MIDDLE EAST TECHNICAL UNIVERSITY
ELECTRICAL AND ELECTRONICS ENGINEERING

EE494 Final Report of Optima Technologies "*Canoptima* : Shadow Fixing Intelligent Canopy"

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Contents

1. *Executive Summary*

In today's world, there are numerous ways to deal with the stress that comes from the various pressures in our everyday life. As an illustration, relaxing on a beach sunbed may be an efficient way to unwind until the beach umbrella's shadow shifts and the sun begins to burn. It must be orientated, but given that the sun's location is constantly fluctuating, how many times can the orientation be changed? We at Optima Technologies have decided to develop the Shadow Fixing Intelligent Canopy project in order to be able to give uninterrupted rest time for everyone. Our canopy system determines what has to be done to protect individuals from sunlight after recognizing environmental changes.

The members of the Optima Technologies team can successfully complete the "Canoptima: Shadow Fixing Intelligent Canopy" project because of their exceptional training and experience. The task of creating the required algorithms and calibrating the shadow sensors falls to Muhammed Bahadır Demiryakan and Gazi Eren Tuncay. The mechanical part of the project, including the removal of the canopy, is under the control of Betül Saplı and Göktuğ Tonay. In charge of the modeling and power analysis is Hakan Kutluk.

There are 3 main subsystems in the Canoptima project namely, shadow sensing subsystem, mechanical subsystem and electronics subsystem. The shadow sensing system utilizes the cameras to detect the position of the shadow. Moreover, by the help of the processor, the required position is determined and sent through the serial interface to the microcontroller as movement commands. The electronic subsystem aims to build connection between the shadow sensing and mechanical system. It controls the actuators and realizes the motion which is specified by the processor. Finally, the mechanical system specifies the kinematics design, structural design, and the production of the design. All the subsystems will be explained thoroughly in the next sections.

This document aims to explain the Shadow Fixing Intelligent Canopy product of Optima Technologies in full detail. First, further information about the project's background, the problem's outline, and the scope and structure of our firm will be provided. The description of the entire system will then come into clarity. The theoretical review, and the mechanical, electrical, and shadow sensing subsystems will all be thoroughly detailed, along with the design requirements and changes in our suggested design. Subsystem compatibility analysis and compliance with the requirements will be covered in more detail later. Then, we will go through all the Canoptima-related test processes and their respective assessments. After that, the deliverables, our budget, and the power management of our project will be elaborated upon. Lastly, we will be dwelling on the safety of our product and the possible effects it may possess due to its widespread usage. Our weighted objective trees, MATLAB, Python and similar codes, User's Manual and technical drawings for our mechanical subsystem may also be found in the appendices for those who are interested.

2. Introduction

Five seniors in the department of Electrical and Electronic Engineering at Middle East Technical University founded the company Optima Technologies. These five intelligent and exceptional coworkers were brought together by their shared passion and dedication to finding a solution, well, not just a solution but the *optima* solution for the "Shadow Fixing Intelligent Canopy," one of the capstone design projects suggested by the METU EEE Department. This project aims to develop a smart canopy system that would free users from the constant need to modify the canopy they are using anytime there is a change in the direction or angle of the incoming light.

Today's market offers a wide variety of canopies, each with a unique form or size and a variety of design elements. However, none of these canopies are particularly adaptable in terms of their capacity to provide users with an uninterrupted supply of shade so that they may unwind and enjoy their time. On the other hand, Canoptima is a brilliant and useful canopy solution that is noticeably quicker and more nimble than its rivals. Canoptima, the clever canopy, is something every outdoor enthusiast should own. It is very good at determining the precise location of the incoming light source before adjusting its own position to ensure the produced shadow's uniform placement and area coverage and, as a result, maximize user satisfaction.

The Canoptima system consists of a number of interconnected subsystems that work together to sense the 3D coordinates of the incoming light source, evaluate the area and location of the shadow that is cast, and mechanically position the system to maintain the shadow's area and placement as precisely as possible. There are several strategies that can be employed to meet the requirements of each of these subsystems. However, in order to address the best solution the industry has sorely needed up to this point, Optima Technologies is aiming to develop the most reasonably priced, environmentally friendly, user-friendly, and intelligent solutions for these systems.

Optima Technologies aims to thoroughly explain every aspect of the Canoptima project to its clients in this report: First, further details regarding the project's beginnings, the problem's description, and the scope and organizational structure of our company will be given. The overall system description will then become clear. The theoretical study, the mechanical, electrical, and shadow sensing subsystems, as well as the design specifications and modifications to our suggested design, will all be covered in great detail. A more thorough discussion of subsystem compatibility analysis and requirement compliance will come later. Next, we will go over each of the Canoptima-related test procedures and their corresponding evaluations. The project's budget, power management, and deliverables will then be discussed in more detail. Finally, we will focus on the safety of our product and any potential repercussions that its broad use might have. For those who are interested, the appendices also provide our weighted objective trees, MATLAB, Python and similar scripts, User's Manuals, and technical drawings for our mechanical system.

2.1. Background of the Project

The shadow-fixing intelligent canopy idea is built on the issues that the average person faces on a daily basis. Although it could seem like an easy chore, manually moving one's umbrella or canopy to maintain a specified shade is often not preferred. Even while adjusting the shadow by reaching up does not require much effort, the more time spent outside, the more frequently a manual adjustment is required.

The level of discomfort a person feels will mostly determine how frequently they rise up to adjust their canopy, thus this is another crucial point to keep in mind. Each person has a limit to how much shadelessness they can tolerate, so when that limit is reached and the person needs to manually adjust the canopy, some of the shadow has already been lost, and on top of that, an unpleasant experience that stops the relaxation has now taken place. With this project, the shadow is automatically adjusted through constant adjustment. This is a significant benefit that improves everyone's quality of life.

As Optima Technologies, we first researched the market and discovered that the two primary solutions to this issue currently call for the employment of either generic, non-electric beach umbrellas or canopies or non-smart, electrical awning systems that still require user input to function. This led us to believe that the market really does require an original solution to this issue. Then, we reasoned that since technology is a part of every aspect of our lives, why not eliminate some of the pointless duties by fusing these outdated approaches with modern technology? Thus, the Canoptima Project was launched using this line of reasoning.

2.2. Problem Statement

For a variety of reasons, people regularly talk about outdoor activities. When one is exposed to the sun for an extended period of time, a shadow is almost always required to offer shade. The problem that Optima Technologies is dedicated to resolving is one in which the amount of time spent in the sun is rather considerable. Given the need to adjust the shadow casting device as the sun moves, this activity may get laborious after a while. For this purpose, we developed Canoptima: Shadow Fixing Intelligent Canopy. Our canopy adjusts its orientation in reaction to the light source and strives to retain the original shade as consistently as possible.

The physical design requirements of the product is as follows:

- The canopy must always be between 30 and 50 cm long.
- There are at least three poles under the tent.
- The poles must be attached to the ground.
- There should be 50 cm between adjacent poles on the ground.

The functional requirements of the product is as follows:

- The system should be compatible with a light source that moves smoothly inside a spherical sector that is no more than 45 degrees in any one direction.
- For different, arbitrary light source positions and orientations that change in 3D, the canopy should be able to autonomously optimize its orientation without requiring user input in order to maintain the position and coverage of the shadow as constant as possible with respect to the initial region denoted by the poles.

The performance requirements of the product is as follows:

- The fixing ratio should be as close to 1 as is practical. It is calculated by dividing the intersection of the first and subsequent shadows by their union.
- The system should be able to relocate 3 times in 20 seconds.

Appendix 1 of this report contains a weighted objective tree for the Canopy system built by Optima Technologies, which outlines the types of objectives we have pursued and put into practice for various functional needs. This information is essential because these decisions directly affected the design choices Optima Technologies made while creating Canoptima.

2.3. Scope and Organization

Optima Technologies provides the best solution by using novel methods in light of the issue that prompted the creation of the "Shadow Fixing Intelligent Canopy" and the conditions surrounding the project. The company considers each partner's idea as a potential approach to enhance the creation of the product and assesses the advantages and disadvantages in an effort to identify the best option in terms of cost, usability, energy consumption, etc. Optima Technologies links every sector with a wide range of Canoptima Project divisions and partners from diverse fields of expertise.

3. System Design

System design explanation will start out with a discussion of a theoretical review of the project's mechanics. The three subsystems of our project will next be thoroughly detailed. Namely, the mechanical, electronics, and shadow detection subsystems.

3.1. Theoretical Review

The theory supporting our choice of mechanism is covered in this section of the report. We built a MATLAB script to find the optimal outcome that our system is capable of. For maximization, we use the intersection over the intersection over the union area of the shadows (IOU). The angle definitions regarding our system can be found in Figure 3.1.1.

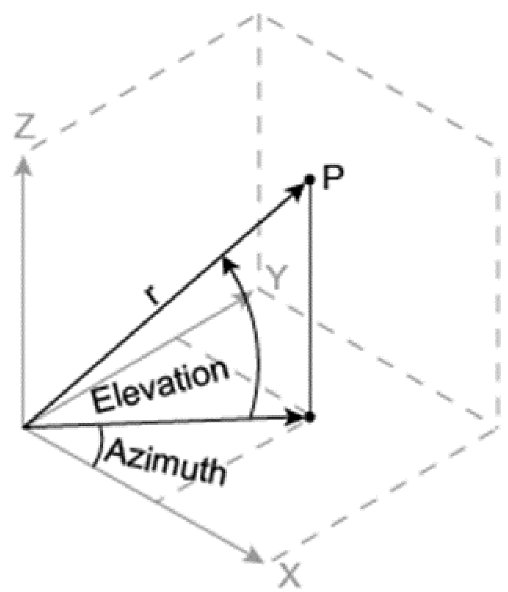


Figure 3.1.1. Angle Definitions

We compared the best solutions for two mechanisms, one having the freedom of tilting and one doing only xy translational movement. We compared these results for the elevation of 90, 64 and 45 degrees, azimuth of 0, 45 and 90 degrees and three distances of light at 160, 200 and 240 cms.

The 3D look can be seen in Figure 3.1.2, where the green dot represents the light source, the blue surface is the canopy, red surface is the initial shadow and the black part is the calculated shadow.

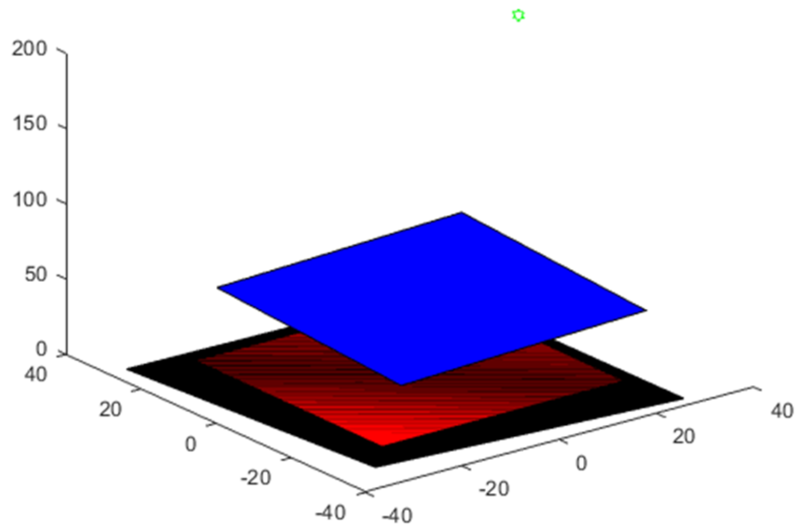


Figure 3.1.2. 3D representation in MATLAB

The top 2D view of the shadows can be seen in Figure 3.1.3.

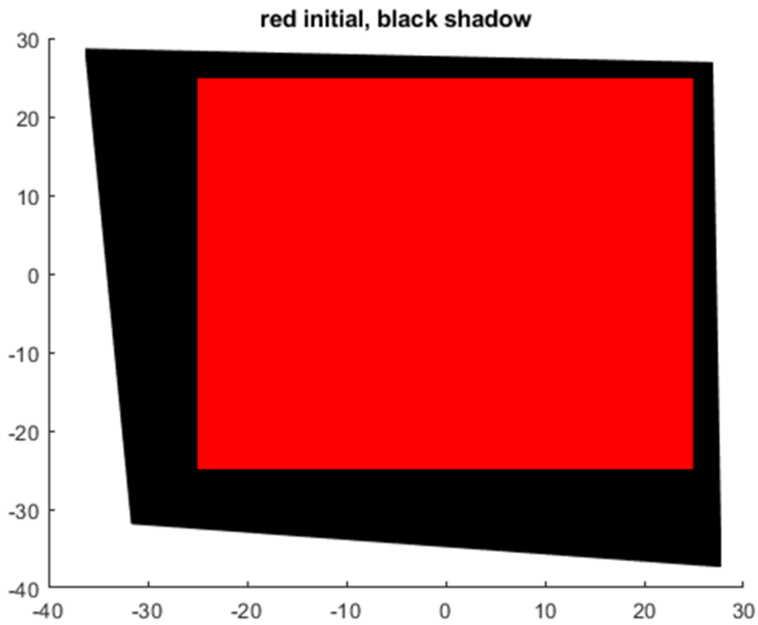


Figure 3.1.3. 2D shadow representation in MATLAB

Now, we compare our values in Table 3.1.1, Table 3.1.2 and Table 3.1.3.

