Capability Development Document : solar tracker project

Jérémie Bondo, Az-edine Abouhafs

référent : Quentin Legros

Introduction and context

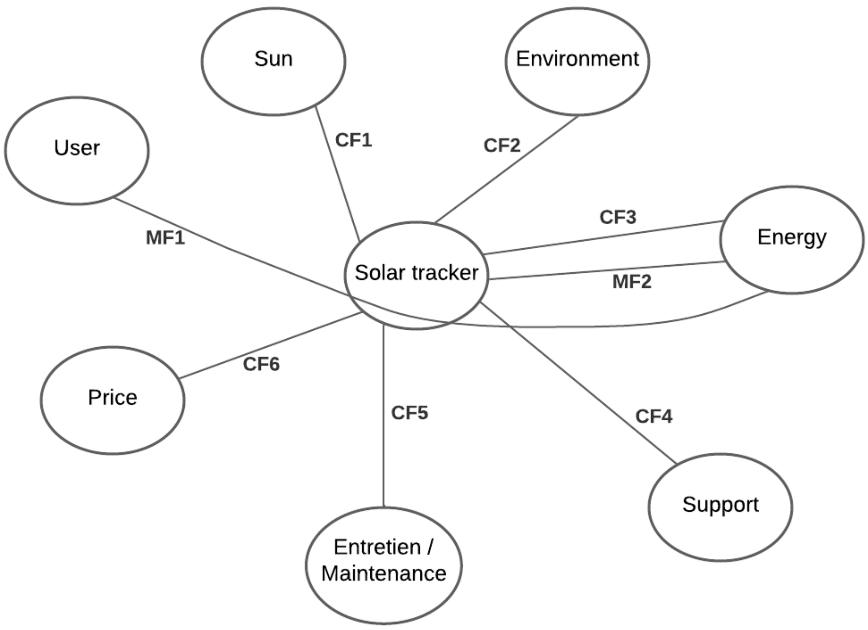
"The world cannot function without energy, and no progress is possible without it." - Thomas Edison.

In a world increasingly complex where humans constantly seek to push their limits, energy is at the heart of all debates. We want to continuously produce more and faster, and this frantic race cannot happen without energy. However, our production methods are not sustainable for the environment; what will become of us since our production is self-destructive? It is necessary to find new means of production, environmentally sustainable methods, and eco-friendly approaches. In this endeavor, we currently have energies known as renewable energies. These energies utilize our natural resources directly available on Earth, and these resources are renewable and therefore inexhaustible, unlike current methods that, for example, use fossil energy sources that pollute. Among renewable energies, there are wind, geothermal, hydraulic, and solar energies. The latter will be of interest to us in this report, as it is obtained through photovoltaic cells illuminated by light. However, a problem persists in solar energy: the Earth's spatial movement. Indeed, the Earth orbits around the sun throughout the year and also rotates on its axis. The Earth's first movement is called revolution, and it is responsible for the succession of seasons. Its second movement is the rotation on itself, called rotation, and this movement is responsible for the succession of days. To achieve optimal energy production, photovoltaic cells must be positioned perpendicular to the solar rays. Due to Earth's movements, a fixed photovoltaic cell plate does not receive the maximum amount of energy throughout the day. How can the annual energy gain be maximized ? One of the answers to this question is the solar tracker, an object that will be created throughout this report. This document will analyze the utility, use of the tracker, the implementation of its mechanism, and the human-machine interface created on which the evolution of our energy production can be observed.

Project synopsis

The project is simple: to manufacture a tracker capable of following the apparent movement of the sun in the sky. This project will be divided into three main parts: the 3D design of the model,the programming of the tracker's operation and the implementation of the human-machine interface. There is also an electronic component, but it will consist solely of wiring and soldering. These parts are interdependent, as without programming, the tracker does not move, and a flawed design will also result in the tracker not functioning correctly. These steps have been structured and planned according to a specific timeline, which can be found in the appendix (see appendix 1). Regarding resources, this project is led by two students, Az-eddine Abouhafs and Jérémie Bondo. You must have at your disposal electronic and computer equipment available, as well as a theoretical budget, here the budget is fixed on 100 euros. This project is not without risks; there are numerous risks at the programming level, in 3D design, and risks associated with the components. To successfully complete this project, these risks must be anticipated and resolved before they even arise. Each member has a specific role: Az-eddine Abouahfs is responsible for the implementation of the human-machine interface and programming, while Jérémie Bondo is in charge of the 3D design of the tracker.

Here is a functional analysis of the project with the main functions and constraints:



<u>spider chart</u>

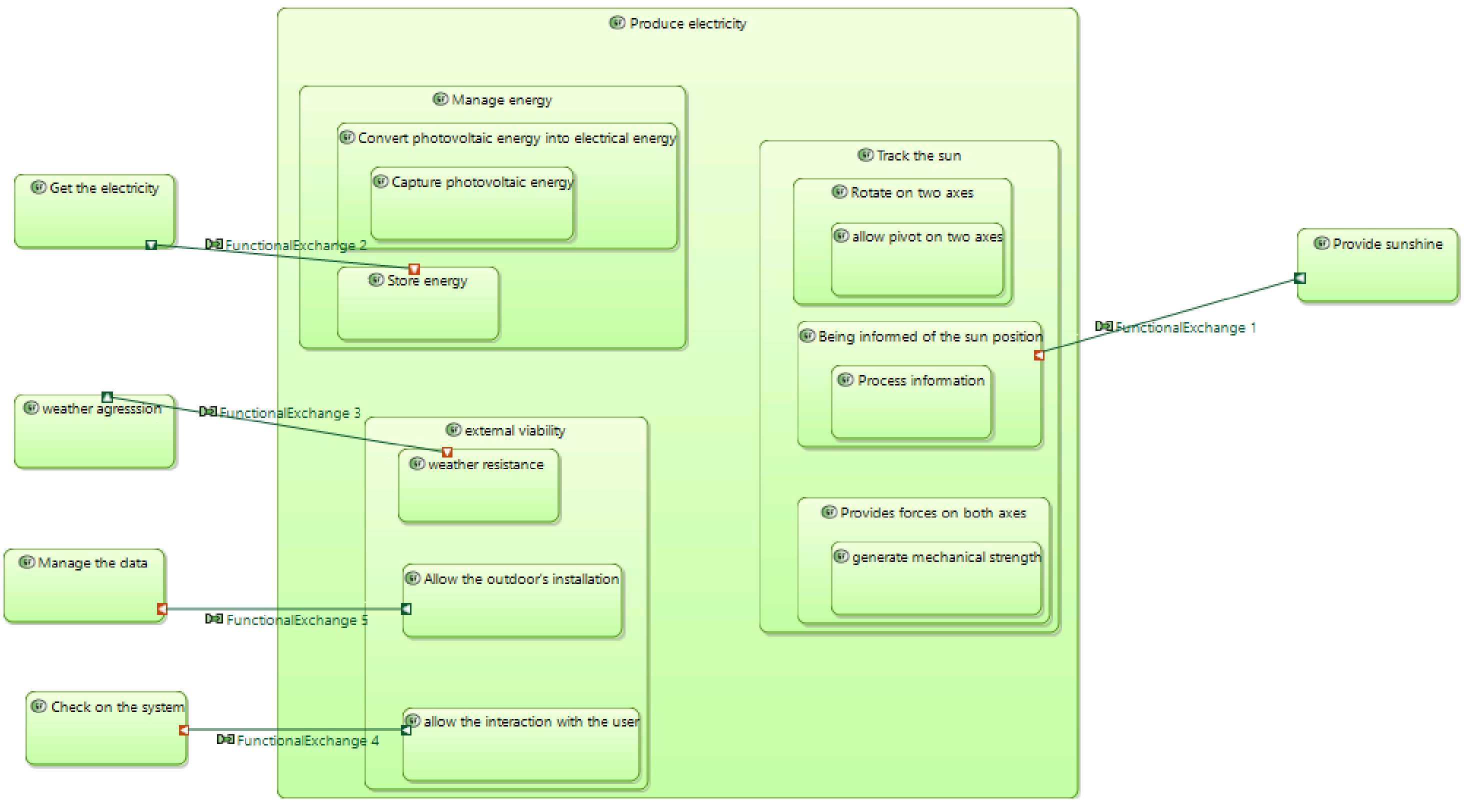
Service functions	**Assessment criteria**	**Level of appreciation**	**Acceptation limit**
MF1 : Produces and stores the energy	- Depending on the photovoltaic cells performance	0.5W/panel in a good day	-0.2W/panel
MF2 : Allows the user to recover the energy	- Energy level of the battery	2 x 3400 mAh	-25%
CF1 : Allows to be oriented towards the sun at all seasons	- Angle of rotation	110 degrees around the West/East axis	± 15 degrees
CF2 : Resists challenging weather conditions	-snow, rain, wind -temperature -humidity	-5°C à 40°C 40% à 70%	
CF3 : Self-control	- Autonomy	H24 – 7d/7	
CF4 : Carry/Protect the sensors and the card	- Structural stability - Durability - Ease of installation	PLA 6 months -1years	
CF5 : Maintain the system to ensure good performance	- Cleaning of panels -Repair of equipment	Once a month	
CF6 : Must be as cheap as possible	- Budget	100€	± 10€

Main functions and constraint functions of the solar tracker

1 System architecture

Capella, a powerful system engineering software, plays a pivotal role in shaping and implementing successful projects within the corporate landscape. Its utility and importance extend across various dimensions, making it an invaluable asset for project management and development. One of the primary advantages of Capella lies in its ability to provide a comprehensive and structured approach to system engineering. By offering a collaborative and model-based environment, Capella allows teams to design, analyze, and document complex systems with precision. This capability is particularly crucial in the early stages of a project, as it facilitates clear communication and alignment of objectives among diverse stakeholders.

Below is a detailed representation of the system architecture created using the Capella software :



Root system function on Capella

2 functional units

As mentioned earlier, the project is subdivided into three parts, which will themselves be functional units: the 3D design part, encompassing all rotation mechanisms; the computer part, involving the programming of the tracker and the human-machine interface part, where the system's operation can be visualized.

To set up these various functional units, you need parts, components. Before any choice you have to know how much your photovoltaic cells can produce. So in this example Jérémie took one of the cells and an amperemeter and he measured during the course of the day on the Monday ninth of October 2023, the production of current with his cells. You can see below the values he get on this table:

	Optimal orientation	Horizontal orientatio
heure	Max current in mA	Min current in mA
8h29	1,1	0,3
9h33	48,1	19,3
10h31	64,2	32,1
11h27	74,1	35,1
12h27	75,2	46,2
13h28	79,1	48,9
14h08	85,1	52
14h44	85,7	53,1
15h40	77,2	47,3
16h35	61,4	34
17h34	17,1	10,2
18h30	6,5	3,9
19h30	1,2	0,5

<u>Current obtained with a cells</u>

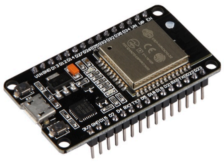
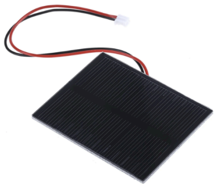
He chose two orientations, one horizontal where you would simply place our cells on the ground, and an optimal one where the tracker is always positioned at 90 degrees to the sun. Here are the solar data for this day :

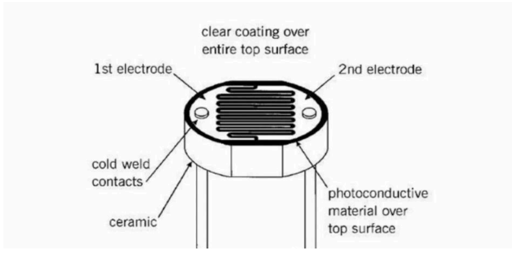
Dawn:	07:31:09
Sunrise:	08:01:46
Culmination:	13:39:37
Sunset:	19:16:41
Dusk:	19:47:14
Daylight duration:	11h14m55s
Distance [km]:	149,445,438
Altitude:	34.36°
Azimuth:	161.96°
Shadow length [m]:	1.46
at an object level [m]:	1

Solar data during Monday, October 9, 2023

The first essential components are the photovoltaic cells, of course this tracker will have 12 photovoltaic cells. Next, since the tracker should implement a human-machine interface, a microcontroller will be needed. To enable the tracker to move in space in different directions, two servo-motors will be needed as well as two ball bearings for smoother movement. Additionally, since you want to generate energy, it must be utilized. A regulator must be considered to maintain a constant voltage and charge or power any electronic device that will be connected to the system, and you also need three photoresistors in order to control the rotation of the motors.

