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Camera & Laser Based Distance Control

Project Report for Mobile Working Robot Systems

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Hereby I declare that I wrote this thesis myself with the help of no more than the mentioned literature and auxiliary means.

Berlin, 12.08.2025

(Sebastianus Dustin Susanto)

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Abstract

Agriculture plays a vital role in sustaining life by providing food, raw materials, and economic stability. Among its many challenges, weed control is particularly important, as weeds compete with crops for water and nutrients, leading to reduced yield and slower crop growth. Among various weed control methods, mechanical weed control using laser weeding is both environmentally friendly and cost-effective. However, achieving precise laser weeding remains a significant challenge. This report presents a solution for maintaining a constant distance between the sensors (camera and laser) and the ground.

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1 Introduction

Weeds compete with crops for water and nutrients, significantly affecting crop growth and yield. Therefore, researching effective weed control methods is essential for sustainable agriculture.
Among the available techniques, chemical weed control is the most commonly used. However, it often leads to environmental pollution and contributes to the development of herbicide-resistant weed species. Biological control methods, which rely on plant extracts and pathogens to produce herbicides, can be expensive and potentially toxic to mammals. Physical methods, such as flame and laser weeding, offer efficient and precise weed removal but require advanced equipment. Mechanical weed control is more environmentally friendly and cost-effective, yet it faces operational and terrain-related challenges.[GS24]
To achieve accurate weed control, modern systems must integrate sensor technology, computer vision, and high-precision navigation. However, one of the major obstacles in real agricultural fields is the unevenness of the soil surface, which causes continuous variation in the distance between the sensors (camera and laser) and the ground. These variations impact image sharpness, distort spatial transformations from pixel to Cartesian coordinates, and reduce the effectiveness of laser targeting.
Therefore, this project aims to develop a camera- and laser-based distance control system that maintains a constant height between the sensing equipment and the ground, ensuring improved weed detection and more efficient laser-based weeding.

1.1 Project Goal

To ensure high-quality weed imaging, accurate pixel-to-Cartesian coordinate transformation, and efficient laser-based weeding, our project utilizes a line laser, a global shutter camera, and a linear actuator. These components work together to maintain a constant distance between the sensors (camera and laser) and the soil surface, thereby improving system precision and overall weeding performance.

1.2 State of Technology

In urban and semi-structured environments such as industrial parks and campuses, painted lane markings are often faded or poorly maintained, making them difficult to detect using CCD cameras. To address this issue, researchers have utilized 2D laser range data for fast and reliable curb detection. This laser data is then fused with image data using Extended Kalman Filters (EKF) to estimate road midlines and boundaries. These efforts reflect a growing trend of integrating geometric (laser) and visual (camera) sensing for robust feature detection in complex environments.[WKB02]

In agricultural settings, accurate depth perception is also critical. Systems such as the Active Laser-Camera Scanner (ALACS) combine a red line laser, an RGB camera, and a linear motion stage to create a dynamic scanning system based on laser triangulation, achieving depth measurement errors of less than 4 mm even under variable lighting and occlusion conditions in orchards. This demonstrates the feasibility of laser-camera fusion in outdoor, unstructured environments.[ZCL+23]
Simultaneously, spectral laser-based plant discrimination systems using multi-wavelength laser modules have shown excellent performance in real-time crop/weed classification. By calculating normalized vegetation indices (NDVIs) from the reflected beams, these sensors achieve plant identification accuracies above 90% at speeds up to 7.5 km/h.[APA+16]
Additionally, a modular laser weeding system has been developed to ensure compatibility with conventional farming machinery. The platform integrates a parallel-kinematics actuator with 445 nm, 36 W blue diode lasers for precise weed targeting. The next step in development includes incorporating plant center (heart) detection to align the laser more accurately with critical plant structures. Field trials are scheduled for the upcoming season.[Hor]
Collectively, these developments underscore the importance and feasibility of combining laser-based distance sensing and camera vision in unstructured agricultural environments. However, one key challenge remains: maintaining a stable and accurate sensor-to-soil distance, especially over uneven terrain.
To address this, our project proposes a system that integrates a line laser, a global shutter camera, and a linear actuator to actively regulate sensor height in real-time. This ensures consistent image sharpness, accurate pixel-to-coordinate mapping, and effective laser-based weed targeting—ultimately improving the overall efficiency and reliability of autonomous weeding systems.