Table 3.1.1: Shadow Sensing Unit Test I - Azimuth Angle Test

Distance Value (R)	Elevation Angle Value	Azimuth Angle Value	Actual Performance	Expected Performance (xy motion only)	Expected Performance (xy+tilting motion)
2.0m	45°	0°	0.2425	0.2451	0.3611
2.0m	45°	45°	0.3810	0.3786	0.4402
2.0m	45°	90°	0.3718	0.3055	0.4311

Table 3.1.2: Shadow Sensing Unit Test II - Light Source Distance Test

Distance Value (R)	Elevation Angle Value	Azimuth Angle Value	Actual Performance	Expected Performance (xy motion only)	Expected Performance (xy+tilting motion)
1.6m	90°	NA	0.4217	0.4104	0.4584
2.0m	90°	NA	0.4565	0.4613	0.5017
2.4m	90°	NA	0.4959	0.4968	0.5317

Table 3.1.3 Table: Shadow Sensing Unit Test III - Elevation Angle Test

Distance Value (R)	Elevation Angle Value	Azimuth Angle Value	Actual Performance	Expected Performance (xy motion only)	Expected Performance (xy+tilting motion)
2.0m	45°	90°	0.3718	0.3055	0.4311
2.0m	64°	90°	0.4328	0.4380	0.4885
2.0m	90°	90°	0.4565	0.4613	0.5017
2.0m	45°	0°	0.2425	0.2451	0.3611
2.0m	64°	0°	0.4328	0.4380	0.4885
2.0m	90°	0°	0.4565	0.4613	0.5017

Previously we have shown these calculations for a canopy of 500x500 mm. The tables present now show the results for a canopy of 600x600 mm. As can be seen, the differences between the expected performances have slightly increased; however, we believe the improvement is still not significant enough to overcome the complexity and the monetary cost it brings.

Here we believe we face an engineering trade-off. Even though we are aware of the fact that a mechanism that can do tilting motion can give better results, we can see that trying to achieve such a mechanism will bring so much more complexity and R&D time. It will also cost more. Therefore, this makes the decision of disregarding the small advantage much more favorable. It should also be noted that there would also be a concern due to gaps between the joints bringing vibration problems and hence, result in significant loss in robustness.

Disclaimer: The calculations where the inclination is possible is done considering the mechanical constraints of the system. The mechanical system can be seen in detail in part 3.2. Here, in order to keep the canopy at 30 cm, the pole lengths should be 22 cm due to the parts on top to attach the canopy. Moreover, in a system that can do tilting, the legs should be linear actuators and have motors equipped in them.The motor with the shaft included takes up 6 cm. Adding the coupler and joint connection elements result in a 6 cm more reduction. Therefore, the maximum stroke of this system ends up to be 10 cm. 10 cm stroke corresponds to an angle of around 11 degrees, which is what was used in the calculations.

3.2. Subsystem 1: Mechanical

The mechanical subsystem is the first subsystem of the Canoptima Project. Kinematics design, structural design, and the production of the design, including the actual assembly, are all included in this section.

Since we have established in section 3.1 that the xy translational movement was our preferred method of motion, we built a system that can perform this movement. Since there is no need for any movement in the z direction, the canopy legs remain stable and may be positioned as low to the ground as possible to get the largest ratio of IOU.

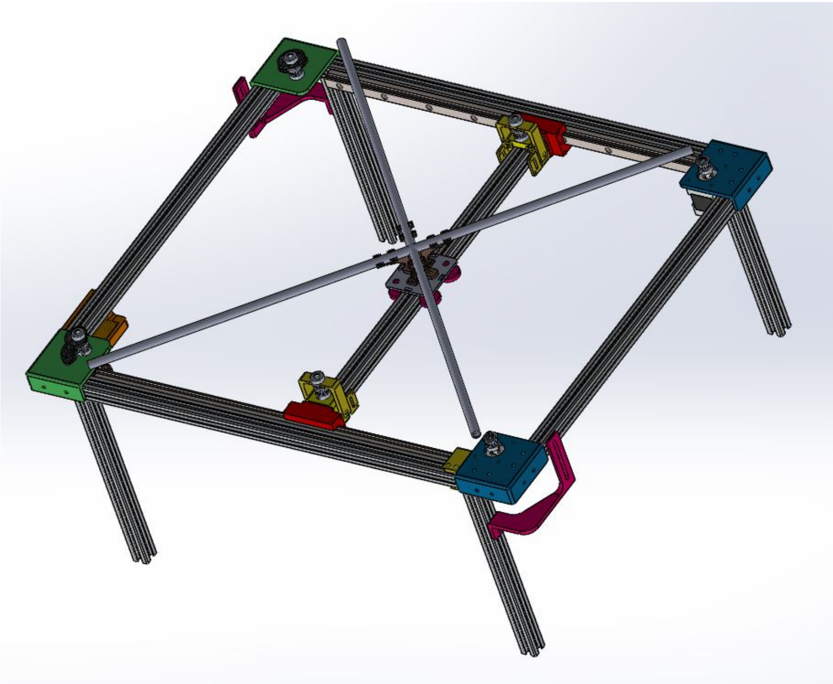


Figure 3.2.1 Canopy top view without the top

Figure 3.2.1 shows the system without the top attached for better viewing. As can be seen, there are four poles, and a rectangular frame on top, which are all aluminum sigma profiles. The poles are 20x20x500 mm each, and are 500 mm apart from each other. The frame on top has a size of 540x640 mm. Another bar made of the same material is housed inside the frame and is attached to the frame by means of two linear guideways. The bar can glide inside the frame in this manner, giving us mobility in only one direction. A car that can slide down the middle bar achieves the second degree of freedom. The canopy is connected to the top of this car using a connection piece that can hold carbon fiber tubes, which can be seen in Figure 3.2.2. Said tubes are then attached to the canopy top itself.

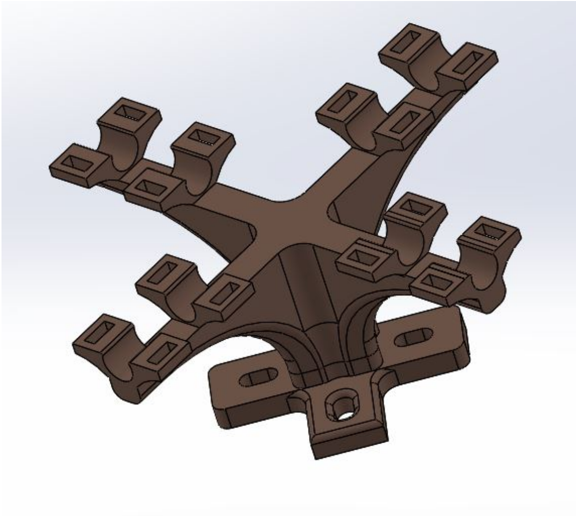


Figure 3.2.2 Tube holder

We have two cameras in our system, and we placed these cameras by the help of two camera holders, which can be seen in Figure 3.2.3.

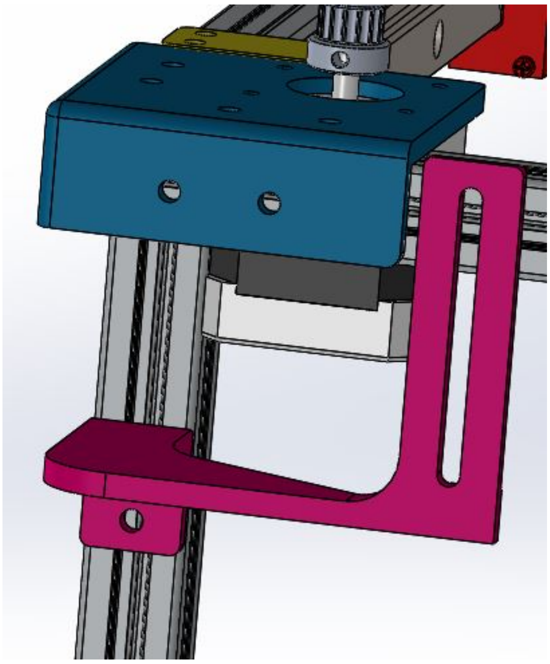


Figure 3.2.3. Camera holder

The system is connected by belts and consists of two step motors. In addition to the pieces specifically created and 3D printed for this design, such as the motor attachment, the camera and the tube holder, the mechanical unit also includes various connecting components, like gears, bolts, etc and some supporting parts to fix them. Figure 3.2.4 shows a close-up of a few elements of the mechanism.

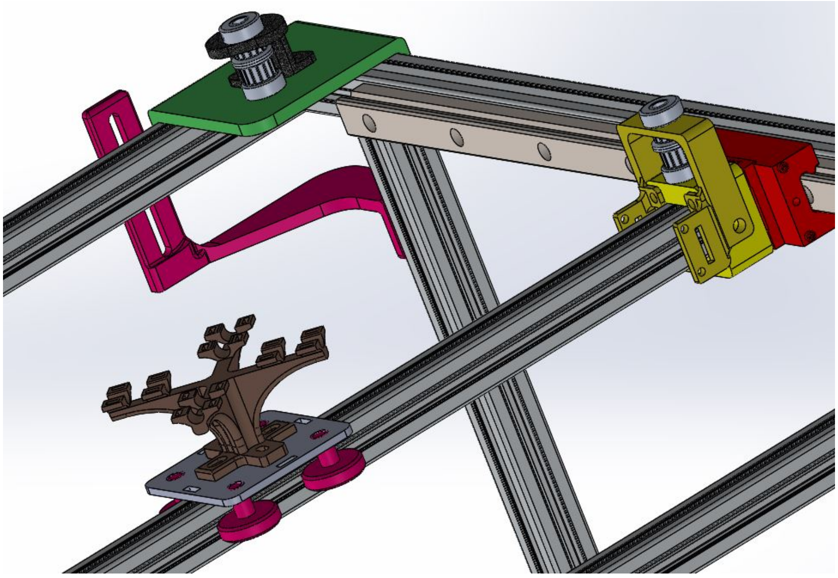


Figure 3.2.4 Close-up view

Figure 3.2.5 and Figure 3.2.6 show the canopy with the top attached from the top and bottom view, respectively.

Figure 3.2.5 View from above the canopy

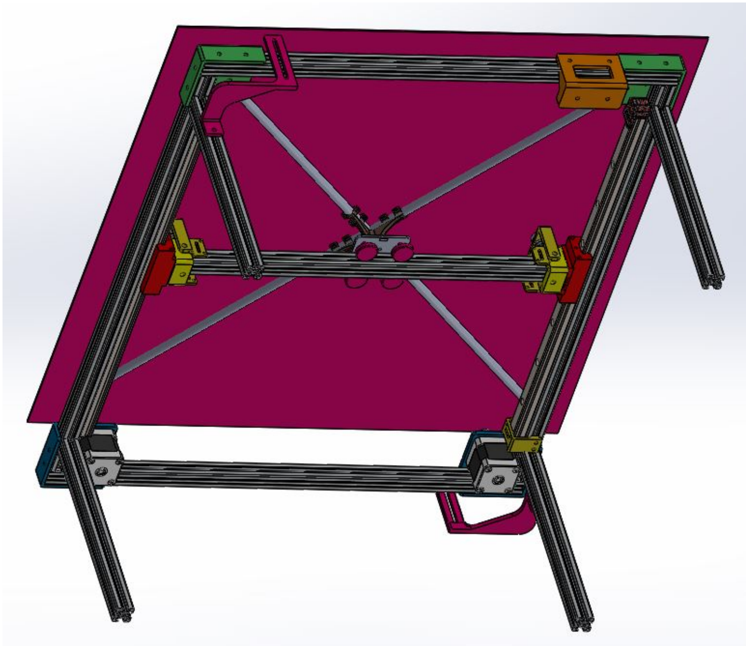
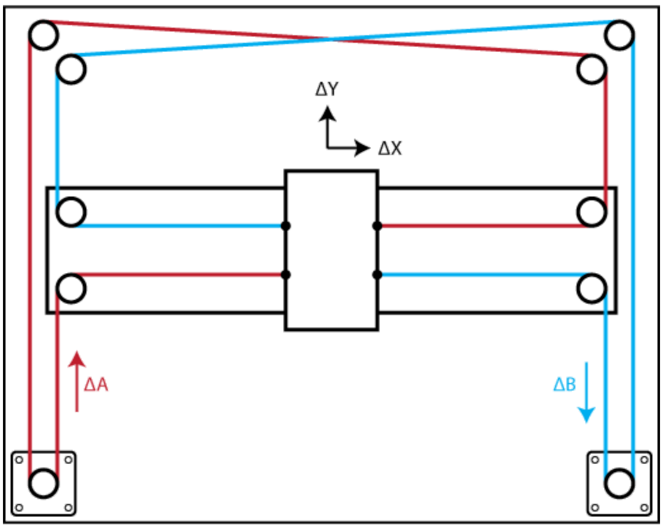


Figure 3.2.6 View from underneath the canopy

The technical drawing of the system can be seen in Appendix 16.3.