Below are the various selected components along with their main characteristics:

 Figure : esp32 (gotronic.fr)		 Figure : Photovoltaic plates (Seeedstudio.com)		 Figure : Servo-Motor (Robot-maker.com)	 Servo-Motor, source : go-tronic.com	
esp32		**Power rating**	**0.5W**	**Tension**	**4,8 - 6,6V**	
Power supply	**5V**	**Current**	**100 mA**	**Torque**	**15kg.cm**	**10kg.cm**
Consumption	**70 mA**	**Dimensions**	**70x55x3mm**	**Rotation angle**	**180°**	**280°**
Programming language	**C, C++**	**Price**	**3,3€**	**Price**	**17€**	**14,65€**
Price	**20€**			**Weight**	**50g**	**65**
Weight	**7g**					

<table>
<tr>
<td colspan="2">
Figure : Voltage regulator (Aliexpress.com)</td>
<td colspan="2">
Figure : Ball bearing (123roulement)</td>
<td colspan="2">
Figure : Ball bearing (SKF.com)</td>
<td colspan="2">
Figure : Photoresistor (Gotronic.fr)</td>
</tr>
<tr>
<td colspan="2">Voltage regulator DC-DC</td>
<td colspan="2">Ball bearing, Nachi 6012</td>
<td colspan="2">Ball bearing, 12 YTF SKF</td>
<td colspan="2">Photoresistor</td>
</tr>
<tr>
<td>Input Voltage</td><td>3,2V - 42V</td>
<td>Inside diameter</td><td>60 mm</td>
<td>Inside diameter</td><td>12 mm</td>
<td>Current consumption</td><td><2mA</td>
</tr>
<tr>
<td>Output Voltage</td><td>1,25V -35V</td>
<td>outside diameter</td><td>95 mm</td>
<td>outside diameter</td><td>26 mm</td>
<td>Power supply</td><td>5V</td>
</tr>
<tr>
<td>Output current</td><td>3A (Max)</td>
<td>Price</td><td>19.34€</td>
<td>Price</td><td>19 €</td>
<td>Price</td><td>0,65€</td>
</tr>
<tr>
<td>Rendement</td><td>92%</td>
<td>Weight</td><td>200g</td>
<td>Weight</td><td>30g</td>
<td>Weight</td><td><2g</td>
</tr>
<tr>
<td>Price</td><td>0,6€</td>
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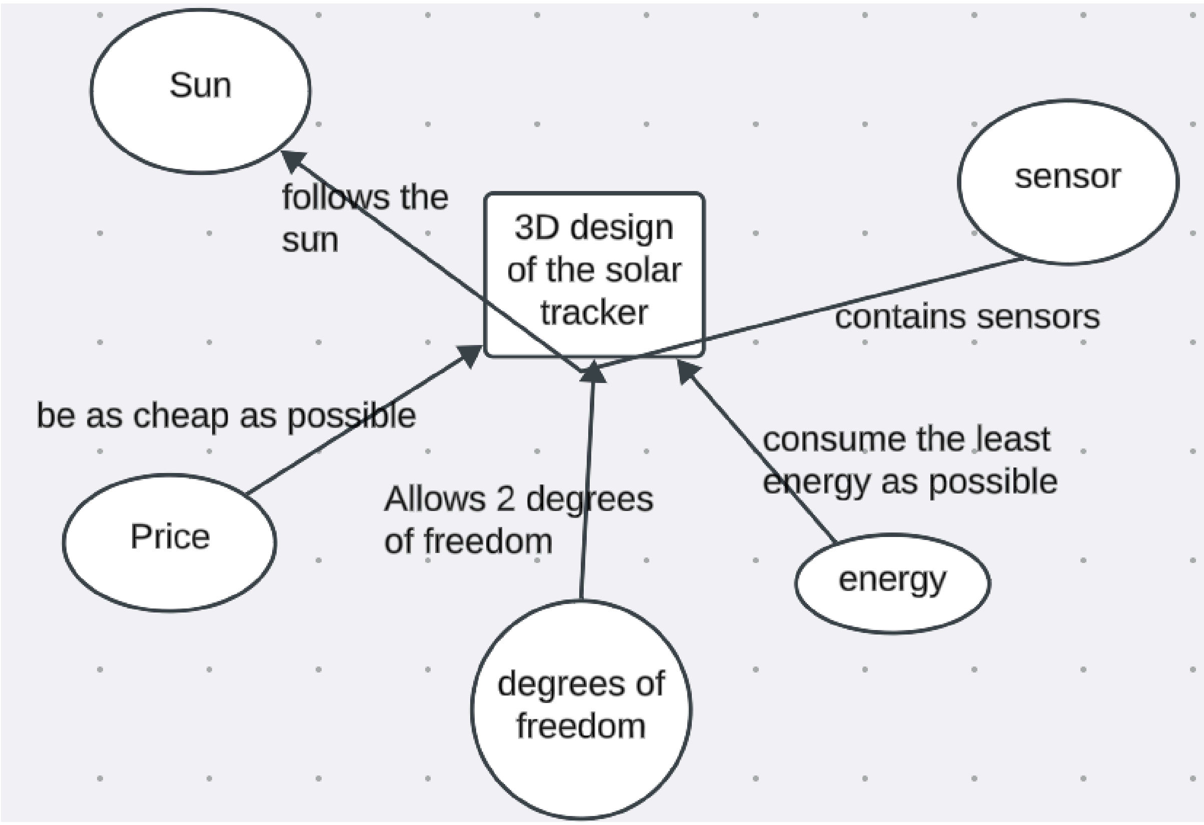
<u>Characteristics of the main components of the solar tracker</u>

You can find all the technical data sheets for the components in the appendix (see appendix 2).

2-1 3D Design

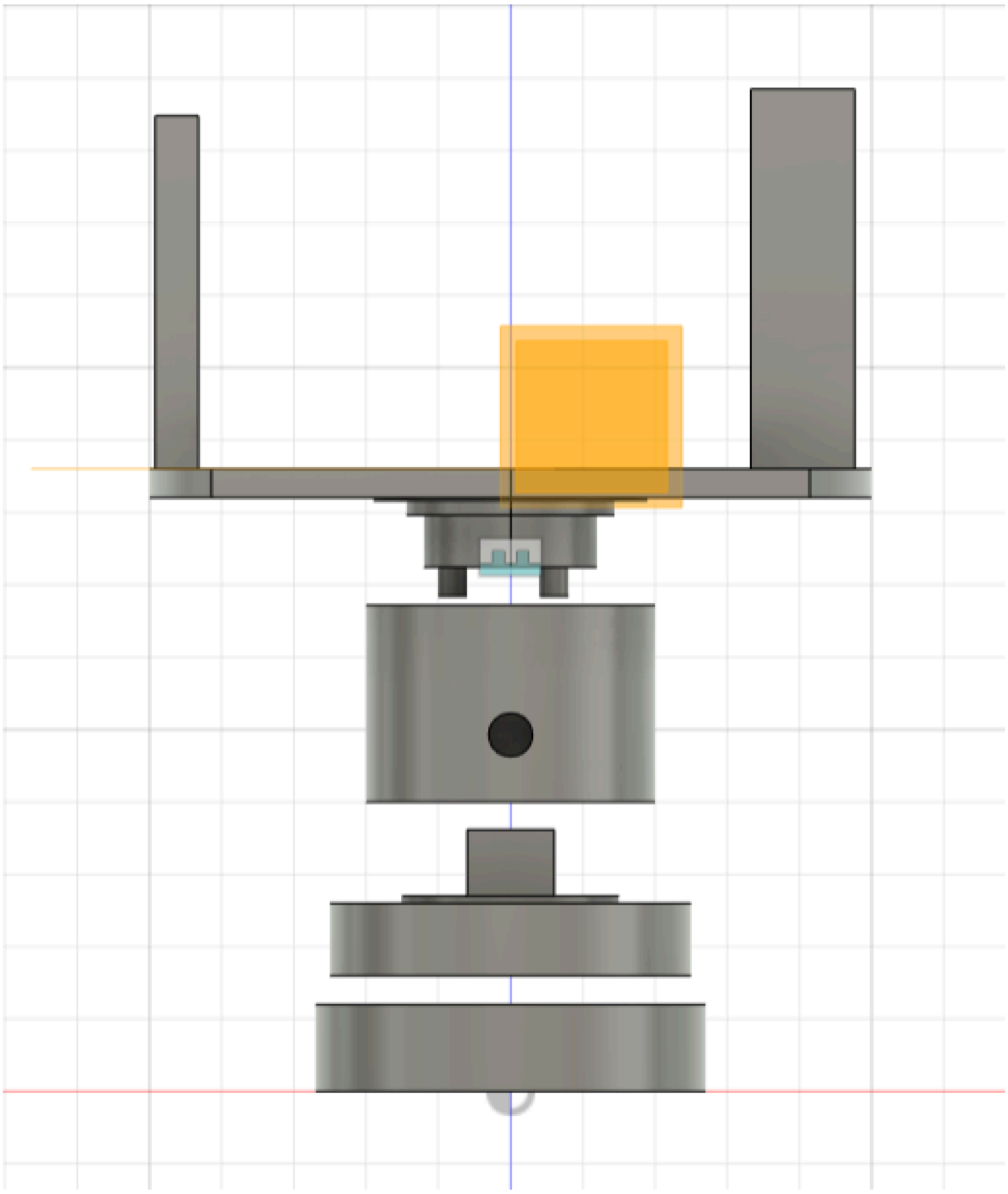
The 3D modeling of the tracker must be able to meet its objective, its main purpose: to be able to follow the sun with the minimum of energy consumption. Indeed, the model must be capable of rotating along two distinct axes to maintain itself at ninety degrees to the sun. To achieve this, the two motors and the two ball bearings mentioned earlier will be used. Additionally, as constraints on this functional unit, there are energy considerations; the 3D design of the motor should be as lightweight as possible to minimize the consumption of the two motors, the choice of material of the modeling is also an important point, the lighter the material the better. In addition the modeling must be as small as possible to complete this purpose. Because of the earth's movements on itself and around the sun, in order to follow the sun, the modeling must have two degrees of freedom. Finally, as another constraint, there is the climate. The 3D modeling must withstand daily weather conditions and should be as inexpensive as possible because there is the budget as mentioned before.

These functions can be found in the radar chart below :



Radar chart of the 3D design

After seeing all of this, an implementation was carried out as follows, with a motor inserted into the design:



3D view of the modelisation, on vision 360

As a test to be conducted, Some tests will be performed in the wind tunnel of the Vinci building at Polytech Orléans, where the model will be put to the test and see at what wind speeds it can withstand. Then, another significant test would be to test the rotation of the components along the two axes.

