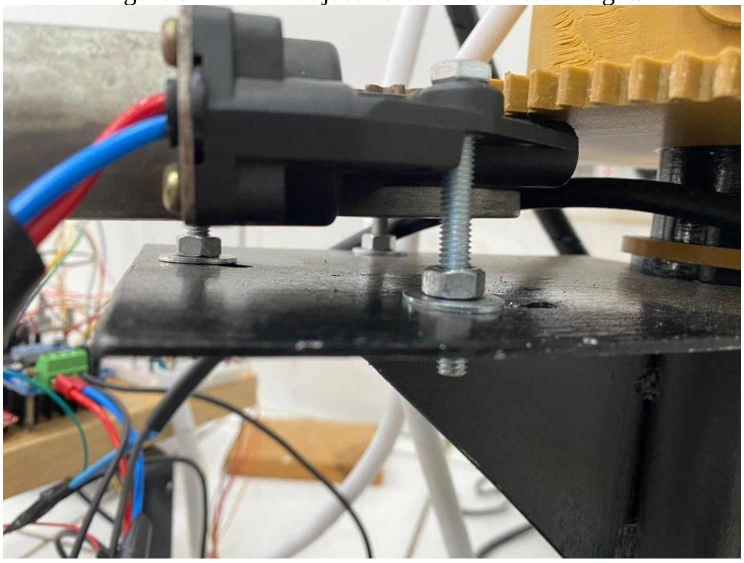
Source: Author's own.

Figure 30 – Radial oblongts of the engine holes.



Source: Author's own.

Figure 31 – Axial adjustments of the motor height.



Source: Author's own.

4.2 RESULTS AND DISCUSSIONS

When starting the tests with the LDR sensors, it was verified the need to place 10kΩ potentiometers to equalize the resistances at the same luminous intensity. It is interesting to mention that the wires that connect the LDR sensors to the potentiometers due to their length carry noise due to the interference of electromagnetic fields, and must have shielding.

Another problem found was in relation to the H bridge that serves to drive the motors, which must have a minimum capacity of 43A,

A short circuit was identified between the communication of the honeycomb power supply and the computer, because the honeycomb power supply was generating a different voltage for the motors and Arduino, in this way the microcontroller (Arduino UNO) damaged the COM7 port of the computer, generating reading errors and not allowing the computer to communicate between the software and the microcontroller,

During the testing phase, it was noticed that the solar tracker was sometimes lost during solar tracking and because of this the upper motor (responsible for the rotation of the horizontal axis) reached an extreme point that hit between the structure of the dish and the central structure (responsible for supporting the entire solar tracker), so it was necessary to place a limit switch both in the upper and lower parts [Figure 32 and 33], as they restrict the rotation of the dish to a maximum tracking point.

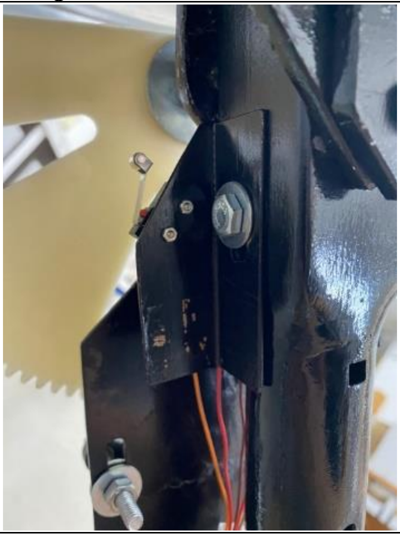
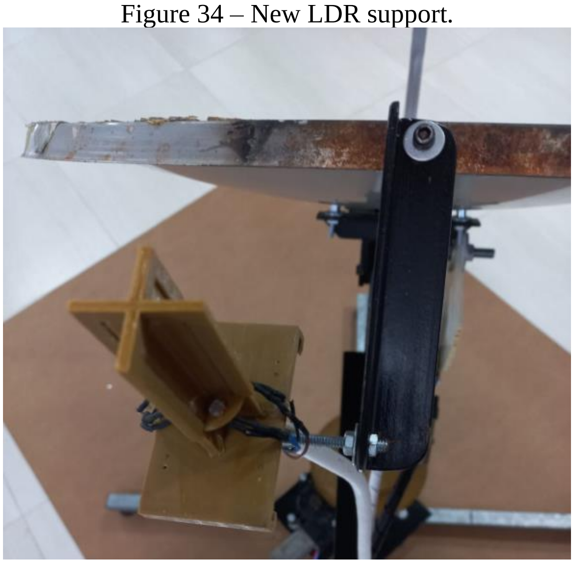
Figure 32 – End of higher education.	Figure 33 – Lower limit switch.
	
Source: Author's own.	Source: Author's own.

Figure 34 – New LDR support.



Source: Author's own.

When mentioning the shading in the LDRs, it is interesting to point out to place these photoresistors close to the walls of the LDR support, since if they are placed far from these walls, they will not shade enough to fully cover the photoresistors and will make the reading of the values inaccurate.

The project is complex and several difficulties have been solved. The solar tracker was put into operation in real conditions exposed to the sun and was working satisfactorily.

As a result, the design of the tracker that acts as a converter from solar energy to thermal energy was obtained, which was optimized according to the tests

5 CONCLUSIONS

When developing the project, it was found that the values of the LDR resistances were not the same, so it was necessary to use potentiometers instead of resistors with fixed values of 10K, because in this way it was possible to control the resistance and leave them the same. However, when the LDR values were checked on the serial monitor of the Arduino IDE software, it was seen that sometimes the values had a large oscillation and one of the factors responsible for this event was the presence of electromagnetic interference coming from our hands or electronic equipment.

Greater effort will be required to make available or eliminate some items manufactured in high-cost equipment, but this proposal has a good potential to become an economical alternative for the generation of medium and high temperature heating considering low-income populations.

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