We utilized the coreXY mechanism found in 3D printers for belt connectors. Figure 3.2.7 shows the relationships as well as their equations of motion.



Equations of Motion:

$\Delta X = {}^{1}/_{2}(\Delta A + \Delta B)$, $\Delta Y = {}^{1}/_{2}(\Delta A - \Delta B)$

$\Delta A = \Delta X + \Delta Y$, $\Delta B = \Delta X - \Delta Y$

Figure 3.2.7. CoreXY motion [1]

3.3. Subsystem 2: Electronics

Electronic subsystem of the canoptima project mainly acts as a bridge between shadow sensing and mechanical subsystem. It controls the actuators to manipulate the canopy position based on the commands from the shadow sensing unit.

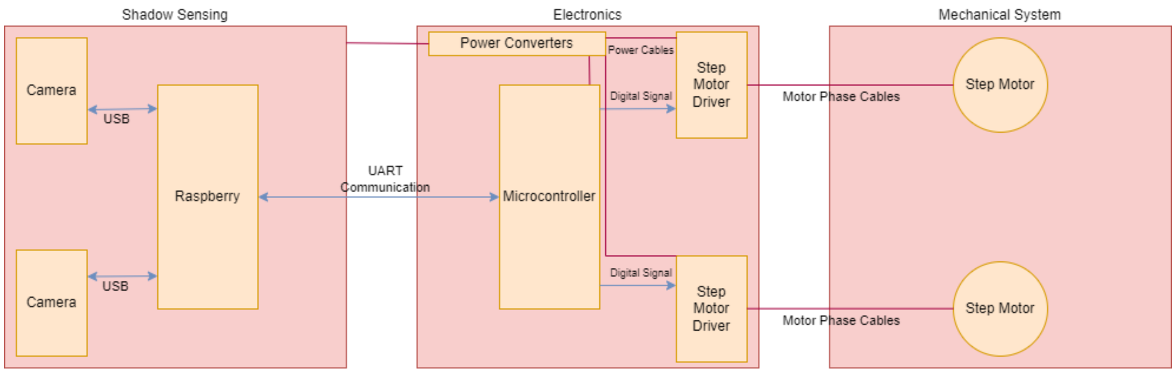


Figure 3.3.1. Simplified diagram of overall system.

A simplified diagram of the overall system can be seen in figure 3.3.1, as can be seen from the figure microcontroller mainly controls the step motors depending on the command from shadow sensing. It also reads limit switches to check the mechanism limits.

To supply our system from the grid we are planning to use an AC/DC converter to create 12V. We will use that voltage to supply power to our motor. Moreover, we will use a buck type converter to create 5V. 5V rail will be used to supply power to Raspberry PI and 2 cameras which we are using to detect the shadow. In order to supply power to the microcontroller and logic part of the step drivers we also need 3.3V. To create 3.3V a linear type of voltage regulator is used with 5V input. Simplified power distribution diagram of the overall system can be seen in figure 3.3.2.

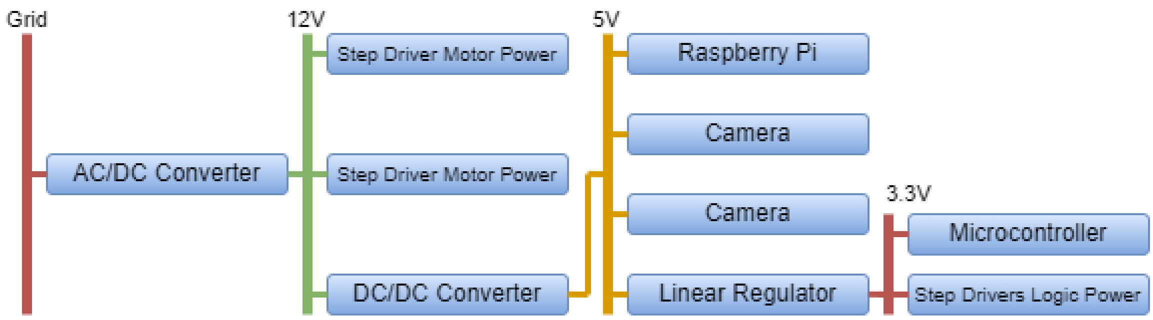


Figure 3.3.2. Simplified Power Distribution Diagram

Communication between camera and Raspberry PI will be done with USB communication. Since it is highly standardized and plug and play type of implementation, we will not give any further information about it. However communication between Raspberry PI and microcontroller will be UART in the physical layer. Since we will place them closely, and data loss in path is not a big deal, to optimize the cost we decided to not to use any physical layer like RS485 which is immune to industrial conditions. In the software layer, we are using a custom protocol since we are only communicating between our own devices. However, it is highly possible that some of the data will be corrupted and cause malfunction in the device. To solve this problem, we are adding a cycling redundancy check(CRC in short) to our message packages.

Figure 3.3.3. Structure of data package

Structure of a data package can be seen on figure 3.3.3. We can actually omit the start byte, however in the case of a corrupted package case it is possible to lose the start and end points of a message, in this case by finding the start byte we can solve the problem.

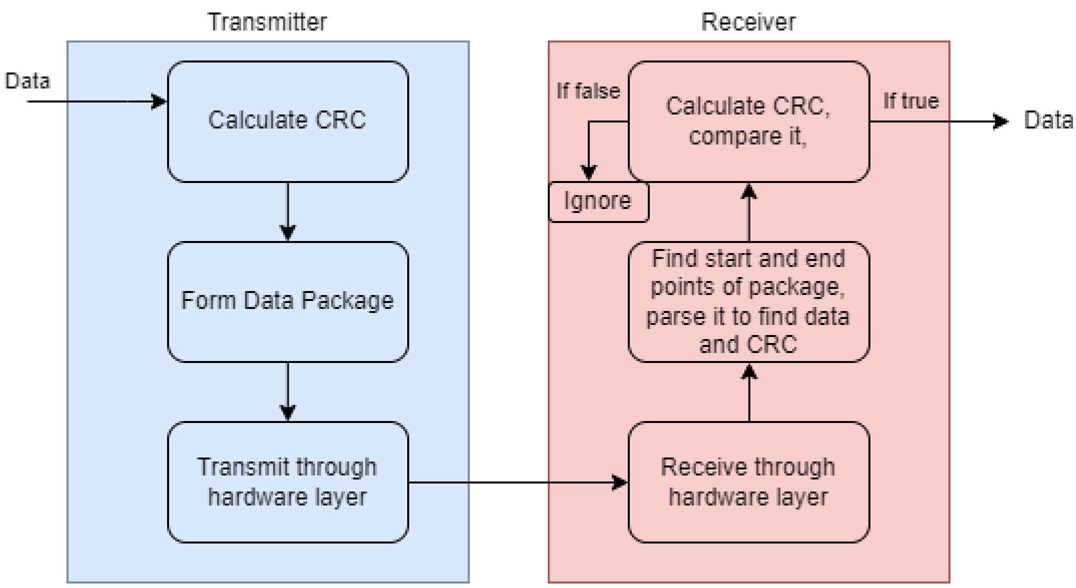


Figure 3.3.4. Diagram of communication

A simple diagram of communication can be seen on figure 3.3.4, we can also see how CRC works, even if one bit on the communication changes then the calculated CRC will be different, hence it is easy to identify corrupted packages in this system.

Data part of the message contains 2 bytes of information about the movement direction. Each byte represents a DoF of the system. If the corresponding byte of the package is 0x00 this means that no motion is necessary in that DoF, 0x01 and 0x02 represents direction. In the case of loss of shadow, or in the case of fast change in the shadow system needs to be resetted to function correctly, If both of the bytes are 0x03 then the system will be resetted, any other value is rejected. Part of the code which we are parsing the message can be seen below for better understanding.

```
 if(RXbuf[1] == 0x01 && RXbuf[2] == 0x00){
else if(RXbuf[1] == 0x01 && RXbuf[2] == 0x01){
else if(RXbuf[1] == 0x01 && RXbuf[2] == 0x02){
else if(RXbuf[1] == 0x02 && RXbuf[2] == 0x00){
else if(RXbuf[1] == 0x02 && RXbuf[2] == 0x01){
else if(RXbuf[1] == 0x02 && RXbuf[2] == 0x02){
else if(RXbuf[1] == 0x00 && RXbuf[2] == 0x01){
else if(RXbuf[1] == 0x00 && RXbuf[2] == 0x02){
else if(RXbuf[1] == 0x00 && RXbuf[2] == 0x00){
else if(RXbuf[1] == 0x03 && RXbuf[2] == 0x03){
```

Figure 3.3.5 Data package parsing part of the code

Figure 3.3.5 shows the valid data packages, if any other message will be delivered to our system then no actuation will be created. Moreover these actuation signals are created to create an optimum solution, this means that if the mechanism reached the stroke then the actuation should not be created in order to protect the mechanism. For that purpose limit switches are used, and checked before creating the actuation signals.

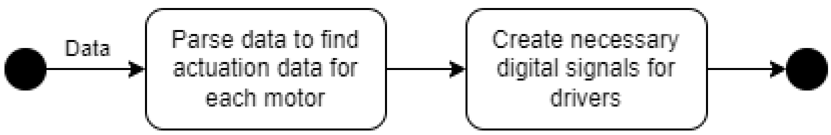


Figure 3.3.6 Software in microcontroller

Figure 3.3.6 shows the basic diagram in software in the microcontroller. Microcontroller basically executes the command coming from Raspberry PI to manipulate the position of the canopy.

After a valid message is received from the Raspberry PI, corresponding data packages are loaded into two variables. To create digital signals for the drivers we are using a timer interrupt, inside of the interrupt, our code checks the limit switches and creates the signals depending on the commands and limit switches.

3.4. Subsystem 3: Shadow Sensing

Our third subsystem is the shadow sensing subsystem. As can be understood from the name, its primary purpose is to sense the shadow on the ground and activate the mechanical unit to maximize the fixing of the shadow.

In this part, we have looked at the shadow sensing unit from two perspectives. The first one is the system features which include the placement of the equipment on the device. The other one is the detection and optimization algorithm which senses the shadow and transfers the optimum decision to the mechanical unit process, which will be explained later.

Before moving onto the sub-units in the shadow sensing subsystem, it is necessary to look at the evaluation metrics that we use in the Canoptima project. As the fixing ratio of the shadow, we calculate the ratio of the intersection area of the initial and final shadow to the union area of those on the ground. This “Intersection Over Union (IOU)” metric calculation can be seen in Figure 3.4.1.

$$IOU = \frac{\text{area of overlap}}{\text{area of union}} =$$

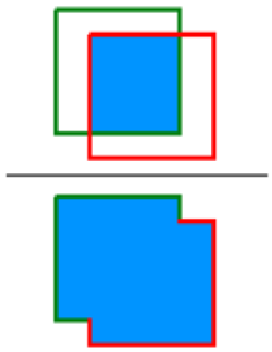


Figure 3.4.1. IOU calculation.

The reason we choose this metric as our fixing ratio is its well-fitting to our problem. As we try to maximally keep the initial shadow, the final obtained shadow needs to cover the initial shadow as much as possible. In this way, IOU metric measures how much an obtained final shape covers the first geometrical area. So, considering the definition and the basics of the problem, choosing the IOU metric as the fixing ratio serves well in our project.