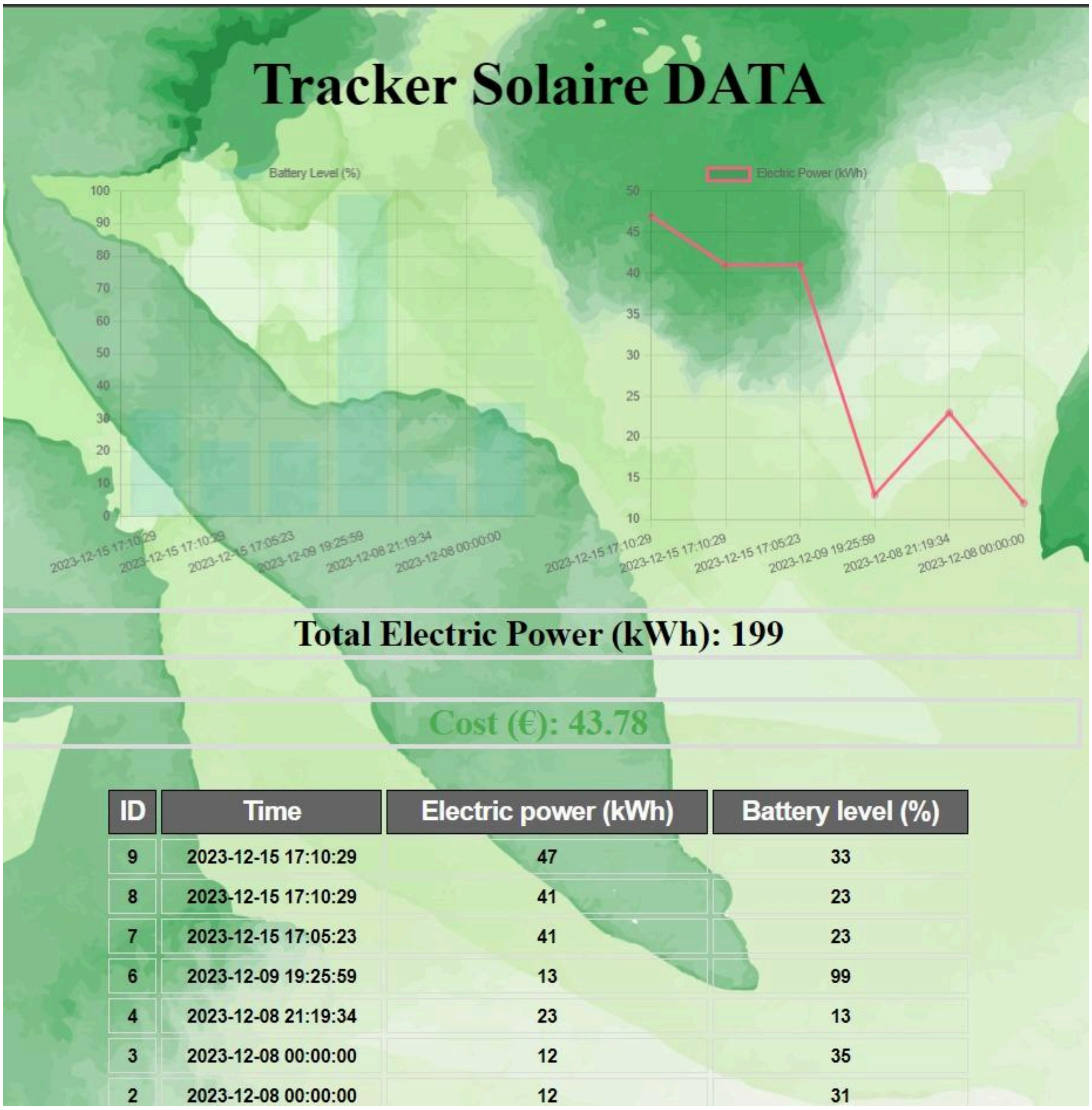
The choices in the modeling were the result of careful consideration. Having two "poles" supporting the upper part helps limit the workload of the upper motor. Additionally, the choice of using ball bearings instead of ball thrust bearings was made due to our budget constraint, as a ball thrust bearing is much more expensive than a ball bearing. Finally, since there are 12 photovoltaic cells, they must be arranged in a way that takes up as little space as possible. Therefore, the lower disc was designed so that it can contain the two poles supporting the 12 cells.

2-2 he human-machine interface

The Human-Machine Interface (HMI) plays a fundamental role in the development and use of computer systems by facilitating communication and interaction between users and machines. Its importance stems from several key aspects that contribute to enhancing user experience, operational efficiency, and overall satisfaction. A well-designed HMI simplifies the use of computer systems by making functionalities accessible and intuitive. It enables users, even without in-depth technical expertise, to interact effectively with software, applications, or devices, reducing the learning curve and minimizing potential errors. Additionally, an effective HMI contributes to increased productivity. By providing user-friendly and well-organized interfaces, it allows users to accomplish tasks more quickly and efficiently. Thoughtful design takes into account the specific needs of users, guiding them seamlessly through the system's functionalities, resulting in smoother use and increased productivity. Furthermore, the HMI plays a crucial role in reducing errors and inefficiencies. A clear and well-structured interface minimizes the risks of misinterpretation of information or improper use of functionalities. By providing immediate and understandable feedback, it helps prevent errors and quickly resolve issues, enhancing the reliability and precision of operations.

For all these reasons, the interface must be both as clear as possible and also as useful. There is a need in analyzing the user's needs to understand what they expect directly upon opening it. This is the interface of a solar tracker, so it would be most interesting to analyze its energy production over time. Additionally, other features can be integrated such as charging electronic devices. Indeed, by having the mAh capacity of the device, we can implement a function that could provide us with the required charging time for the device and also indicate the remaining charging time if they are, for example, batteries.

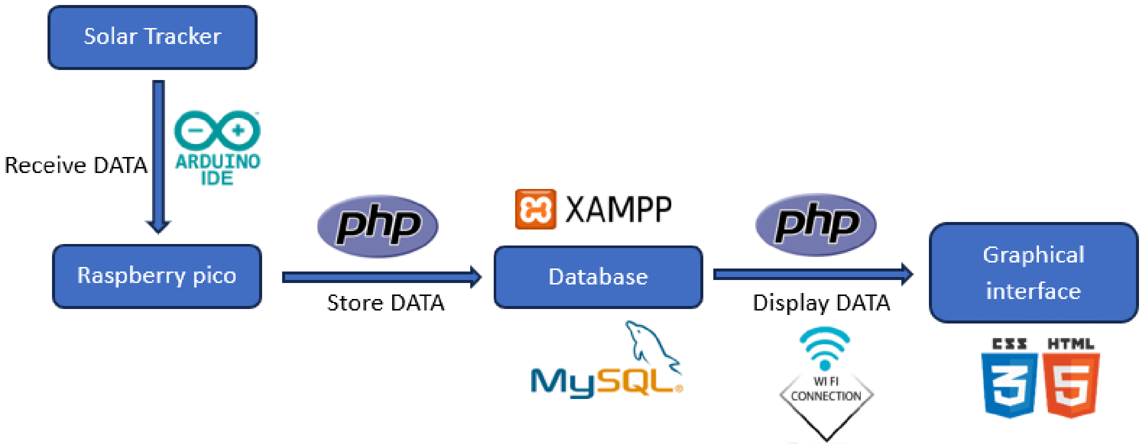
Below is an example of a created interface, where you can see direct data such as the current produced by the system as well as the battery level.



ID	Time	Electric power (kWh)	Battery level (%)
9	2023-12-15 17:10:29	47	33
8	2023-12-15 17:10:29	41	23
7	2023-12-15 17:05:23	41	23
6	2023-12-09 19:25:59	13	99
4	2023-12-08 21:19:34	23	13
3	2023-12-08 00:00:00	12	35
2	2023-12-08 00:00:00	12	31

Human-Machine Interface (HMI) of the solar tracker

To set up this interface, several diverse applications need to be used. The data is received on the Raspberry Pi, which has a code directly integrated into it to process and send the data. The data is then sent directly to a database created on Xampp. Afterward, the display of the data on the interface is done using HTML and CSS code. The image below summarizes the process of setting up the HMI.



Implementation of the HMI

This interface has been tested and is functional. It can be further enhanced with the functionality of charging electronic devices mentioned earlier, along with a graph displaying the energy produced throughout a day. You can find the codes in the appendices (see appendix 7).

These computer languages were the best in this case because they allow :

-Flexibility, indeed the combination of HTML, CSS, PHP, and Python allows maximum flexibility in HMI design. Each language plays a specific role, providing a solution tailored to its respective strengths

-Interactivity: The use of PHP and Python allows dynamic interaction with the user, real-time data manipulation, and adaptation of the HMI based on changing needs.

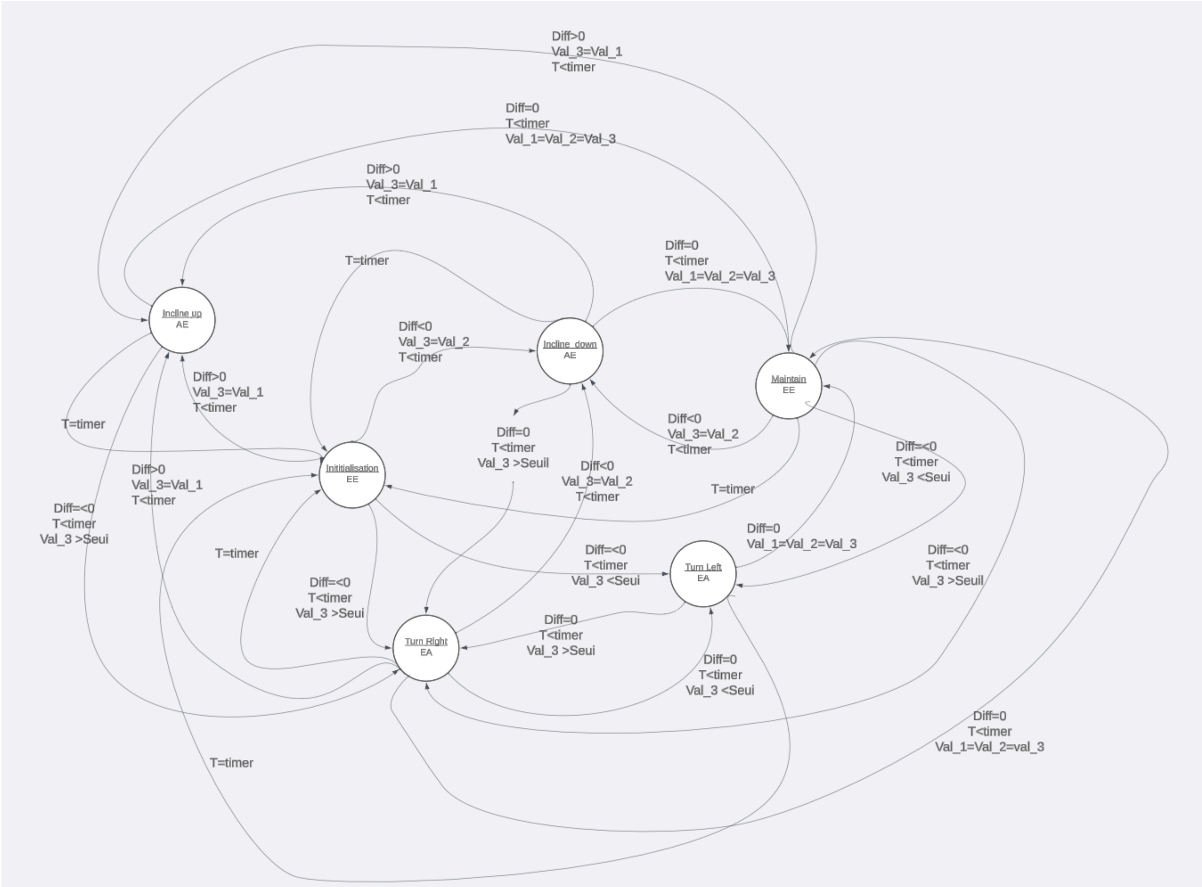
-Standardization: HTML and CSS are standardized languages widely supported by web browsers, ensuring broad compatibility and a consistent user experience.
-Processing Efficiency: PHP and Python offer powerful server-side processing capabilities, handling complex operations without overburdening the client's web browser.

2-3 the programming of the tracker

As mentioned earlier, the primary role of the tracker is to follow the sun and be constantly positioned at 90 degrees to the sun's rays. To achieve this, our motors will need to rotate at the correct angle, and this is done using a computer program. This complex program can be created using state machines. Indeed, the use of state machines holds significant importance in the development of computer programs, providing an organized structure and efficient management of the system's states and transitions. This approach offers several crucial advantages for software development:
-Clarity in Program Logic: State machines provide a clear visual and conceptual representation of program logic. By breaking down the system into states and transitions, they facilitate understanding of control flow, simplifying the design, maintenance, and debugging of the code.
-Structured State Management: State machines enable structured and orderly management of the different states in a system. Each state represents a specific condition of the system, simplifying the management of complex behaviors by dividing them into distinct logical steps.
-Maintainability and Scalability: The use of state machines simplifies software maintenance and scalability. By adding new states or modifying transitions, changes can be made in isolation, minimizing the risks of undesirable effects on other parts of the program.
-Handling Complex Cases: For systems with multiple use cases or scenarios, state machines offer an effective approach to manage complexity. They clearly represent different conditions and sequences of events, simplifying the handling of specific cases.
-Facilitation of Communication: The graphical representation of state machines facilitates communication among development team members. State diagrams provide a common

language to discuss program logic, reducing the risks of misunderstandings or divergent interpretations.

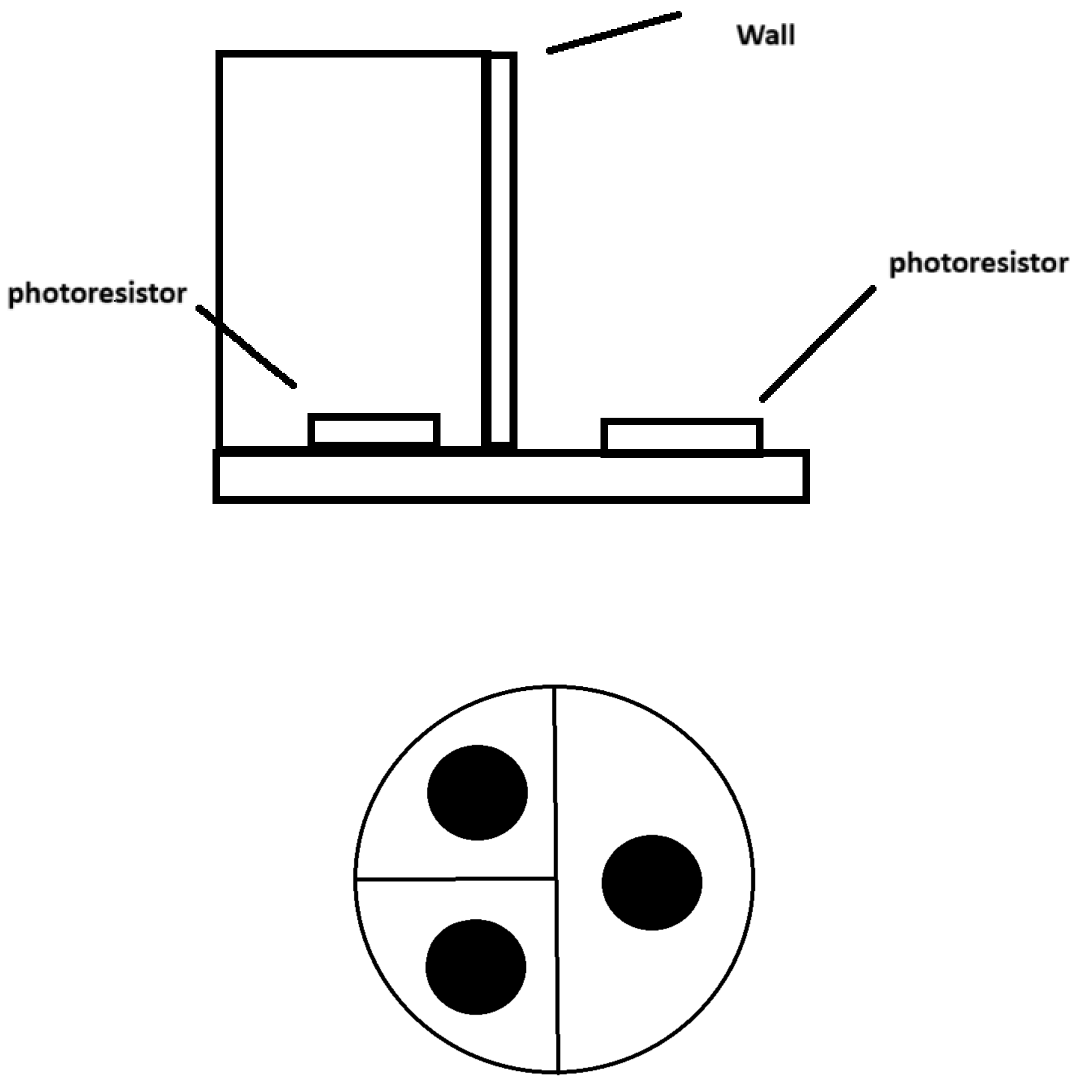
Using this design method, you can obtain the following state machine:



State machine for motor operation

You can see that the inputs here are the values provided by our sensors; there are 3 sensors. "Diff" represents the difference between the values of sensor 1 and sensor 2, "Val_3" is the value of sensor 3, "Val_2" corresponds to sensor 2, and "Val_1" to sensor 1. It is noteworthy that we have a timer, which operates as an interrupt. With the Raspberry Pi, you can retrieve the time and light intensity data throughout the day. When the light intensity is below a certain threshold at the end of the day by using the timer, the tracker returns to its initial position. The sun rises in the East and sets in the West, so normally the tracker will tilt in one direction throughout the day and return to the initial state at the end, unlike the "turn" states that follow the seasons, where the tracker will rotate in one direction and then in the other. The "Diff" value will mainly determine whether the tracker tilts or not, while "Val_3" will be responsible for its rotation. The "Maintain" state is when the tracker is stationary and does not move. The positioning of the sensors is as shown below. You must also be careful about the tracker placement because depending on its positioning, the entire program changes.

This program runs every 30 minutes because the rotation of the sensors consumes a significant amount of energy. You can find in annex XX the corresponding code, with the microcontroller you can go on the internet and get information, in this code a function to get the current season and activate the tracker has been created. Then the tracker sends information to the database.



Placement of the photoresistors, paint

3 - Risk analysis

The project is not without risks, as there are numerous parameters and potential failures to consider in the completion of the solar tracker. The first risk is a poor 3D modeling, which is the core of the project; a failure at this level can impact:

-The precision of Mechanisms: Inadequate 3D modeling can lead to errors in representing the rotation and tilt mechanisms of the solar tracker. This can directly affect the tracker's ability to effectively follow the sun's path, compromising the system's performance.

-The compatibility of Components: Incorrect modeling may result in compatibility issues among various components of the tracker, such as motors, bearings, and sensors. This could lead to malfunctions during the actual assembly of the tracker.

- On the energy Production: If the modeling does not accurately consider seasonal variations and solar movements, the energy production of the solar tracker may fall below expectations. This could jeopardize the profitability and efficiency of the project.

-Additional Costs: Errors in 3D modeling can result in additional costs associated with necessary adjustments or delays caused by corrections needed in the design. This can impact the overall project budget.

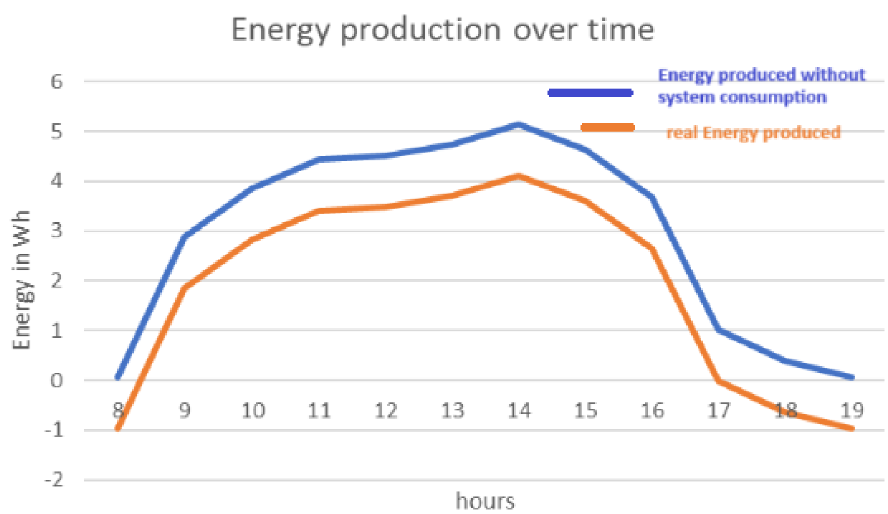
Additionally, there are project-related risks, such as delays in component deliveries and team coordination problems. Communication or coordination difficulties among team members could impact the project's progress. Finally, there are technological risks, such as electronic hardware failure. Electronic components may experience dysfunction, leading to solar tracker malfunctions, while interference and communication errors between sensors, the microcontroller, and motors could compromise solar tracking.malfunctions

4 Cost and Expected results

Finally with all the informations of the components, you can obtain the total cost of the tracker like this :

Désignation	Quantity	Unit price (euros)	Total
Photovoltaic cells	12	1,95	23,4
Raspberry pico	1	9,5	9,5
Servo-motor 1	1	17	17
Servo-motor 2	1	14,65	14,65
Voltage regulator	1	0,65	0,65
Ball Bearing 1	1	19.34	19,34
Ball Bearing 2	1	5.24	5.24
3D printing	40	2	80
Total			169.78

After all this functional analysis, by performing some calculations using the measurements shown above, and considering the nominal energy consumption of the motors, it is possible to obtain the energy production over a day of the solar tracker as follows:



Energy production over the course of the day on the 9th October 2023 in Orléans

We can see in blue the energy produced, that is only the energy that the photovoltaic cells provide to the tracker, and in orange, the energy supplied by the entire tracker assuming activation for 3 minutes every 30 minutes of the system. During this day, if the tracker is positioned at ninety degrees to the sunlight throughout the day, it can produce 24.961 W. As said previously the tracker costs 169.78 euros, in France the price of the kWh depends, on some factors but let's consider a fixed price at 0.2561 euros for one kWh, with some mathematics you can obtain the investment recovery date :

$$Energy\ production\ over\ a\ year\ in\ kWh:\ 24.961\ \times\ 365\ \times\ 10^{-3} = 9.11\ \text{kWh}$$

$$ROI:\ \frac{169.78}{9.11\ \times 0.2561} =\ 74\ years$$

It is disappointing because 74 years is a whole life for a human being, this can be explained by the price of the tracker which is very expensive in comparison to others with the same number of photovoltaic cells.

5 Business analysis

Let's talk about the economic aspect of the project, building a solar tracker needs economic resources, as said previously this project has a budget of 100 euros, the tracker costs 89.78 euros (without the 3D impression). The main point of this tracker is the 3D modelisation, indeed at a “little scale” the tracker is quite expensive in comparison to other tracker that you could find on Amazon, AliExpress or AliBaba but its modelisation allows it to support more weight and have a better stability. On the 3D modelisation there are two pillars which will maintain the plate on which the photovoltaic cells will be fixed, furthermore the two pillars are fixed on a rotating plate which give the structure an extreme stability. Here the two students tried to build a tiny tracker we consider as a prototype to something much bigger which can produce way more energy. This bigger tracker could be commercialized in order to get profit. So how to do it ?.