The advantage of the IOU metric can also be thought from the possible implementations of our device in daily life. People on the beach or in gardens always desire the shadow on them to remain stable. Since we have also proven with the calculations in the mechanical subsystem, keeping the shadow between the poles of our canopy leads to the optimal solution in fixing. When we gather the expectations of people with the results of our simulations, we need to solve the shadow fixing problem by always covering the area between the poles. At this point, the IOU metric shows at which level we could achieve our aim by simply covering the initial area and not disturbing the environment by making larger and larger shadows.

Apart from the intersection over union ratio, there are also other metrics used in the detection algorithms, such as average precision with the percentage of the correct positive predictions or precision recall curves [2]. Since the Canoptima project does not compose any classification or regression problem as in object detection algorithms, the utilization of other metrics is not applicable for this problem.

As an option, we have planned to adapt the precision metric to our problem. That is, if a line is detected and belongs to the shadow, then it counts as a correct positive detection. After a time period, we can calculate the success of our system with the following formula for this metric:

$$Precision = \frac{Number\ of\ frames\ with\ detected\ correct\ positive\ lines}{Total\ number\ of\ frames}$$

In the detection algorithm, which is explained in the following subchapters, we have used constraints such as the slope of the sides of the shadow area. As a result of them, our line detection algorithms showed very high performance. Therefore, the precision metric which we thought of as an assistant tool was not quite different from around 99%. Hence, we have maintained using the IOU metric during the whole Canoptima project since it comprehensively fulfills the area fixing concept.

In the next chapters, we have explained the system features and the detection and optimization algorithm in parallel to the theoretical explanations.

3.4.1. System Features

In the Canoptima project, in order to have a safe design with simple calculations, we have chosen our canopy to have four poles with square shape. As mentioned previously, we have also decided to construct our design based on the idea of covering the initial shadow, which is the area between the poles of the system. For this purpose, we needed to be able to control the area between the poles as much as possible. Therefore, our solution is to cover this area by placing two cameras on the opposite corners of a diagonal. The 3D drawing of the system on GeoGebra with one light source position can be seen in Figure 3.4.1.1 and 3.4.1.2.

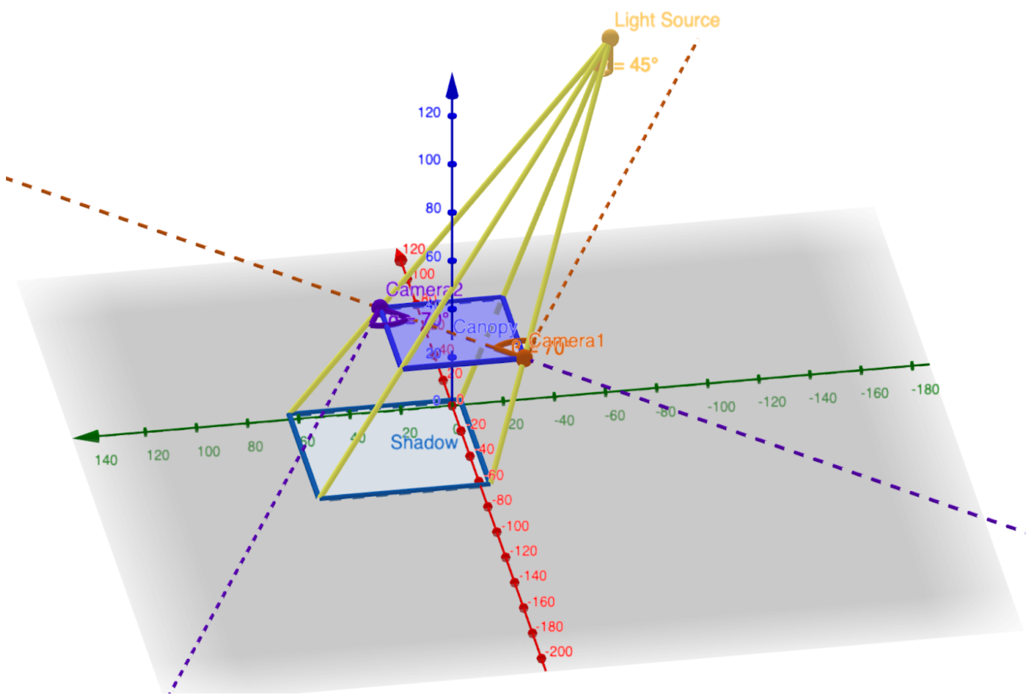


Figure 3.4.1.1. 3D system design for the cameras (side-look).

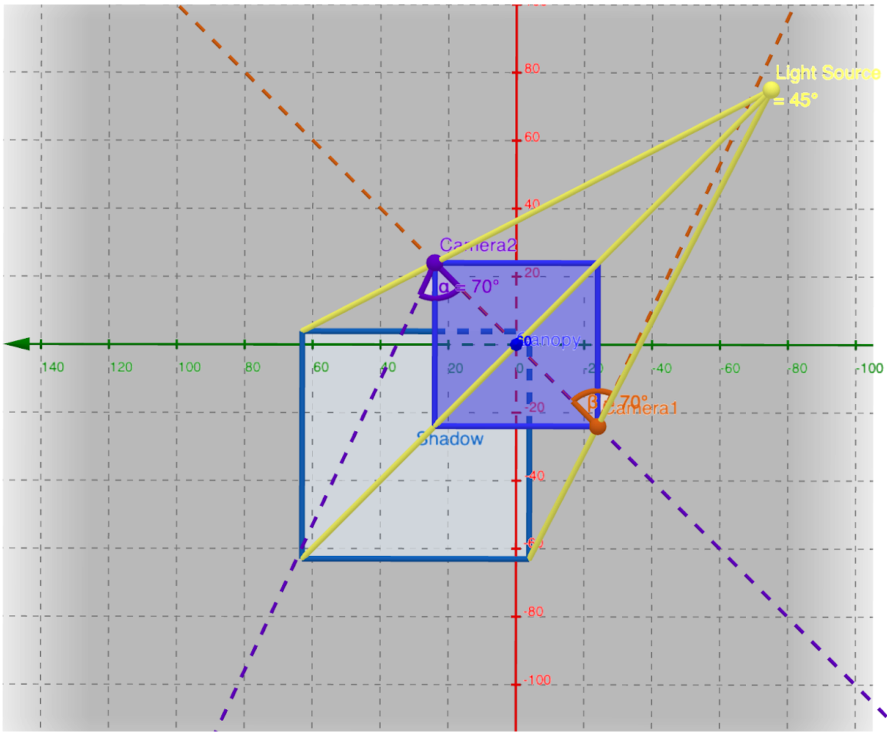
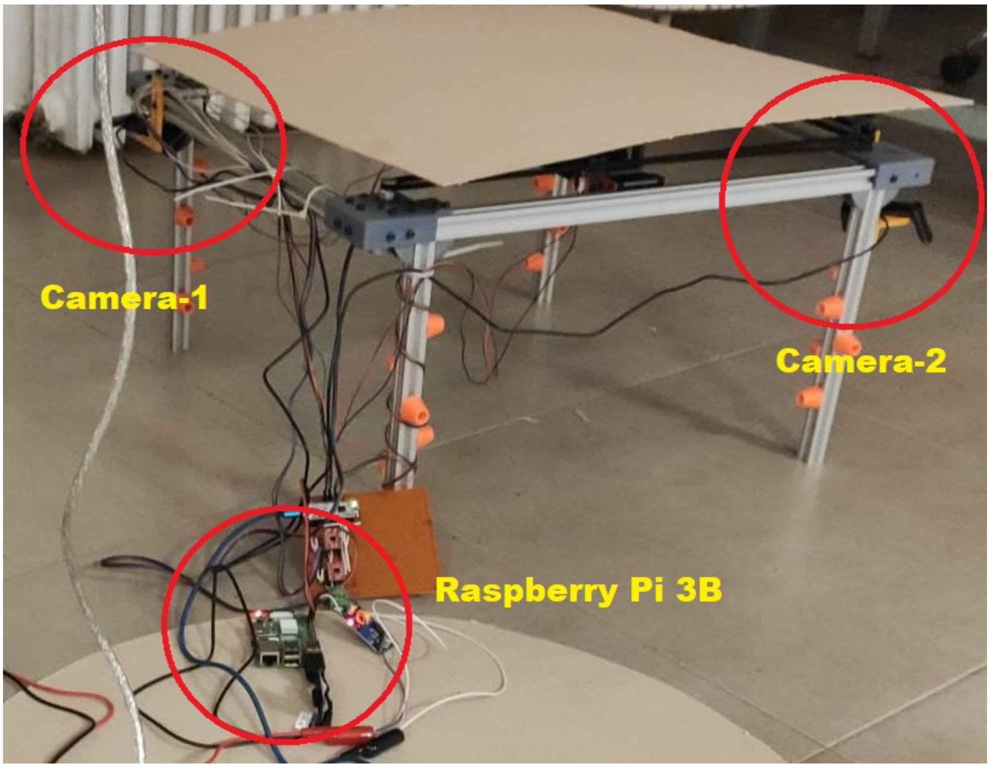


Figure 3.4.1.2. 3D system design for the cameras (top-look).

As seen in Figure 3.4.1.1 and 3.4.1.2, the purple dashed lines indicate the angle of view of one camera and the orange drawings demonstrate that of the other camera. When the angles are computed for the extreme cases, in which the light source is on the 45° angle from the plane of the diagonal, the field of view (FOV) of the camera needs to be at least 70° for a complete detection of the corner of the shadow. On the other hand, our solution does not require a complete detection but a covering of the initial area. Hence we could achieve successful operation with Logitech C270 model cameras, which have 55° FOV [3]. In this way, we have also contributed to the budget of the project since higher FOV means more expenses for the cameras. The look of two cameras with their connected processor Raspberry Pi 3B is shown in Figure 3.4.1.3.



3.4.1.3. Cameras with Raspberry Pi 3B.

3.4.2. Detection and Optimization Algorithm

Up to now, we have explained how the shadow fixing is achieved at best by placing the obtained shadow in the initial area defined by the poles of the system. To implement this in our system, at first, we need to be sure of the fact that any side border of the shadow is outside of the initial area. If any line of the shadow is detected in this region, it indicates that full coverage is not completed. Therefore, When we try to detect the shadow lines under the canopy, then we can determine whether fixing is done or not.

Even though line detection for the shadow is a simpler solution, it still comes up with its own difficulties. We need a robust algorithm to have the lines of the shadows in any noisy case. For this purpose, we have applied a HSV masking technique [4] in Python with OpenCV. In that, we determine minimum and maximum hue, saturation and value thresholds to get rid of unrelated features on the image. The thresholding mask that we use with the values can be seen in Figure 3.4.2.1.

Figure 3.4.2.1. HSV mask for line detection.

As clearly seen in Figure 3.4.2.1, the masking operation contributes to the detection algorithm remarkably. After that, we adopt the “Canny Edge Detection” algorithm [5] to extract the edges on the image and then, between those, we specify the lines on the image by using “Hough Line Detection” algorithm [6] in OpenCV. During the development process, we still have faced many problems and observed unexpected outputs. For this, as a last checkpoint, we decided to put a slope constraint into the program. Since our cameras are going to be fixed on the system and the shadow will always have a square form, the detected lines will have the slope of the vertical or horizontal lines of the projected shadow. Hence, our overall detection algorithm chooses the line that is filtered through these specifications and draws it on the frame. Examples from both cameras in our system with line detections are shown in Figure 3.4.2.2 and 3.4.2.3.

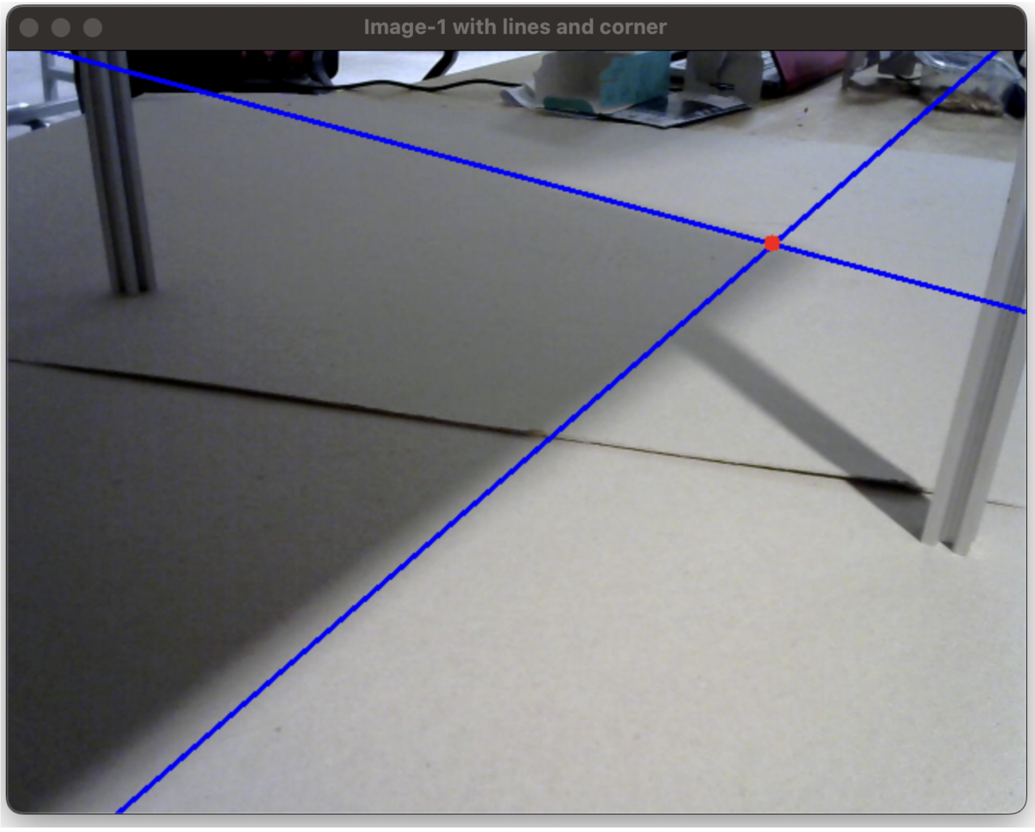


Figure 3.4.2.2. Two line detection from Camera-1.

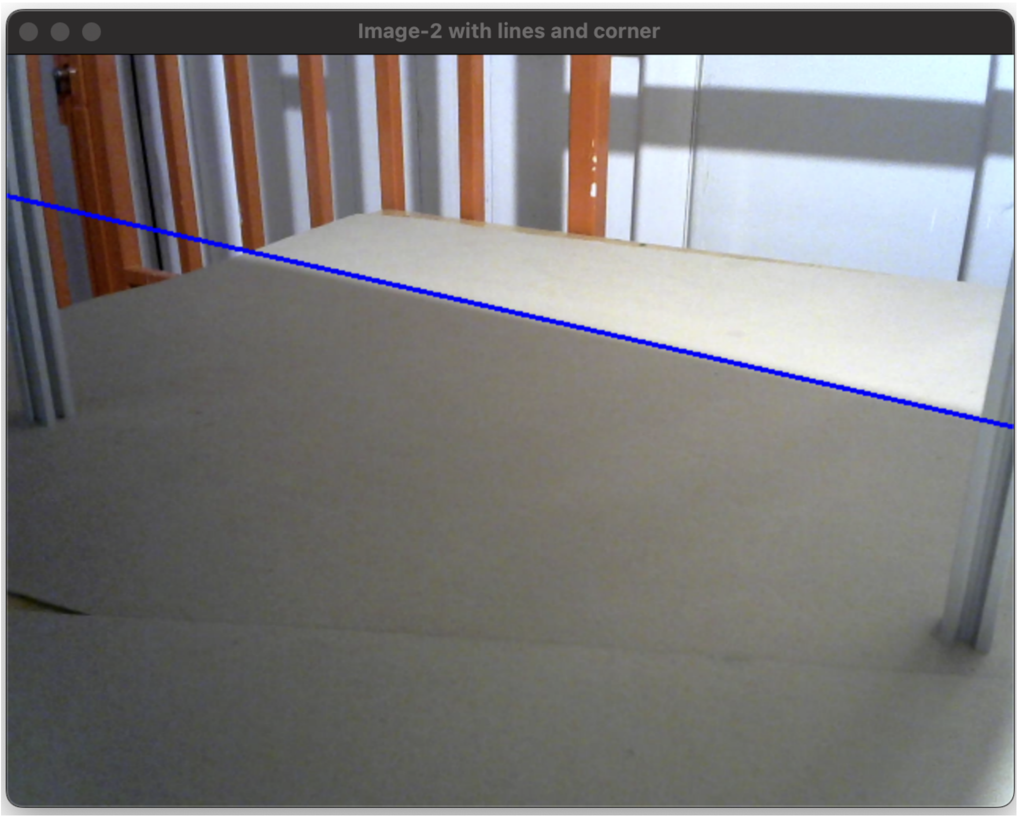


Figure 3.4.2.3. Single line detection from Camera-2.

In case of any shadow line detection inside the initial area, we need to move the canopy to carry that line outside of the region, i.e. cover the initial area completely with the shadow. This situation makes us move to the optimization subunit of our system. In order to determine if a line is objected to move, we compare its position with the line connecting neighbor poles. Examples of this operation on both cameras are displayed in Figure 3.4.2.4.

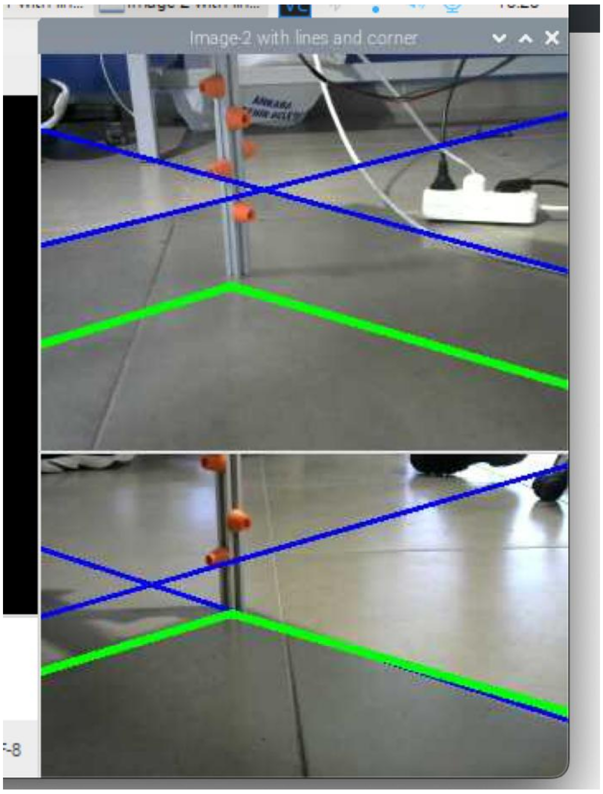


Figure 3.4.2.4. Comparing the detected shadow with initial area borders.

In Figure 3.4.2.4, we display the limits of the initial area with imaginary green lines. In our detection algorithm, four sides are named as “right (east)”, “left (west)”, “forward (north)” and “backward (south)” with a reference orientation. Whenever a detected (blue) shadow line is inside the region defined by green lines, the canopy finds the direction name of that line and sends the activation signal to the optimization function.

The mission of the optimization function in our algorithm is to decide the activation type of the motors. Although it seems like a simple operation with the transferred command from the detection subunit, we have added extra features to improve the performance of our design.

The first check in the optimization side is done by collecting the consecutive 10 commands coming from the detection algorithm. While continuously moving the canopy according to the commands, we also check in the background whether most of the recent commands are similar or not. That is, we collect “backward” and “forward” commands in one group while doing the same for “right” and “left” commands in another group. Therefore, in case of any reverse command, we do not let the canopy directly move to the reverse side but wait for a very small time to acquire the majority of the commands as the same. It improves the reliability of our algorithm.

Another check in the optimization sub-unit is performed against any completely wrong orientation of the canopy. In other words, when the light comes to the initial region and the canopy does not move to cover that area by shadow, that means something is wrong and the system automatically resets itself by moving the canopy into the middle in 2 seconds. Then, from the middle, it is easier to move the light source direction for the canopy and the detection continues. This fast reset enables us to react for any wrong case and recover the functioning immediately, which makes our system more robust.

Controlling the commands according to these specifications, our optimization function sends the resulting decision to the controller in our system via UART serial communication. We have chosen the baud rate 9600 for this operation and command frequency as 25 Hz. After the commands arrive one-by-one, the mechanical and electronics subsystem activates motors accordingly.

The flow diagram of the whole operation of the shadow detection subsystem can be seen in Figure. 3.4.2.5. The flow chart shows the operation done on one camera input. However, the second camera has the same operations. The decision will be given by the microprocessor after taking both of the results coming from both of the cameras. Move signals are calculated and sent to the other signal sending thread. In the thread the reset signal is generated. If reset is needed the canopy position is reseted. Otherwise, move message is prepared with respect to the calculated move signals in the main thread and the message is sent through UART interface.

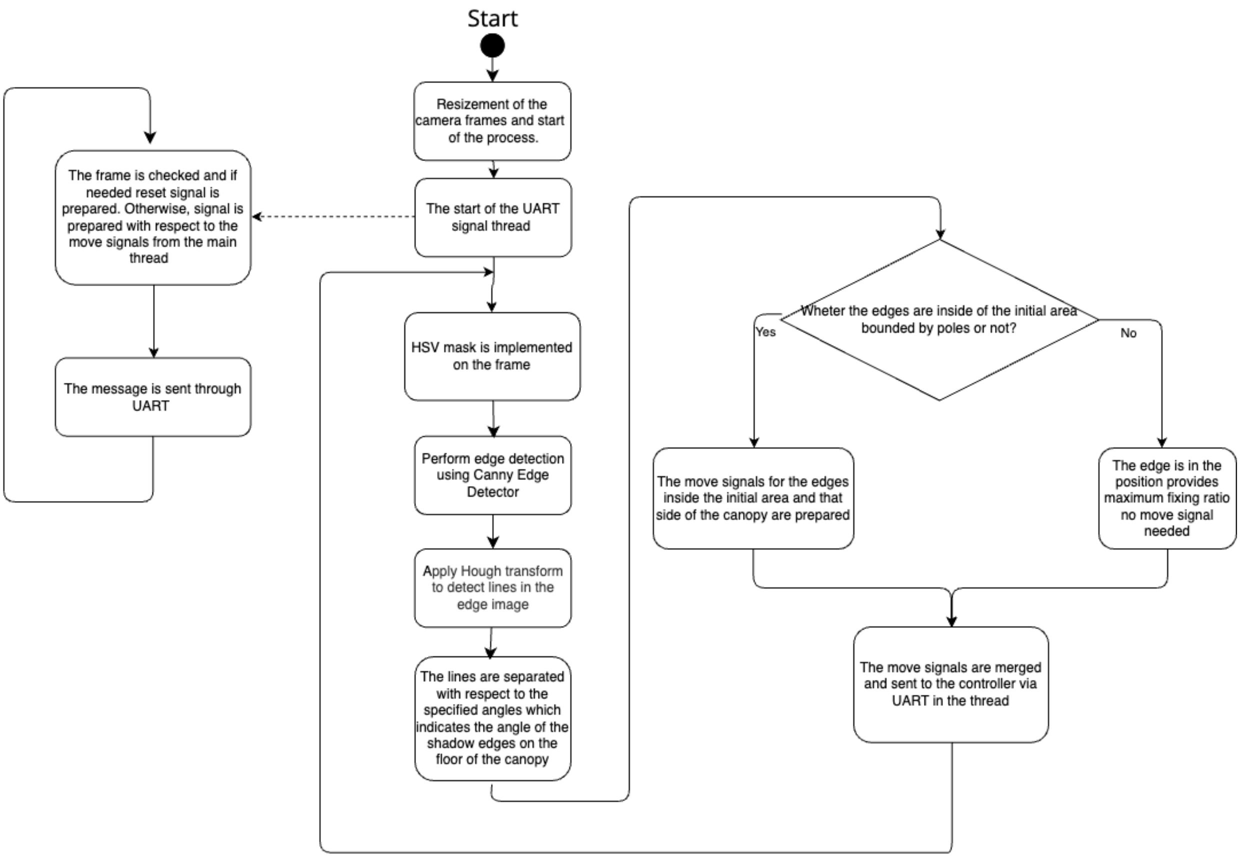


Figure. 3.4.2.5. Flow Chart of the Detection Algorithm and the Optimization Method

4. *Design Requirements*

In this section, we will be once again providing general design requirements of the project. The special design choices for each of the subsystems can be found in the previous section in which we discuss the overall system design in full detail.

The physical design requirements of the product is as follows:

- ☐ The canopy must have a height between 30 and 50 cm at all times.
- ☐ There are at least 3 poles under the tent and the canopy shape should be of a polygon with the number of poles indicating the corners.
- ☐ The poles must be fixed to the ground.
- ☐ The distance between adjacent poles should be 50 cm on the ground.