The main goal here is to enlarge the structure with quality materials which could resists outdoors conditions, the PLA is not viable because of the sun and the localisation of the tracker (the tracker must be placed in a sunny place) aluminum is a good substitute for it because it is light, resistant, inexpensive and malleable. The amount of kilograms of aluminum needed depends on the metallurgy company which will do the modelisation, according to a technician, 80 kg would be enough but inform yourselves before anything, furthermore you will have to model all this aluminum it is possible to ask to a metallurgy company. The photovoltaic cells must be replaced with others bigger and more productive ones, you can find on some websites such as TopRegal.com ou Besled.fr. You can find in annex the chosen cells (cf annex 11) In order to have an homogeneous structure, it’s better to have an even number of cells, four for example.

Concerning the motors this is a little bit more difficult, because here we have a bigger tracker with bigger components so we have to find two bigger motors which are able to make the structure rotate.

The motors will have the weight of the cells, the structure and for one of the motors it will have to support the weight of the other. So how to choose ?

The first motor, the "lower one" will have around 186 kilograms to rotate, this is the weight of the cells, the support of the cells and the second motor. In order to accomplish the rotation its couple must respect the following equation :

$$Couple \geq I \times angular\ acceleration$$

with I : inertia

In general the angular velocity of the motor is written in "rpm" rotation per minute, let's convert, if *R* is the rpm so :

$$rotation\ speed\ (in\ rad/s) = (R \times 2\pi\ rad) \div 60$$

The speed of the servo motor can be chosen so there is no particular problem here, the tracker won't have to adjust himself as fast as possible so *R* can be very small to be able to respect the relationship, for example *R* = 0.2 so the system will do one rotation in 5 minutes

$$rotation\ speed = (R \times 2\pi\ rad) \div 60 = 0.02094\ rad/s$$

$$angular\ acceleration = rotation\ speed / 60 = 3.49 .\ 10^{-4} rad/s^2$$

$$Inertia = \frac{1}{2} mr^2\ for\ a\ cylindrical\ object$$

Here let's consider the cells and the support as a cylinder of radius r 2 meters

$$Inertia = 372\ kg.m^2$$

So the couple needed on this motor is :

$$Couple = 3.49 .\ 10^{-4} \times 372 = 0.1297\ Nm$$

For this motor, the Nema 17 on the website stepperonline.com would be fine because it has a couple of 36 Ncm so 0.36 Nm it would be able to rotate the system and it is note expensive in comparison to others with the same couple as the Nema 17 serie iCL on the same site.

For the second motor, the "upper one", the equation to be verified is the same. It will have the weight of the photovoltaic cells, the upper support on the rotation so around 106 kg. On the 3D modelisation the upper part with the photovoltaic cells can be considered as a rectangle with those dimensions : length = 3.42 meters, width = 2.2 meters and thickness = 15 cm. Those mensurations are the result of the positioning of the cells and the support. So let's do some calculation :

$$Inertia\ for\ a\ rectangle\ =\ 1/12\ \times\ m\ \times\ (l^2+\ L^2)\ =\ 176.90\ kg.m^2$$

The rotation speed is the same here (0.2 rpm) :

$$rotation\ speed\ =\ (R\ \times\ 2\pi\ rad)\ \div\ 60\ =\ 0.02094\ rad/s$$

$$angular\ acceleration\ =\ rotation\ speed\ /\ 60\ =\ 3.49\ .\ 10^{-4} rad/s^2$$

$$couple\ =\ 176.90\times 3.49\times 10^{-4}\ =\ 0.0620\ Nm$$

With those specifications, it's possible to find a good servo motor and not expensive, on the website stepperonline.com you will find every type of servo motor, as the Nema 11 with a torque of 7 Ncm (around 0.07 Nm) it will be possible to make the system rotate and it is very light it has a weight of 110 g you can find it's specifications in annex (cf annex 13)

The rest of the components are quite the same with the little tracker, it keeps the same system of tracking but it can be improved. Indeed the ball bearings must be upgraded because there will be more weight on them, here it is the static and dynamic load values which are important. On the "lower" ball bearing which will be connected with the "lower" motor, there will be all the weight of the structure, the structure has a mass around 186 kilograms so the weight exerted will be around 1825 so 1.825 kN in order to respond to this need the ball bearing NSK 61800TN will correspond perfectly, you can find its datasheet below (cf annex 14).

For the second ball bearing the "upper" one it will have the mass of the cells and the upper structure to support, around 106 kilograms, so the weight exerted on it would be half the total weight (because the 3D modelisation reduces the weight on the motor with two pillars). Indeed it would have around 520 N to support, in order to respond to this need the ball bearing Rs-Pro 618-9957 will correspond, you can find its datasheet below in annex (cf annex 15). The microcontroller remains the same, but the regulator must be upgraded, indeed the regulator of a generator will correspond easily.

In order to create a business or a company transport and storage must be taken into account, concerning the transport from the manufacturing company to the storage company there are a lot of options DHL, UPS, FedEX, or you could do it yourself by renting a truck. This last solution is probably cheaper. In addition, for the storage of the trackers and the components you could use Amazon, it is a worldwide company located in all the areas of the globe they probably have a warehouse near your city. The advantage of Amazon is that they ensure the visibility of the product, store, sell and do all the accounting in exchange of 15 percent of your benefices. Furthermore if your company will be located in France you will have to take into consideration the taxes. Here is the probable total cost of this bigger tracker :

	quantity	unit price	mass (kg)	total
photovoltaic cells	4	65	24	260
motor 1	1	9.58	0.110	9.58
motor 2	1	27.34	0.60	27.34
aluminium	80	0,3	80	24
tracking	1	10	2	10
Manufacturing	1	120		120
transport	1	150		150
ball bearings	1	14.74	0.116	16.56
microcontroller	1	20	0.020	20
regulator	1	5	0.146	5
ECO-WORTHY Batterie Lithium 12V 280AH	2	580	11	1160
total				1765.56

But here you want to make a profit, so you have to sell it for more, 2000 euros for example. This price is chosen in comparison with other trackers on the market. Indeed you can see in the following board some options for solar trackers :

Caracteristics	lumio	TOPREGAL	ILIOS
Price	12000 €	1321 €	2000 €
photovoltaic cells	7,2 m2	11,22 m2	7,48 m2
Tracking	Yes (2 axis)	No	Yes (2 axis)
HMI	Yes	No	Yes
Installation	Yes	No	No
Custom products	No	No	Yes

You can observe that a real solar tracker as the one which is provided by “Lumio” is very expensive, this option contains the installation and the maintenance, “TopRegal” provides a second option with cells without a tracking method but the surface is almost equivalent to the tracker which is being created here by the fictive company “Ilios”.

By considering the nominal current consumption of the motors and by making a production analogy with the small tracker, we can estimate the energy production :

hours	little tracker	bigger tracker
8	5,5	20,79346558
9	240,5	909,2415403
10	321	1213,582264
11	370,5	1400,723454
12	376	1421,516919
13	395,5	1495,239207
14	428,5	1620
15	386	1459,323221
16	307	1160,653442
17	85,5	323,243874
18	32,5	122,8704784
19	6	22,68378063

Analogy of energy production of the big tracker by using the little one

Here the maximum energy produced of the little tracker during the day was used as a reference for the photovoltaic cells of the big tracker. So over the course of a day the big tracker can produce around 11169 W, with some calculations the date of return of investment can be obtained :

$$Energy\ production\ over\ a\ year\ in\ kWh:\ 11.169\ \times\ 365\ \times\ 10^{-3}$$=4077 kWh

$$ROI:\ \frac{2000}{4077\ \times 0.2561} =\ 1.9\ year$$

So we can see that on a larger scale the system is much more efficient and we have a better return on investment.

Conclusion

In conclusion, this report has thoroughly explored the construction of a solar tracker, an ambitious project subdivided into three main parts: mechanical modeling, the development of the human-machine interface, and the programming of the sensor. Each step has been carefully examined to ensure the accuracy, functionality, and efficiency of the solar tracker. Mechanical modeling formed the core of the project, requiring special attention to ensure the accuracy of the rotation and tilt mechanisms. Achieving adequate 3D modeling was identified as crucial to avoid potential risks related to component compatibility, mechanical resistance, and energy production. The human-machine interface was designed with the end-user in mind, offering a clear and informative visualization of energy production, as well as the ability to recharge electronic devices. This interface is a crucial element to ensure smooth interaction with the solar tracker and maximize its utility. Sensor programming, done with state machines, was precisely developed to allow the tracker to effectively follow the sun. Planned tests, such as those in the wind tunnel, are crucial to assess the model's resistance to environmental conditions and ensure the correct rotation of components along the two axes. By addressing potential risks, we identified organizational, modeling technical, and electrical and electronic risks. These risks were anticipated in the project planning and management process, demonstrating our commitment to the success of the solar tracker.

In summary, this project reflects our commitment to sustainable innovation by harnessing renewable energies efficiently. The solar tracker is designed to address current challenges in energy production while anticipating and mitigating potential risks. A solar tracker is a good system to maximize your energy production but is not the only one. Indeed there are a lot of possibilities depending on your location, thermal activity, water points, average air flows … Concerning the solar tracker there are an infinity of ways to create it, in annex 17 there is a list of all the possible ideas of the group.

Annexes table

Annex 1 : datasheet of the servo-motor BMS-620 MG

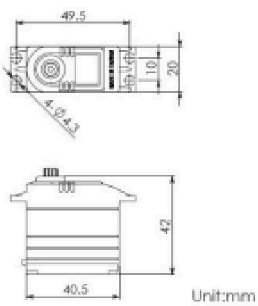
You can find the forecast schedule on Celene on the space of Jeremie Bondo.

Annex 2 : datasheet of the servo-motor BMS-620 MG

Blue Bird Technology Co., Ltd.

Item No.:BMS-620MG
Date: 2020/4/14

Particular Specification

Item No	BMS-620MG
Weight (gram)	51 g / 1.8 oz.
Size (mm)	40.5 x 20 x 42 mm / 1.59 x 0.79 x 1.65 in.
Torque at 4.8V	9.1 kg-cm / 126 oz-in
Torque at 6.0V	10.6 kg-cm / 147 oz-in
Speed at 4.8V (sec/60° at no load)	0.15 sec
Speed at 6.0V (sec/60° at no load)	0.13 sec
Ball Bearing	Yes. Dual
Metal Gears	Yes
Motor Type	3 Pole Motor
Analog / Digital	Analog
Operating Voltage Range	4.8V to 6.0V
Operating Temperature Range	-20°C to +60°C
Idle Current	3mA
Running Current	4.8V 170mA / 6V 180mA
Stall Current	4.8V 2350mA / 6V 3020mA
Dead Bend Width	3us
Direction	Clockwise / Pulse Traveling 1500 ~ 1900us
Horn / Gear Spline	25 teeth
Connected Cable Length	300 mm / 11.81 in.
Connectted Housing	JR system
Power Push Chips	Mos-FET
Wire Info	Brown Wire = Battery Negative
	Red Wire = Bettery Positive
	Orange Wire = Signal
Product Picture / Dimension Sketch	 

Annex 3 : datasheet of the servo-motor S06NF

S06NF STD

UPC : N/A **Model :** **Qty. :** 1

Package:

One polybag one piece

Description:

56.0gwith torque 13.0kg-cm (6v) 13.5kg-cm (7.2V);wire: 30cm Metal Gear Servo.