The functional requirements of the product is as follows:

- ☐ The system should be compatible with a light source which moves smoothly within a spherical sector of a maximum of ±45 degrees in all directions.
- ☐ For various light source positions and orientations in 3D, the canopy should arrange its positioning automatically to maintain the location and coverage of the shadow as constant as possible with the initial shadow indicated by the poles.

The performance requirements of the product is as follows:

- ☐ The system can take 3 different positions in 20 seconds.
- ☐ The fixing ratio ought to be as near to one as is reasonably possible. The intersection of the first and succeeding shadows is divided by their union to determine it.

5. Design Modifications

Proposed design in Conceptual Design Report was almost the same as the design which is planned to be implemented in the Critical Design Review report. Yet, the canopy shape which was planned before as a circle is changed to square canopy with the request of the customer. The request actually was that the canopy is to have a polygon shape with respect to the number of poles indicating the corners. As we have 4 poles in the design, the canopy has been shaped as a square.

The modification of shape of the canopy was not affecting electronic and mechanical system designs. However, the modification which has been done on the system, has affected mainly the shadow sensing subsystem. When the canopy was shaped as a circle, the algorithm was detecting the circle shadows. However, with this modification, we created a new algorithm that detects the edges or corners if applicable of the square shadow which is created by the square canopy. The change in the algorithm is explained in the shadow sensing subsystem section in Critical Design Review Report.

Overall, except for the modification of shape of the canopy, no modifications have been done on the design that is proposed in the Conceptual Design Report and Critical Design Review Report. The proposed design in Critical Design Review Report was taken as reference and implemented as it was proposed.

6. Compatibility Analysis of Subsystems in Interface, Software Version, Timing

As engineers, we have to be careful about the compatibility of the products we have used in our systems. For this purpose we have to discuss the components we have used in our design.

First components to be discussed in our system are the cameras. We are using 2 cameras to detect the shadow position. To process and detect the image, we are using Raspberry PI. A connection between each camera and Raspberry PI is made with a universal serial bus (USB) connection. USB is an important standard which is developed by many companies. These companies form a nonprofit union (USB-IF) to provide support and continue its development. In our case we are using USB cameras, which is actually using USB video device class (UVC). Since the USB devices are tested before sale, and checked for compliance we can use them directly. Companies which are producing equipment like the camera we used, pay USB-IF for these compliance marks. This means that by only checking the datasheet of a camera we can be sure about its USB compliance. Because of this, for the signal compliance of the camera for our system, the only thing we need to do is to check it before buying. For the temperature and ingress protection we do not have any specifications, so we did not pay attention to those specifications since they highly affect the price. Any other specifications about the camera have already been discussed in this report.

For the signal compliance of the Raspberry PI, we again have USB compliance in USB ports. However, we know that Raspberry PI will also communicate with the microcontroller, and we have to be sure about their compliance before connecting it. For UART connection in Raspberry PI we have 2 options, we can use USB to Serial bridge or we can use the UART ports of the GPIO's of the Raspberry PI. In either case we have 3.3V CMOS output and input stage compliant with 3.3V CMOS output. This means that if we use a microcontroller with 3.3V CMOS compliance, then we can connect them. For this condition we do not have anything to do with Raspberry PI, hence we will continue our discussion on the microcontroller.

These days, most of the microcontrollers have complied with our requirement created by the Raspberry PI, for this purpose, we decided on the STM32 family of microcontrollers. STM32 also has a logic level voltage of 3.3V (Most of its pins are also

5V tolerant, this means that you can apply 5V to input pins without any hesitation.), this means that we can communicate with the Raspberry PI. However, to communicate, we also specify some information on UART (like baud rate, parity, number of stop bits etc.), since we are designing both sides of this communication, we can set these parameters as the same on both sides. Moreover, we will create signals for step drivers (Enable, Direction, Step) to be sure that these signals will be understood correctly by the stepper motor driver. We will again check the voltage levels and their design standards. For this purpose we checked the datasheets of available drivers in the market, and found out that A4988 drivers are fit for our problem.

With this information, we are sure that all signal interfaces are good. A simple diagram of these interfaces can be seen below in Figure 6.1.

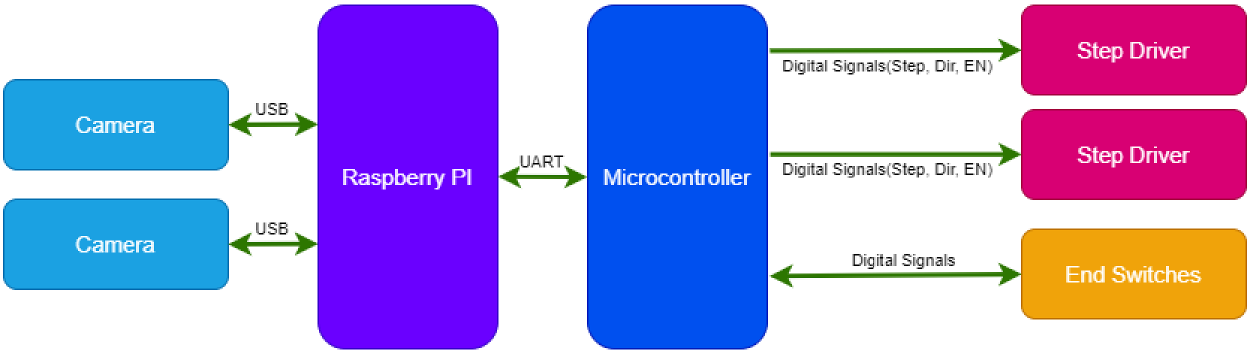


Figure 6.1. Simple signal diagram

Coming to software versions, the Pyserial Library in Python will be used to connect Raspberry Pi to the microcontroller. By the help of the library, baud rate (speed) of the connection can be arranged with respect to the required speed. Also by using the library, the read, write and other functionalities can be implemented easily. It is more practical than trying to connect Raspberry PI with the microcontroller using firmware applications where the signals must be sent manually.

Timing of the USB communication is done in its hardware and software layer, it is not our responsibility and modifying it is also quite hard. For the timing of the serial communication between Raspberry PI and the microcontroller, synchronization will be done on each valid package. When all packages in the buffer are transmitted the communication line stays in IDLE state, this can be detected in hardware. By detecting line idle signals inside of the microcontroller we will synchronize and adjust the timing. There is no strict requirement for other signals, they can be adjusted inside of the microcontroller. In the case of any problem, a logic analyzer can be used for analyzing these signals and debug purposes.

7. Compliance with Requirements

The system requirements and our specifications in the Canoptima Project to meet those are listed in Table 7.1. Please note that, as we explained in Section 3.1, the tilting motion increases the cost of the product considerably while only increasing the efficiency slightly. As engineers, we decided to reduce the costs by having the trade-off of having slightly less IOU values.

Table 7.1. System-level and all subsystem-level requirements.

System Requirements	Subsystem Specifications
The system should detect the shadow for light source positions in a spherical sector of ∓45° in all directions.	Shadow: Field of view (FOV) of the camera should be chosen accordingly. We chose ours to have 55 degrees, which was enough for our case as explained in Part 3.4.1.
Pole positions on the ground are fixed. The canopy's height is between 30cm and 50cm at all times.	Mechanical: Poles are fixed, there is no z axis motion and the pole lengths are 30cm.
System should be able to respond to at least 3 different light source positions in 20 seconds.	Mechanical: Should not be too heavy/bulky. For this reason we chose sigma profiles made of aluminum and carbon fiber tube holders. This way we provide a lightweight and sturdy solution at the same time. Shadow: Detection should not be time-consuming. Electronical: Needs to be fast to not limit the shadow detection system. The diagonal length (the worst case - the longest path) is 59 cm. Our step motor has a 1.8° step angle that results in 1 revolution per second. The pulley diameter is 27.5 mm, meaning we can move 86.4 mm in a second. This means our choices are sufficient.

8. Tests Procedures and Assessment of Test Results

In the Canoptima project, we have planned our tests for each subsystem separately. That is, we are testing the functioning of the device on subsystem-level. The details of these tests for mechanical, electronics and shadow sensing units are shown in the following subchapters.

8.1. Tests for Subsystems

The parameters considered for the tests of the subsystems are identified below:

1. Light source angle: The angle of light source with respect to the ground normal. When the light source is at the centered top of the canopy, the light source angle is defined as 0°.

2. Light source distance: The distance of light source measured from the center of the initial canopy position on the ground.

3. Canopy position on x-axis: The position canopy takes on x-axis after moving the light source. Considering the two actuation directions of the canopy, one direction is defined as the x-axis by determining the positive and negative ranges. When the canopy is at the center, the canopy position on the x-axis is defined as 0cm.

4. Canopy position on y-axis: The position canopy takes on y-axis after moving the light source. Considering the two actuation directions of the canopy, the direction perpendicular to the x-axis is defined as the y-axis with its positive and negative ranges. When the canopy is at the center, the canopy position on the y-axis is defined as 0cm.

8.1.1. Tests for Mechanical Unit

The mechanical unit test aims to verify if the subsystem meets the mechanical requirements defined in the project.

The measurement tools to be utilized while testing:

- Ruler
- Timer

To test the mechanical unit, we have planned to conduct different procedures:

1. The first test is conducted to determine if the poles are fixed to ground by manually checking. The distance between adjacent poles is going to be measured by using a ruler to check if they are 50 cm apart. Moreover, the height of the canopy is measured to check for 30-50 cm.

2. For the second test, the light source is moved from azimuth angle -45° to +135° on the same axis while keeping the radius constant and time will be measured by the timer.

The first expected outcome from the mechanical unit is the poles are fixed to ground with 50-centimeter adjacent distance and a height between 30-50 cm. The other outcome expected is that the canopy can take an optimal position under 10 seconds when the light source is moved from -45° to 135°. The test tables and expected outcomes are defined below in Table 8.1.1.1 and 8.1.1.2.

Table 8.1.1.1 : Mechanical Unit Test I - Fixed Poles Distance & HeightTest

Tests	Actual Performance (Y/N)	Expected Performance
Poles are fixed to ground	Y	Y
Distance Between Adjacent Poles = 50 cm	Y	Y
Canopy height is between 30-50 cm	Y	Y

Table 8.1.1.2: Mechanical Unit Test II - Time Limit Test

Light source azimuth angle	Actual Performance	Expected Performance	Error
-45° to +135°	9.5seconds	10 seconds	-0.5 seconds

8.1.2. Tests for Electronics Unit

The electronics unit tests consist of two different power consumption tests, one for the minimum load case (idle state), and one for the maximum load case (maximum power consumption state).

The measurement tools to be utilized:

- Voltmeter
- Ammeter

The ground truth for these tests is going to be our theoretical calculation, in which the input voltage and input current values will be multiplied with each other and to obtain the input power demand of the system.

1. First test is conducted by keeping the light source distance and angle constant and measuring the voltage and current values for idle state every 2 seconds for 10 seconds.

2. The second test is conducted by changing the light source distance and angle at various values and measuring the voltage and current values for maximum power consumption state every 2 seconds for 10 seconds.

The test tables and expected outcomes for these tests are defined below in Table 8.1.2.1 and 8.1.2.2.

Table 8.1.2.1: Electronics Unit Test I - Idle State Power Consumption Test

State of the System	Actual Performance	Expected Performance	Error
Idle	10.856W	12 W	-1.144 W

Table 8.1.2.2: Electronics Unit Test II - Maximum Load Power Consumption Test

State of the System	Actual Performance	Expected Performance	Error
Maximum Load	11.3W	13 W	-1.7 W

8.1.3. Tests for Shadow Sensing Unit

We consider the fixing ratio obtained for a specific light source angle and distance, and compare the data with the simulation that has been done for different light source angles and distances.

The measurement tools to be utilized:

- Light source
- Ruler

Ground truth is defined as the data obtained by the ruler for the shadow sensing subsystem. The decided cases for the tests will be realized and the fixing ratio (intersection/union of the initial and final shadows) will be measured. Then, we will compare the measured data with the simulation/expected result.

1. First test is done by changing azimuth angle values (0°, 45°,90°) while R and elevation is constant.

2. Second test is done by changing R values at 90° elevation. At this elevation angle, azimuth angle values do not matter.

3. Third test is done by changing elevation angle (45°, 64°, 90°) with constant R and azimuth angle, in 2 different azimuth angle (0°, 90°) positions.

The test tables and expected outcomes for these tests are defined below in Table 8.1.3.1, 8.1.3.2 and 8.1.3.3.

Table 8.1.3.1: Shadow Sensing Unit Test I - Azimuth Angle Test

Distance Value (R)	Elevation Angle Value	Azimuth Angle Value	Actual Performance (cm^2/cm^2)	Expected Performance (cm^2/cm^2)	Error (cm^2/cm^2)
2.0m	45°	0°	0.2425	0.2451	- 0.0026
2.0m	45°	45°	0.3810	0.3786	+ 0.0024
2.0m	45°	90°	0.3718	0.3055	+ 0.0663

Table 8.1.3.2: Shadow Sensing Unit Test II - Light Source Distance Test

Distance Value (R)	Elevation Angle Value	Azimuth Angle Value	Actual Performance (cm^2/cm^2)	Expected Performance (cm^2/cm^2)	Error (cm^2/cm^2)
1.6m	90°	NA	0.4217	0.4104	+ 0.0113
2.0m	90°	NA	0.4565	0.4613	- 0.0048
2.4m	90°	NA	0.4959	0.4968	- 0.0009

Table 8.1.3.3 Table: Shadow Sensing Unit Test III - Elevation Angle Test

Distance Value (R)	Elevation Angle Value	Azimuth Angle Value	Actual Performance (cm^2/cm^2)	Expected Performance (cm^2/cm^2)	Error (cm^2/cm^2)
2.0m	45°	90°	0.3718	0.3055	+ 0.0663
2.0m	64°	90°	0.4328	0.4380	- 0.0052
2.0m	90°	90°	0.4565	0.4613	- 0.0048
2.0m	45°	0°	0.2425	0.2451	+ 0.0026
2.0m	64°	0°	0.4328	0.4380	- 0.0052
2.0m	90°	0°	0.4565	0.4613	- 0.0048

8.2. Tests and Requirements

The tests in the Canoptima project aim to fulfill the defined requirements. The matching of tests and the corresponding requirements can be seen in Table 8.2.1.

Table 8.2.1 Table: Tests and Corresponding Requirements

		Requirements							
		Req1	**Req2**	**Req3**	**Req4**	**Req5**	**Req6**	**Req7**	**Req8**
TESTS	**MU-1**	✓	✓	✓	✓				
	MU-2							✓	
	EU-1					✓	✓		
	EU-2					✓	✓		
	SSU-1					✓	✓		✓
	SSU-2					✓	✓		✓
	SSU- 3					✓	✓		✓

The abbreviations used in Table 8.2.1 are given below:

Req (Requirement), MU (Mechanical Unit Test), SSU (Shadow Sensing Unit Test), and EU (Electronics Unit Test).

Req1: The canopy height between 30 and 50 cm

Req2: At least 3 poles and the canopy shape is polygon wrt. pole number

Req3: The poles must be fixed to the ground.

Req4: The distance between adjacent poles should be 50 cm on the ground.

Req5: The system should be compatible with a light source which moves smoothly within a spherical sector of a maximum of ±45 degrees in all directions.

Req6: The canopy should arrange its positioning automatically to maintain the location and coverage of the shadow as constant as possible.

Req7: The system can take 3 different positions in 20 seconds.

Req8: The fixing ratio, which is defined as the ratio of the intersection over union of the initial and succeeding shadows, should be maximized with the defined constraints.

8.3. Evaluation of Test Results

According to the results of the tests for all the subsystems, we can conclude that our design meets well the requirements defined for the shadow fixing intelligent canopy project. While fixing the shadow with top performance, we have obtained the test results with mostly very small errors, which is an indicator of the accurate implementation of the theoretical concepts.

The system works as expected with respect to the simulation results and also is capable of providing the most efficient canopy positions with respect to various light source angles and distances. These various repeated tests demonstrate the precision and robustness of the system.

9. Deliverables

9.1. Equipment

- Canopy

This is our primary output; it is the amazing canopy system we promise, one that is clever, user-friendly, and energy-efficient.

- Adapter

A suitable power adaptor will be given to the user in order to activate the canopy system.

9.2. Documents

- Warranty

Optima Technologies offers a 2-year warranty to its devoted clients. This warranty covers everything, therefore it can be used for any hardware or software-related problem. On the other hand, it firmly excludes errors caused by faulty user applications that do not follow the manual's recommended rules.

- User's Manual

A thorough user manual that explains how to initiate, use, and preserve our product is given in section 16.2 User's Manual to Canoptima consumers. Each customer should strictly adhere to these suggested rules shown in the user manual in order to prevent any improper system operation and receive the best results.

10. Budget

Table 10.1 Bill of Materials for Canoptima Project

NAME	AMOUNT	PCS PRICE ($)
Sigma profiles (20x20)	3.91 meters	12
Linear guideway rail &2 cars	1 meter	35
Sigma car	1	5
GT2 pulley	10	0.5
GT2 belt	4 meters	5
Carbon fiber tube	2	4.2
Corner fitting connections	12	0.1
Nuts, bolts,washers	1	4
Limit switch	4	0.25
220v-12v power supply	1	7
Microcontroller (STM32)	1	4.75
A4988 Step motor driver	2	0.75
Voltage regulator	2	0.75

Raspberry pi 3B	1	60
NEMA17 step motor	2	5
Logitech c270 camera	2	18
Cardboard	1	1
	Total Cost =	198.35$

11. Power Management

Simplified power diagram of the overall system has already been presented in Figure 3.3.2, but for convenience we are presenting it again in Figure 11.1.

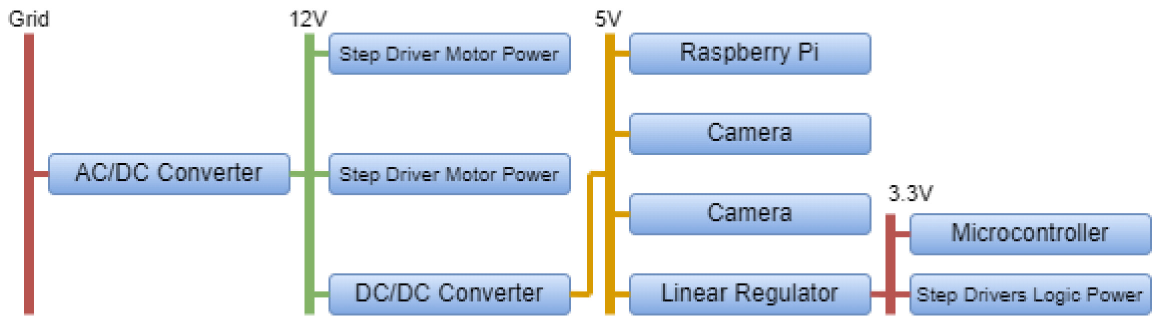


Figure 11.1. Simplified Power Distribution Diagram

As can be seen on the figure, we have 3 different DC voltage buses.

Table 11.1 Power consumption analysis table

Component	Operating Voltage(V)	Operating Current(mA)	Power Consumption(W)
Raspberry Pi	5	700*	3.5
Each Camera	5	200	1
Microcontroller	3.3	60	0.198
Logic Side of Each Motor Driver	3.3	20	0.066
Power Side of Each Motor Driver	12	300	3.6

(*)Peak consumption is 3000mA but in our system mean current is about 700mA

For our system we have 2 cameras and 2 motor drivers, this means that our total power consumption value will be approximately 13W, as shown in Tables 8.1.2.1 and 8.1.2.2. However, when we add the efficiencies of the converters we expect that our consumption from the AC/DC converter will be approximately 20W.

For the measurement of the power consumption on the DC side, we can use 2 simple multimeters. Power consumption of the products in the list found with this type of test.

12. Safety

As Optima Technologies, we believe in the fact that creating the best solutions is crucial to our society. However, these best solutions should not compromise the safety of the society we serve. In this section, we will be talking about some potential safety issues regarding our intelligent canopy.

The main concern might be that how the cameras under the tent of our product operate: As Optima Technologies, we hereby declare that under no circumstances the images or recordings in general we obtain from the cameras are stored in any medium in our servers and they are solely used to obtain the optimum position for the canopy and produce the best user experience. We also acknowledge that, even though Optima Technologies does not keep the log of any video captures, there is always a risk of being hacked by malicious hackers. However, we are always working on protecting our customers by actively updating and improving our customer protection services.

Another concern might be the durability of our product. Since the product will have people sitting, standing and laying underneath, Canoptima should definitely be durable. As Optima Technologies, we firmly believe that our customers should always feel valued and protected, hence, in our electric canopy, we have used the most reliable materials while producing and assembling the mechanical parts so that the collapse risk of our canopy is totally eliminated.

13. Impact

13.1. Societal Impact

Canoptima is the intelligent solution for an important problem in our lives: We want to enjoy our time outside and unwind but we can only do that as long as the environmental conditions allow us. In this sense, one important constraint is the sun. We do like to enjoy the sunlight, but most of the time we prefer to relax under a tree or non-electric canopy that casts a shadow on the ground. As the time passes though, the location and the size of this shadow changes, so we either have to change our place, or change the orientation of these non-electric canopies. However, with the widespread usage of our intelligent canopy, we will be able to spend the maximum amount of time outside as a society, which will allow us to connect and socialize with each other even more. The intelligent canopy will also help the health of the people by reducing the amount of time they spend under the sun that goes unnoticed to them while they are sleeping or socializing, by casting a shadow on top of them and hence protecting them anytime. Hence, to conclude, we believe that the widespread usage of our product will benefit our beloved society immensely.

13.2. Environmental Impact

Optima Technologies developed Canoptima, a clever shadow-fixing canopy solution, to make it easier for everyone to spend time with their loved ones and unwind outside. Our customers may initially wonder whether or not having a fixed, constant shadow at a certain area might have some adverse environmental effects, but at Optima Technologies, we do not believe that this would be a problem because our product Canoptima only assists people in obtaining a constant area of shadow automatically rather than manually adjusting their non-electric tents, which have long been used in our daily lives and produced no adverse environmental effects.

Another environmental concern of Canoptima may be due to its power consumption, however, as we have shown in Section 11 Power Management, we expect our product to consume only about 20 W, which is definitely less than the average power consumption of a light bulb, that is typically around 60 W. Hence, we can safely conclude that as Optima Technologies, we do not expect any adverse environmental effects due to the widespread usage of our intelligent canopy.

14. Conclusion

We all like lounging on the beach under our canopies, enjoying the sea breezes while reading our favorite books or simply enjoying the sunshine. Or, on occasion, we may just wish to take our loved ones on family picnics so we can make the nicest memories while they indulge in the delectable food and drinks we packed. In each of these circumstances, our top aim is to enjoy our time without encountering any obstacles. However, as our exposure to the sun lengthens, we must adjust the placement of our canopies in order to maintain our shadow coverage.

Therefore, Canoptima, the most intelligent shadow-fixing canopy made with the greatest engineering methods and cutting-edge technology, allows you to spend your time undisturbed, according to the new solution suggested by Optima Technologies to solve this issue.

Our solution approach to the problem is generating the optimal movement that keeps the maximum fixing ratio by using the location data of the shadow created by the light source. There are 3 main subsystems in the Canoptima project namely, shadow sensing subsystem, mechanical subsystem and electronics subsystem. The shadow sensing system utilizes the cameras and detects the position of the shadow. Moreover, by the help of the processor, the required position is determined and sent through the serial interface to the microcontroller as movement commands. The electronic subsystem aims to build connection between the shadow sensing and mechanical system. It controls the actuators and realizes the motion which is specified by the processor. Finally, the mechanical system specifies the kinematics design, structural design, and the production of the design. By the help of all subsystems the canoptima project achieves to protect its users from harmful light beams.

Optima Technologies is committed to providing the best solution to our clients, regardless of the difficulties a particular project may face. This option, which we like to refer to as the "optima solution," will be provided to you by the knowledgeable technical staff at our outstanding, market-leading company. It will spare you the stress of having to get up to adjust your canopy when all you really need to do is lay down on your sunbed and enjoy your priceless time.

Remember, if there is no solution, then Optima is the solution, and we are here to present it.

15. References

[1] “Principle of Operation,” CoreXY. [Online]. Available: https://corexy.com/theory.html. [Accessed: 16-April-2023].