Feature:

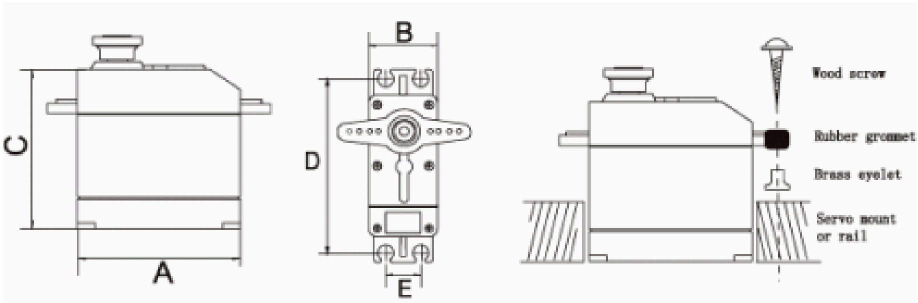
- Futaba, JR, Sanwa and Hitec compatible.

Important Notes:

- Specify the connector type when you purchase the servo.
- Refer to the figure when installing the servo accessories.
- For engine powered airplanes and boats, rubber must be used to reduce vibration.
- Please choose correct model for your application.
- Torque over-loaded will damage the servo's mechaniSM-.
- Keep the servo clean and away from dust, corrosive gas and humid air.

Specification (Specifications are subjected to change without notice.)

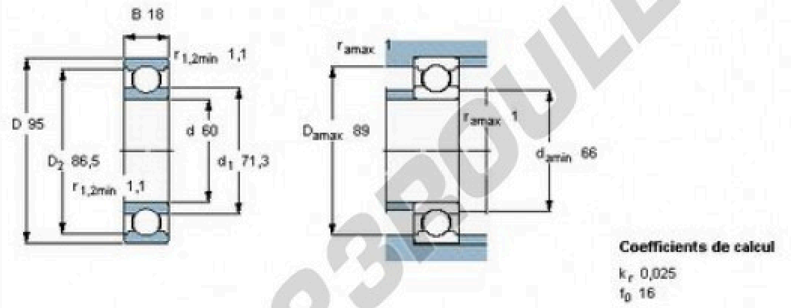
Wire (cm)	Size (MM)					Weight		6V			7.2V		
								Speed	Torque		Speed	Torque	
	A	B	C	D	E	g	oz	sec/60°	kg-cm	oz-in	sec/60°	kg-cm	oz-in
30.0	40.4	20	37.6	48	10.0	56.0		0.18	13.0		0.16	13.5	



RoHS CE

Annex 4 : datasheet of the ball bearing Nachi 6012 SKF

Dimensions d'encombrement			Charges de base		Vitesses de base		Désignation
			dynamique	statique	Vitesse de référence	Vitesse limite	
d	D	B	C	C_0			* Roulement SKF Explorer
mm			kN		tr/min		-
60	95	18	30,7	23,2	15000	9500	**6012 ***



Annex 5 : datasheet of the ball bearing FY 12 TF SKF

FY 12 TF

Palier complet à billes à applique carrée avec blocage par vis, palier en fonte, ISO

Ces paliers roulements-inserts à applique carrée sont conformes aux normes ISO. Ils sont constitués d'un roulement-insert, avec une bague intérieure débordante et un blocage par vis de serrage, et conviennent pour des applications où le sens de rotation est constant ou variable. Le roulement est monté dans un palier en fonte, qui peut être boulonné à la paroi ou au châssis d'une machine. Les paliers roulements-inserts peuvent admettre un défaut d'alignement initial modéré mais ne permettent normalement pas de déplacement axial.

- Résistent à de hauts niveaux de contamination
- Conçus pour des températures et vitesses élevées
- Supportent des charges relativement lourdes
- Économiques

Overview

Dimensions

Diamètre d'arbre	12 mm
Largeur globale du palier	26 mm
Largeur totale	32.9 mm
Entraxe des trous de boulon	54 mm
Largeur de roulement, totale	27.4 mm

Performance

Charge dynamique de base	9.56 kN
Charge statique de base	4.75 kN
Vitesse limite	9 500 r/min
Note	Vitesse limite avec tolérance d'arbre h6

Propriétés

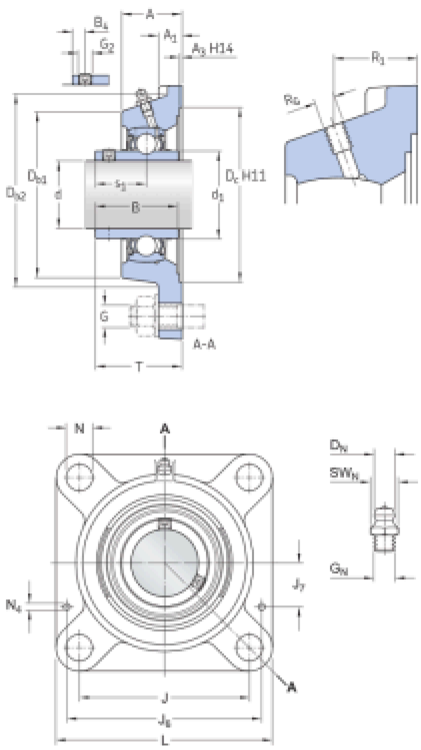
Type de palier	Applique
Type de palier applique	Carrée
Nombre de trous de boulon des dispositifs de fixation	4
Type de trou du boulon de fixation	Lisse
Dispositif de retenue, bague intérieure	Vis de réglage
Type d'alésage	Cylindrique

Douille en caoutchouc	Sans
Matériau, palier	Fonte
Matériau, roulement	Acier pour roulement
Revêtement	Sans
Étanchéité, roulement	Joint et déflecteur des deux côtés
Type d'étanchéité	Contact, standard
Étanchéité, unité	Sans
Lubrifiant	Graisse
Trou de lubrification	Avec
Raccord de lubrification	Avec

SKF

Spécifications techniques

Conformité aux normes	ISO
Spécifique à un objectif	Pour applications de manutention
Matériau, palier	Fonte
Étanchéité, roulement	Joint et déflecteur des deux côtés
Type d'étanchéité, roulement	Contact, standard
Étanchéité, palier complet	Sans
Revêtement	Sans



Dimensions

d	12 mm	Diamètre d'alésage
d_1	≈ 24.2 mm	Diamètre extérieur de la bague intérieure
A	26 mm	Largeur globale
A_1	11 mm	Largeur d'épaulement
A_3	3.2 mm	Profondeur de l'embrèvement de centrage
B	27.4 mm	Largeur de la bague intérieure
B_1	27.4 mm	Largeur globale du roulement
B_4	4 mm	Distance entre la face latérale du dispositif de blocage et le centre du filetage
D_{b1}	50 mm	Diamètre externe du haut
D_{b2}	53 mm	Diamètre externe de la semelle
D_c	55.6 mm	Diamètre de l'embrèvement de centrage du palier
J	54 mm	Distance entre les boulons de fixation

L	76 mm	Longueur globale
N	11.5 mm	Diamètre du trou du boulon de fixation
s_1	15.9 mm	Distance entre la face latérale du dispositif de blocage et le centre de la piste
T	32.9 mm	Largeur globale de l'unité

Trou fileté

R_G	1/4-28 UNF	Filetage du palier pour raccord de graissage
R_1	19 mm	Position axiale du filetage du palier

Raccord de graissage

D_N	6.5 mm	Diamètre de la tête sphérique du raccord de graissage
SW	7 mm	Taille de clé hexagonale pour raccord de graissage
G_N	1/4-28 SAE-LT	Filetage du raccord de graissage

Pieds de centrage

J_6	66 mm	Distance des pieds de centrage
J_7	14.5 mm	Décalage axial des pieds de centrage
N_4	4 mm	Diamètre recommandé des pieds de centrage

Données de calcul

Charge dynamique de base	C	9.56 kN
Charge statique de base	C_0	4.75 kN
Limite de fatigue	P_u	0.2 kN
Vitesse limite		9 500 r/min

	Vitesse limite avec tolérance d'arbre h6

Masse

Masse du palier complet	0.4 kg

Informations de montage

Vis de réglage	G_2	M6x0.75
Taille de clé hexagonale pour vis de réglage		3 mm
Couple de serrage recommandé pour la vis de réglage		4 N·m
Diamètre recommandé des boulons de fixation, mm	G	10 mm
Diamètre recommandé des boulons de fixation, en pouces	G	0.375 in

Annex 6 : Bibliographie and Software used

-Arcadia Capella version 6.1.0

-Gantt Project version 3.2

-Wikipedia

-https://www.youtube.com/watch?v=fb8ZSe8fVIQ&t=281s&pp=ygUYbGUgc2Vydm9tb3RldXIgZXhwbGlxdcOp

-Xamp

-Visual studio code 2019

-Arduino IDE

-https://www.youtube.com/watch?v=YpNMCxc_3ag&t=1s&pp=ygUQdHJhcXVldXIgc29sYWlyZQ%3D%3D

-Amazon

-Lucid Charts

-https://www.jechange.fr/energie/electricite/prix

-https://www.franssen-loisirs.fr/van-life/energie/solutions-ecoflow/stations-electriques-portables/13259-ecoflow-tracker-solaire.html?utm_source=google&utm_medium=cpc&utm_campaign=+PMax%3A+Smart+shopping+-+Ecoflow&utm_term=&gad_source=1&gclid=CjwKCAjw17qvBhBrEiwA1rU9w86MebEG4ckDfH7srFg8Wn_avopQeH0DE08cGg2yvucZcR0TnKxZDhoCY1UQAvD_BwE

-https://www.omc-stepperonline.com/fr/nema-17-moteur-pas-a-pas-l-40mm-rapport-de-vitesse-5-1-reducteur-planetaire-serie-mg-17hs15-1584s-mg5?language=fr&currency=EUR&gad_source=1&gclid=Cj0KCQiArrCvBhCNARIsAOkAGcXzxae4SwGLsIunFV0R9ArYwXeVhQNRSKALr4QIyJ44QoRgqqroCucaAsJ2EALw_wcB

-https://www.besled.fr/panneau-solaire-qn-solar-420wp-qnn182-hg420-54-420-wp-n-type-bi-facial-noir?utm_source=google_shopping_FR_hoofdaccount&utm_medium=cpc&utm_term=BSE407752&gad_source=1&gclid=Cj0KCQiArrCvBhCNARIsAOkAGcWrZQcgGQFO_QSrdsqkoIws6Dff4IBh36U6oF39Rx4zpL8UCLdEf3UaAnnaEALw_wcB

-https://www.omc-stepperonline.com/fr/nema-11-bipolaire-1-8deg-7ncm-9-91oz-in-0-67a-3-8v-28x28x31mm-4-fils-11hs12-0674s

https://fr.rs-online.com/web/p/roulements-a-billes/4089962
https://fr.rs-online.com/web/p/roulements-a-billes/6189957