[2] Rafaelpadilla. (n.d.). *Rafaelpadilla/object-detection-metrics: Most popular metrics used to evaluate object detection algorithms.* GitHub. Retrieved April 16, 2023, from https://github.com/rafaelpadilla/Object-Detection-Metrics

[3] *Logitech C270 HD Web Kamerası, Gürültü önleyici Mikrofon ile 720p video*. Logitech C270 HD Web Kamerası, Gürültü Önleyici Mikrofon ile 720p Video. (n.d.). Retrieved April 19, 2023, from https://www.logitech.com/tr-tr/products/webcams/c270-hd-webcam.960-001063.html

[4] *Color space conversions*. OpenCV. (n.d.). Retrieved April 19, 2023, from https://docs.opencv.org/4.x/d8/d01/group__imgproc__color__conversions.html#ga397ae87e1288a81d2363b61574eb8cab

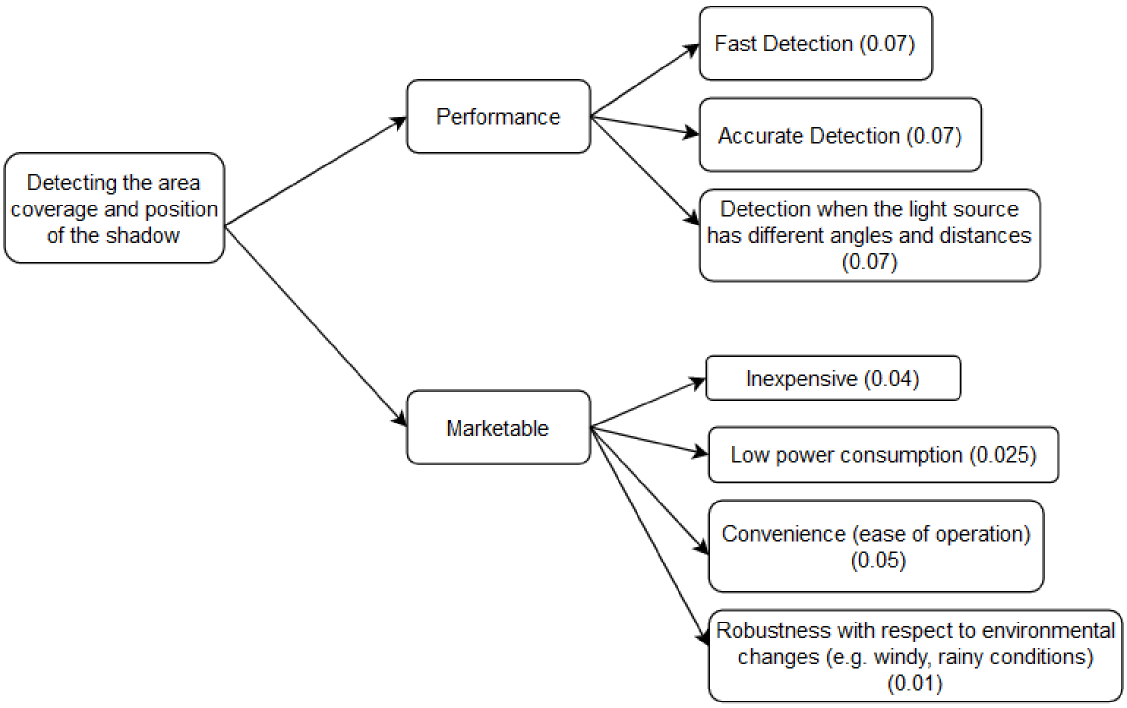
[5] *Canny edge detection*. OpenCV. (n.d.). Retrieved April 19, 2023, from https://docs.opencv.org/3.4/da/d22/tutorial_py_canny.html

[6] *Hough Line transform*. OpenCV. (n.d.). Retrieved April 19, 2023, from https://docs.opencv.org/3.4/d9/db0/tutorial_hough_lines.html

16. Appendices

16.1. Weighted Objective Tree

A weighted objective tree regarding the Canopy system created by Optima Technologies can be found in Figure A1.1, which outlines the types of objectives we have pursued and put into practice for various functional needs. This information is essential because these decisions directly affected the design choices Optima Technologies made while creating Canoptima.



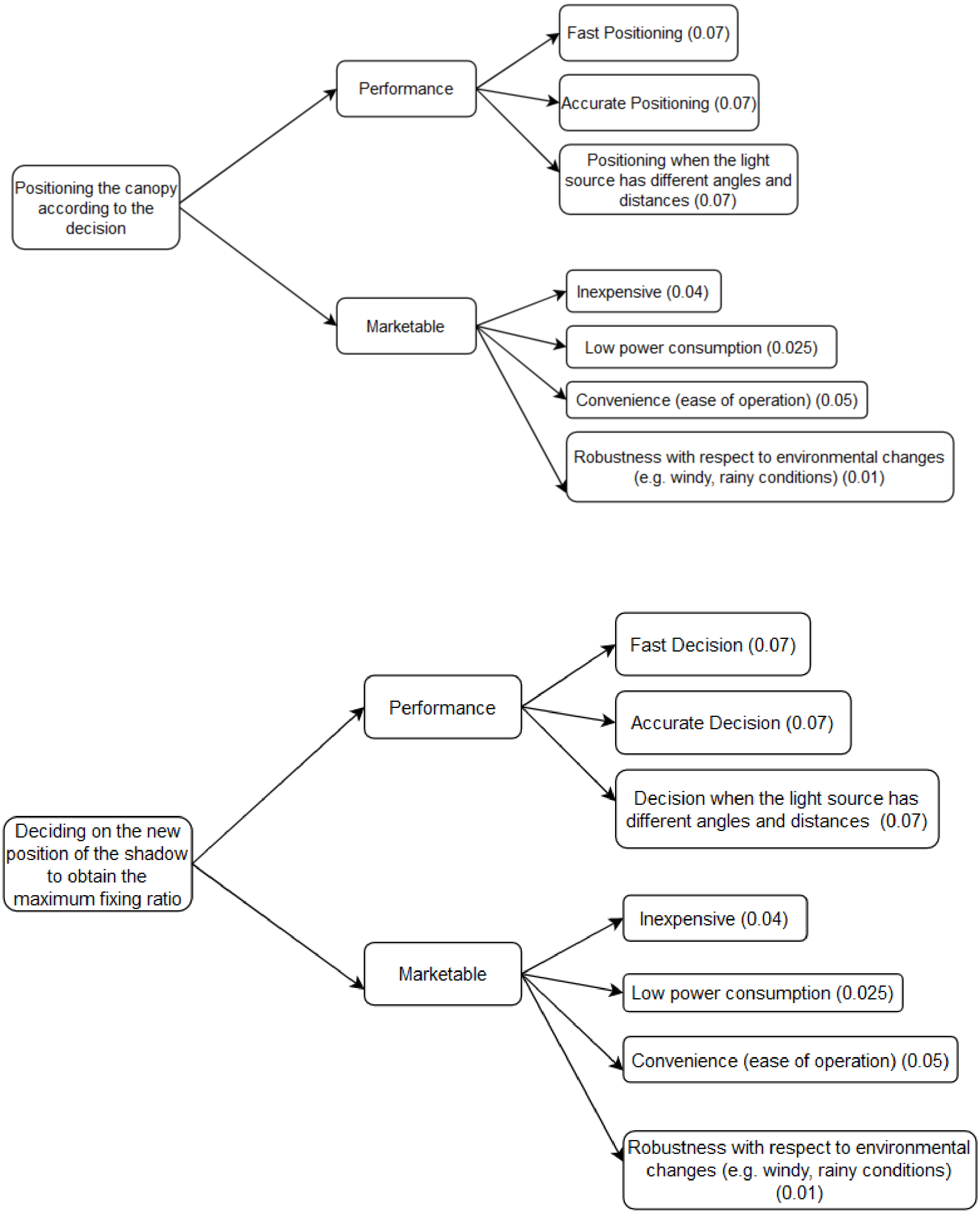


Figure A1.1: The weighted objective tree of Canoptima

16.2. User's Manual

How to use it?

1. The system should be plugged in and the first reset of the system should be waited before using.

2. After the first reset, the system automatically starts the process.

3. After the start, all you need to do is to take your place underneath the canopy and enjoy your time.

4. Please never interfere with moving parts of the product while it is plugged in, after the usage please turn off the system by plugging out.

Do's and Don'ts :

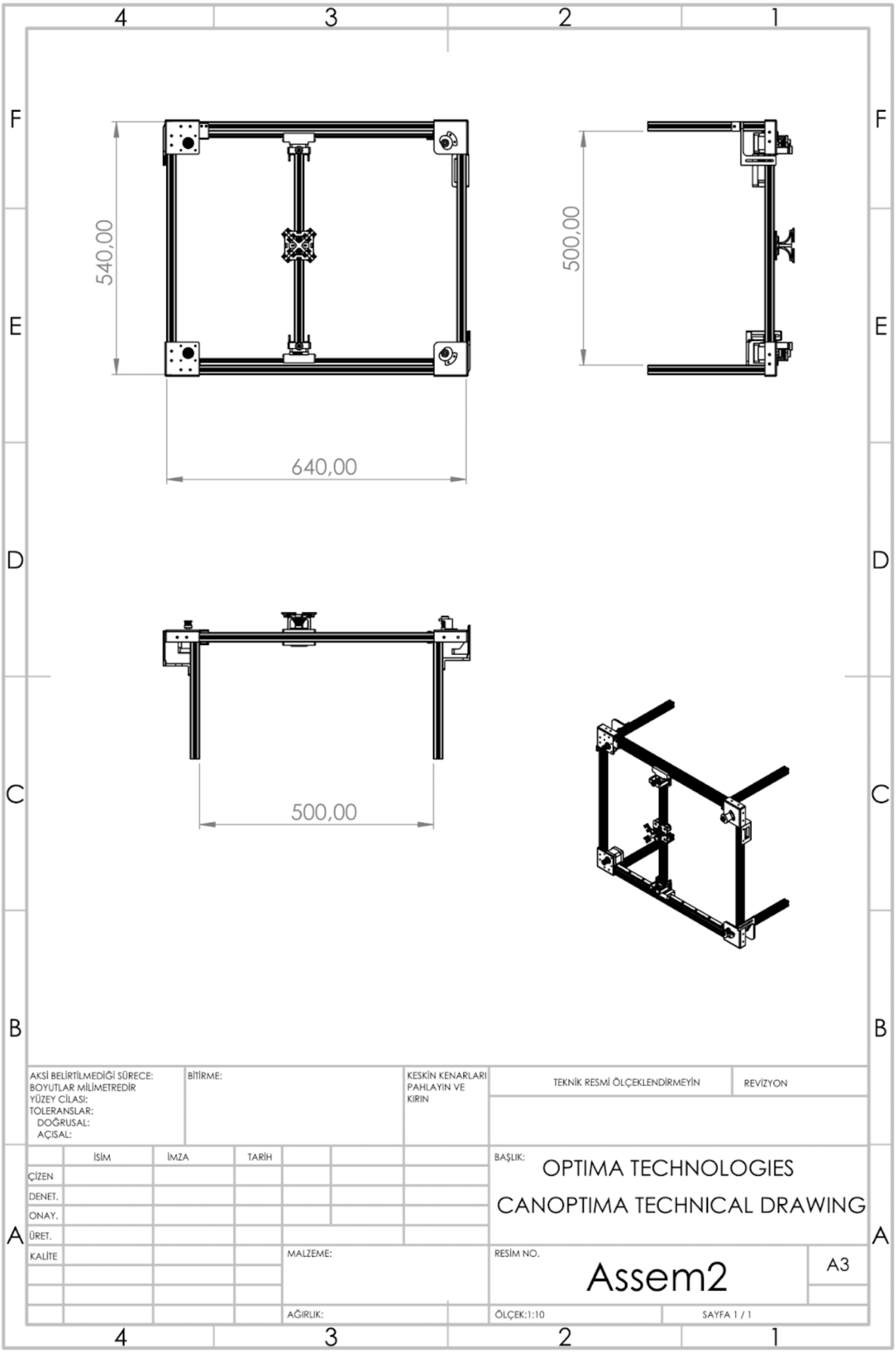
- Please be aware that the system can reset itself in the unexpected motion of the light. Do not interfere physically while resetting. Wait for the system to reset its position, when the canopy takes its initial position, the system will start its process again.

- The tent of the product moves with respect to the position of the light, hence, please do not interfere with the motion of the tent, since it may result in injury and may damage your product.

How to store:

- The product should be stored in a dry and clean environment. It should be checked before use for any damage.

16.3. Technical Drawing for Mechanical Subsystem



16.4. Project Related Codes

The final product codes of Canoptima project can be found in:

https://github.com/Gktut/Canoptima

- MCU:

The embedded code for microcontroller which receives messages from UART and sends required signals to the step motors to realize the motion.

- FreeTiltSolver_040623:

The Matlab code that calculates optimal solution of given light source position in terms of radius, elevation and azimuth given below where The CenterZ variable gives the height of the canopy. The Intersection Over Union (IOU) value of the optimal solution is given as output with the 2D view of the initial and subsequent shadow and the 3D view of the canopy with the shadows.

- canoptima.py:

The python code that takes input from the cameras and calculates the required motion. After the movement is specified, then the movement message is generated and sent through the UART interface.