Annex 7 : Code for the implementation of the human-machine interface

Code to display and connect tables to the database :

```
<!DOCTYPE html>
<html>
<head>
  <meta charset="UTF-8">
  <meta http-equiv="refresh" content="50">
  <title>Sensor Data</title>
  <script src="https://cdn.jsdelivr.net/npm/chart.js"></script>
        <style>
    table {
margin-left: auto;
margin-right: auto;
width: 80%;
}
    .total-electric-power {
      font-weight: bold;
      font-size: 1.2em;
      margin-top: 20px;
                        border: 5px solid #DDD;
    }

    .cost-electric-power {
      font-weight: bold;
      font-size: 1.2em;
      color: #4CAF50; /* Couleur verte */
                        border: 5px solid #DDD;

    }
                body {
  background : url('hello.jpg');
  box-sizing: border-box;
  font-size: 1.8rem;
  letter-spacing: -0.015em;
  text-align: center;
}
div {
 width: 45%; /* ou une valeur appropriée en pourcentage, pixels, em, etc. */
```

```
  height: 400px; /* ou une valeur appropriée en pixels, pourcentage, em, etc. */

display: inline-block;
}
th {
  font-family: Arial, Helvetica, sans-serif;
  font-size: 25px;
  background: #666;
  color: #FFF;
  padding: 6px 6px;
  border-collapse: separate;
  border: 1px solid #000;
}
td {
  font-family: Arial, Helvetica, sans-serif;
  font-size: 18px; /* Ajustez la taille du texte dans les cellules de données */
  text-align: center;
  border: 1px solid #DDD;
   font-weight: bold;
}
    </style>
</head>
<body>

    <h1>Tracker Solaire DATA</h1>

    <div>
    <canvas id="batteryLevelChart"></canvas>
</div>

<div>
    <canvas id="electricPowerChart"></canvas>
</div>


    <script>
<?php
    function connectToDatabase() {
```

```
        $servername = "localhost";
        $username = "root";
        $password = "";
        $dbname = "tracker_solaire";
        $conn = new mysqli($servername, $username, $password, $dbname);
        if ($conn->connect_error) {
            die("Connection failed: " . $conn->connect_error);
        }
        return $conn;
    }

    function fetchData($conn, $sql) {
        $result = $conn->query($sql);
        $data = [];
        while ($row = $result->fetch_assoc()) {
            $data[] = $row;
        }
        return $data;
    }

    $conn = connectToDatabase();
    $sql = "SELECT time, electric_power, battery_level FROM sensordata ORDER BY id DESC LIMIT 6";
    $data = fetchData($conn, $sql);
            $sql_sum_electric_power = "SELECT SUM(electric_power) AS total_electric_power FROM
sensordata";
    $result_sum_electric_power = $conn->query($sql_sum_electric_power);
    $row_sum_electric_power = $result_sum_electric_power->fetch_assoc();
    $total_electric_power = $row_sum_electric_power['total_electric_power'];
            $cost_electric_power = $total_electric_power*0.22;

    $labels = [];
    $electricPowerData = [];
    $batteryLevelData = [];

    foreach ($data as $row) {
        $labels[] = $row["time"];
        $electricPowerData[] = $row["electric_power"];
        $batteryLevelData[] = $row["battery_level"];
```

```
    }

    $conn->close();
    ?>

    // Première figure pour le niveau de batterie (%)
var batteryLevelData = {
    labels: <?php echo json_encode($labels); ?>,
    datasets: [{
        type: 'bar',
        label: 'Battery Level (%)',
        borderColor: 'rgb(75, 192, 192)',
        backgroundColor: 'rgba(75, 192, 192, 0.2)',
        data: <?php echo json_encode($batteryLevelData); ?>,
        fill: false,
    }]
};

var batteryLevelOptions = {
    responsive: true,
    maintainAspectRatio: false,
};

var batteryLevelCtx = document.getElementById('batteryLevelChart').getContext('2d');
var batteryLevelChart = new Chart(batteryLevelCtx, {
    type: 'bar',
    data: batteryLevelData,
    options: batteryLevelOptions
});

// Deuxième figure pour la puissance électrique (kWh)
var electricPowerData = {
    labels: <?php echo json_encode($labels); ?>,
    datasets: [{
        type: 'line',
        label: 'Electric Power (kWh)',
        borderColor: 'rgb(255, 99, 132)',
```

```
    data: <?php echo json_encode($electricPowerData); ?>,
    fill: false,
  }]
};

var electricPowerOptions = {
  responsive: true,
  maintainAspectRatio: false,
};

var electricPowerCtx = document.getElementById('electricPowerChart').getContext('2d');
var electricPowerChart = new Chart(electricPowerCtx, {
  type: 'line',
  data: electricPowerData,
  options: electricPowerOptions
});

  </script>
<p class="total-electric-power">Total Electric Power (kWh): <?php echo $total_electric_power; ?></p>
  <p class="cost-electric-power">Cost (€): <?php echo $cost_electric_power; ?></p>
  <table>
    <?php
    $conn = connectToDatabase();
    $sql = "SELECT id, time, electric_power, battery_level FROM sensordata ORDER BY id DESC";
    $data = fetchData($conn, $sql);

    echo '<table cellspacing="5" cellpadding="5" >
       <tr>
        <th>ID</th>
        <th>Time</th>
        <th>Electric power (kWh)</th>
        <th>Battery level (%)</th>
       </tr>';

    foreach ($data as $row) {
      echo '<tr>
          <td>' . $row["id"] . '</td>
          <td>' . $row["time"] . '</td>
```

```
                <td>' . $row["electric_power"] . '</td>
                <td>' . $row["battery_level"] . '</td>
              </tr>';
        }

        $conn->close();
        ?>
    </table>
</body>
</html>
```

Annex 8 : Consideration of the CSR (Corporate Social Responsibility) approach.

Jérémie Bondo

Concerning the CSR approach, my first idea was to take photovoltaic cells already used and add 6 others directly present in the school, this saved us from more orders and therefore less energy consumption in the production of cells. or in their delivery.

Az-eddine Abouhafs

In this CSR approach we wanted to be eco-responsible, which is why I suggested using PLA, a deformable and reusable plastic.

Annex 9 : Summary table of implemented functions by the students

Objectives	Students	
	Jérémie	Az-eddine
Schedule the development of the project	100%	
Command the pieces	100%	
Research and development	50%	50%
Choose and start the construction of the Modelisation	100%	
Establishment of the human machine interface		100%
Design a code capable of incorporating our sensors, motors and sending information	50%	50%
Testing and Soldering Electronic Components		100%
Imagine and create a potential company from the product	70 %	30%
Writing the capability development document	100%	

Annexe 10 : Self-assessment of acquired or strengthened skills.

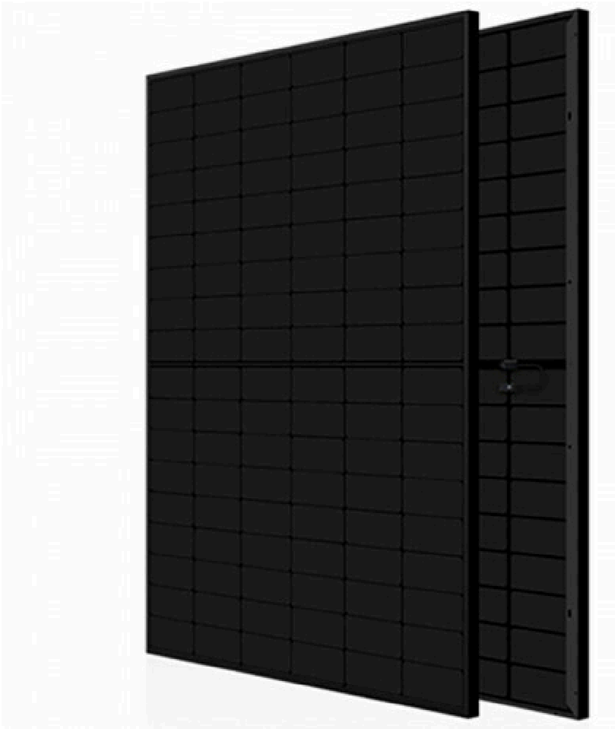
Jérémie Bondo

Personally, I was able to acquire new skills, especially in 3D design using the Vision 360 software. This software was new to me, as I had previously worked with 3D design on the Vision Creo Parametric software. Switching design software posed a new challenge for me. Additionally, in terms of planning, I took charge of the Gantt Project planning software where I learned about managerial planning, the importance of setting deadlines, and the consideration of risks. Furthermore, in this project, I refined my skills in state machines, utilizing my knowledge to build a state machine for a simplified approach in creating the computer program. In addition, I took control of the Capella software, which was useful for the functional analysis of our project." Finally I completed my knowledge concerning business, the keys to create a successful one and make it live.

Az-eddine Abouahfs

Firstly, creating a spider diagram was a key step in visualizing and understanding the project's complexity. This diagram allowed me to clearly map out the different components of the system, identifying interconnections and dependencies. Another important skill I developed pertains to data management. Establishing a database capable of displaying real-time data from a solar tracker was an exciting challenge. I learned to design and optimize a database structure to efficiently store information collected by the solar tracker. Moreover, implementing this database required a deep understanding of query languages, further strengthening my data manipulation skills.

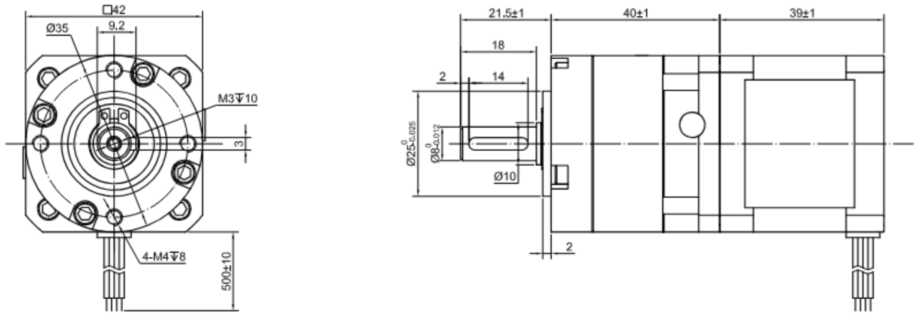
Annex 11 : Photovoltaic cells chosen for the big tracker



Longueur	1722 mm
Largeur	1134 mm
Hauteur	30 mm
Poids	24 kg
Puissance	420 Wp
Matériau des cellules	Monocristallin

Photovoltaic cells QN solar 420 Wp besled.fr

Annex 12 : Servo motor Nema 17



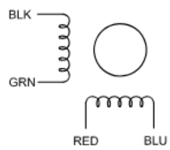
SPECIFICATION \ CONNECTION	BIPOLAR
AMPS/PHASE	1.58
RESISTANCE/PHASE(Ohms)@25°C	1.65±10%
INDUCTANCE/PHASE(mH)@1KHz	3.20±20%
HOLDING TORQUE w/o GEARBOX(Nm)[lb-In]	0.36[3.12]
GEAR RATIO	5
EFFICIENCY	90.00%
STEP ANGLE(°)	1.80
BACKLASH@NO-LOAD	<=30
MAX.PERMISSIBLE TORQUE(Nm)	9.00
MOMENT PERMISSIBLE TORWUE(Nm)	18.00
SHAFT MAXIMUM AXIAL LOAD(N)	100.00
SHAFT MAXIMUM RADIAL LOAD(N)	300.00
TEMPERATURE RISE:MAX.80°C（MOTOR STANDSTILL;FOR 2PHASE ENERGIZED）	
WORKING TEMPERATURE -20°C~150°C[-4°F~302°F]	
INSULATION CLASS B 130°C[266°F]	

TYPE OF CONNECTION (EXTERN)		MOTOR	
PIN NO	BIPOLAR	LEADS	WINDING
1	A —	BLK	A
2	A\ —	GRN	A\
3	B —	RED	B
4	B\ —	BLU	B\

FULL STEP 2 PHASE-Ex. ,
WHEN FACING MOUNTING END (X)

STEP	A	B	A\	B\
1	+	+	-	-
2	-	+	+	-
3	-	-	+	+
4	+	-	-	+

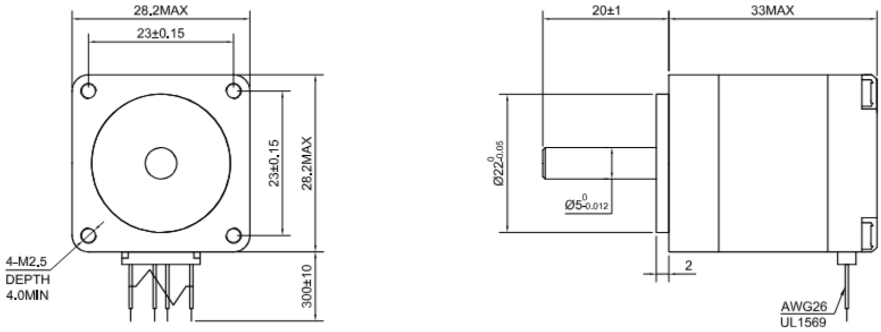
↓ CW ↑ CCW



STEPPERONLINE®

	APVD	12.12.2022	STEPPER MOTOR
	CHKD		
1:1	DRN		17HS15-1584S-MG5
SCALE	SIGNATURE	DATE	

Annex 13 : Servo motor Nema 11



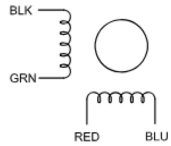
SPECIFICATION / CONNECTION	BIPOLAR
AMPS/PHASE	0.67
RESISTANCE/PHASE(Ohms)@25°C	5.60±10%
INDUCTANCE/PHASE(mH)@1KHz	4.00±20%
HOLDING TORQUE(Nm)[lb-In]	0.07[0.62]
STEP ANGLE(°)	1.80
STEP ACCURACY(NON-ACCUM)	±5.00%
ROTOR INERTIA(g-cm²)	9.00
WEIGHT(Kg)[lb]	0.11[0.24]
TEMPERATURE RISE;MAX.80°C（MOTOR STANDSTILL;FOR 2PHASE ENERGIZED）	
AMBIENT TEMPERATURE -10°C~50°C[14°F~122°F]	
INSULATION RESISTANCE 100 Mohm（UNDER NORMAL TEMPERATURE AND HUMIDITY）	
INSULATION CLASS B 130°C[266°F]	
DIELECTRIC STRENGTH 500VAC FOR 1MIN.(BETWEEN THE MOTOR COILS AND THE MOTOR CASE)	
AMBIENT HUMIDITY MAX.85%(NO CONDENSATION)	

TYPE OF CONNECTION (EXTERN)		MOTOR	
PIN NO	BIPOLAR	LEADS	WINDING
1	A+ —	BLK	A+
2	A- —	GRN	A-
3	B+ —	RED	B+
4	B- —	BLU	B-

FULL STEP 2 PHASE-Ex. ,
WHEN FACING MOUNTING END (X)

STEP	A+	B+	A-	B-
1	+	+	-	-
2	-	+	+	-
3	-	-	+	+
4	+	-	-	+

CCW ↑ CW ↓



STEPPERONLINE®

SCALE	SIGNATURE		DATE	
	APVD		10.30.2020	STEPPER MOTOR
	CHKD			
1.5:1	DRN			11HS12-0674S

Annex 14 : Ball bearing NSK 61800TN

https://docs.rs-online.com/492e/0900766b81406c4e.pdf

Annex 15 : Ball bearing Rs-Pro 618-9957

Roulements à billes

Description du produit

Une gamme de roulements à billes à gorge profonde et simple rangée de RS PRO, offrant une grande polyvalence et de hautes performances générales. Les roulements à billes étanches de RS PRO sont équipés de deux joints en caoutchouc synthétique pour empêcher la saleté et autres particules d'entrer dans le roulement. Ces roulements à billes sont destinés principalement aux applications dans lesquelles la bague interne tourne.

Caractéristiques

Type à roulement à billes	Miniature
Type d'extrémité	Etanche
Nombre de rangées	1
Charge statique nominale	1.379kN
Matériau	Acier
Type de course	Uni
Type d'alésage	Parallèle
Application	Gyroscopes, Anémomètres, débitmètres, boîtes de vitesses miniatures, petits moteurs

Spécifications mécaniques

Diamètre intérieur	8 mm
Diamètre extérieur	22mm
Largeur de course	7mm
Charge nominale dynamique	3.293kN
Charge statique	0.882kN
Masse	0.012kg

Annex 16 : Code for the sensors

```
#include <ESP32Servo.h>
#include <TimeLib.h>
#include "esp_sleep.h"

#define capteur1Pin 32
#define capteur2Pin 33
#define capteur3Pin 34

#define SERVO_PIN_1 12
#define SERVO_PIN_2 13

Servo servo1;
Servo servo2;

// Heures de démarrage et d'arrêt en fonction des saisons
int startHour, stopHour;

// Tableaux pour stocker les valeurs des capteurs sur les 30 dernières
minutes
int capteur1Values[30];
int capteur2Values[30];
int capteur3Values[30];
int index = 0;


void lireCapteurs(int &capteur1, int &capteur2, int &capteur3) {
  // Lecture des valeurs des capteurs
  capteur1 = analogRead(capteur1Pin);
  capteur2 = analogRead(capteur2Pin);
  capteur3 = analogRead(capteur3Pin);
}

// Mise à jour des valeurs des capteurs toutes les minutes
void mettreAJourValeursCapteurs() {
  capteur1Values[index] = analogRead(capteur1Pin);
  capteur2Values[index] = analogRead(capteur2Pin);
  capteur3Values[index] = analogRead(capteur3Pin);
  index = (index + 1) % 30;
}

// Fonction pour calculer la moyenne des valeurs des capteurs sur les
30 dernières minutes
```

```
void        calculerMoyenneCapteurs(int         &capteur1Moyenne,        int
&capteur2Moyenne, int &capteur3Moyenne) {
  // Initialisation des sommes
  long sum1 = 0;
  long sum2 = 0;
  long sum3 = 0;

  // Calcule de la somme des valeurs des capteurs
  for (int i = 0; i < 30; i++) {
    sum1 += capteur1Values[i];
    sum2 += capteur2Values[i];
    sum3 += capteur3Values[i];
  }

  // Calcule de la moyenne des valeurs des capteurs
  capteur1Moyenne = sum1 / 30;
  capteur2Moyenne = sum2 / 30;
  capteur3Moyenne = sum3 / 30;
}

void setup() {
  servo1.setPeriodHertz(50);
  servo1.attach(SERVO_PIN_1, 500, 2400);

  servo2.setPeriodHertz(50);
  servo2.attach(SERVO_PIN_2, 500, 2400);


  Serial.begin(115200);

}

void loop() {
  // Recherche de l'heure actuelle
  int currentHour = hour();

  // Détermination des heures de démarrage et d'arrêt en fonction des
saisons
  int season = getSeason(month());
  if (season == 1) { // Été
    startHour = 9;
    stopHour = 20;
  } else if (season == 2) { // Hiver
```

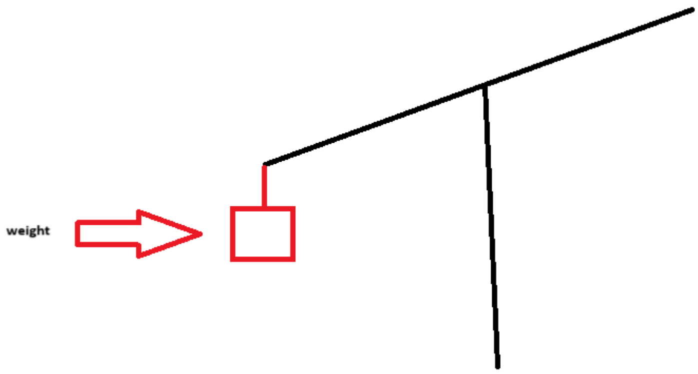
```
    startHour = 8;
    stopHour = 17;
  } else { // Automne et Printemps
    startHour = 8;
    stopHour = 18;
  }
    lireCapteurs(capteur1Value, capteur2Value, capteur3Value);

  // CONDITIONS
 if (currentHour >= startHour && currentHour < stopHour) {
    //servo 1 controle l'inclinaison et servo2 controle la rotation
     if (capteur1Value > capteur2Value && capteur1Value > capteur3Value)
{ //cas improbable car non paramétré pour ça, le moteur est ici mal
placé
           while (capteur1Value > capteur2Value && capteur1Value >
capteur3Value) {
        servo2.write(-1);
        lireCapteurs(capteur1Value, capteur2Value, capteur3Value);
      }
       } else if (capteur1Value > capteur2Value && capteur3Value >
capteur2Value) { // Incliner les plaques
           while (capteur1Value > capteur2Value && capteur3Value >
capteur2Value) {
        servo1.write(1);
        lireCapteurs(capteur1Value, capteur2Value, capteur3Value);
      }
       } else if (capteur1Value > capteur2Value && capteur2Value >
capteur3Value) { //Cas en fin de journée
           while (capteur1Value > capteur2Value && capteur2Value >
capteur3Value) {
        servo1.write(-1);
        lireCapteurs(capteur1Value, capteur2Value, capteur3Value);
      }
       } else if (capteur3Value > capteur2Value && capteur2Value >
capteur1Value) { //Cas en hiver/Automne où le soleil est vraiment bas à
l'horizon
           while (capteur3Value > capteur2Value && capteur2Value >
capteur1Value) {
        servo2.write(1);
        lireCapteurs(capteur1Value, capteur2Value, capteur3Value);
      }
```

```
      } else if (capteur3Value > capteur2Value && capteur3Value > capteur1Value) { //Cas en hiver où le soleil est plus incliné, en début de journée
          while (capteur3Value > capteur2Value && capteur3Value > capteur1Value) {
        servo2.write(1);
        lireCapteurs(capteur1Value, capteur2Value, capteur3Value);
      }
      } else if (capteur2Value > capteur3Value && capteur2Value >= capteur1Value) { //Cas en hiver où le soleil est plus incliné, en fin de journée
          while (capteur2Value > capteur3Value && capteur2Value >= capteur1Value) {
        servo2.write(1);
        lireCapteurs(capteur1Value, capteur2Value, capteur3Value);
      }
    }
      else if (capteur1Value == capteur2Value && capteur2Value == capteur3Value) {
    // Mettre l'ESP32 en veille
     esp_sleep_enable_timer_wakeup(30 * 60 * 1000000); // 30 minutes en microsecondes
    esp_deep_sleep_start();
  }

  } else { //Pas la bonne plage horaire
    // Mettre les moteurs en position initiale
    servo1.write(0);
    servo2.write(0);
  }
}

// Fonction pour déterminer la saison en fonction du mois
int getSeason(int month) {
  if (month >= 6 && month <= 8) // Été : Juin à Août
    return 1;
  else if (month >= 12 || month <= 2) // Hiver : Décembre à Février
    return 2;
  else // Automne et Printemps : Septembre à Novembre et Mars à Mai
    return 3;
}
```

Annex 17 : Ideas of trackers

I - The elevator tracker

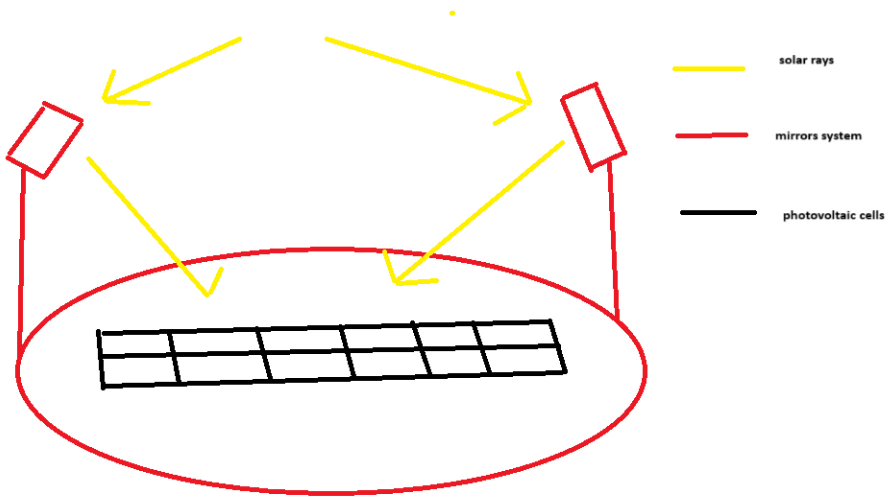
Here the idea is to use the system of an elevator mechanism in order to consume energy only on one movement (when the tracker returns to its starting point).



operating principle of the elevator tracker

II - The solar TrackerS

Here the idea is to create one or two systems as the previous solar tracker but here on those systems there would be mirrors which reflect all the photons on the photovoltaic cells. Here your cells must resist against a greater heat because all it would have more rays toward itself



operating principle of this system