2 Project Management

Project management is essential for the success of any project, as it helps control unforeseen challenges and increases the ability to influence outcomes. At the start of a project, the time schedule, project resources, and requirements list must be clearly defined and confirmed.

2.1 Project Resources

The project team consists of three members: Sebastianus Dustin Susanto, Georgius Kenneth Liauwangsa, and Yurong Li. The Raspberry Pi and global shutter camera were provided by the Chair of AgroMechatronics. Other required components could be purchased online within a €50 budget limit or fabricated using 3D printing. Tools are available for use in lab W212.

2.2 Time Schedule

Our project was divided into four phases. In the concept phase, the project goals were defined, requirements were listed, a time schedule was established, the functional structure was clarified, the preliminary report was completed, and an initial concept for the solution was developed. The results of this phase were presented in the concept presentation. In the design phase, a basic 3D model was created, the software design was planned, and the budget and parts list were prepared. The outcomes were presented in the design presentation. In the testing phase, modifications were implemented, assembly was completed, and obstacle testing and optimization were carried out. The final results of our project were demonstrated in the final presentation.
In the project management process, we held regular team meetings every Monday. Depending on task progress and project needs, additional meetings were scheduled to address specific issues and coordinate work more effectively.

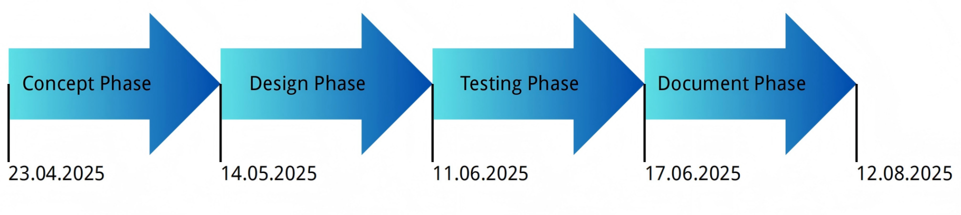


Figure 2.1: Time schedule

3 Identification of Requirements

To ensure clear task definitions and verifiable results, it is necessary to establish a requirement list. Our requirement list is divided into four categories: equipment, process requirements, functional requirements, and safety requirements.

3.1 Equipment

The four main pieces of equipment for the project are:

- Line laser
- Raspberry Pi camera
- Raspberry Pi 5
- Linear actuator

3.2 Process Requirements

3.2.1 Process Requirements – Demands

- The total budget for additional components must not exceed 50 €.
- The robot must always operate at least 10 cm above the ground to allow safe clearance for movement.
- The laser line must be visible enough to be detected by the camera for OpenCV image analysis.
- The slope of the soil surface should not exceed 27 % to prevent the risk of the robot tipping over.
- The height of uneven ground or obstacles should be limited to a maximum of 8 cm. Exceeding this limit increases the risk of the obstacle contacting the camera or prevents the camera from capturing the laser line projected onto the uneven surface or obstacle.

3.2.2 Process Requirements – Wishes

- Between stop stations, the robot should move at a minimum speed of 1 km/h to avoid excessively slow operation.
- The robot should be capable of operating under daylight conditions, enabling day and night operation.

- A warning light should be active during operation so that nearby people can notice the robot and avoid collisions.

3.3 Functional Requirements

3.3.1 Functional Requirements - Demands

- Distance measurement accuracy: target 1 cm, minimum acceptable 2 cm.
- When the robot is at a stop station, the camera and laser should be able to move up, down, or remain stationary during the distance control process.

3.3.2 Functional Requirements - Wishes

- Ideally, an image should be captured every 10 cm of movement for effective weed detection.
- The distance adjustment function should operate while the robot is moving to improve efficiency.

3.4 Safety Requirements

3.4.1 Safety Requirements - Demand

- The laser must be safe for humans, particularly for the eyes.

3.4.2 Safety Requirements - Wish

- All electronic components should be protected against soil, rain, and chemical fertilizers to ensure reliable operation.

4 Concept Finding

Based on the requirement list, the state of technology, and our technical knowledge, a brainstorming session was conducted. All possible solutions and corresponding components were listed in a Morphological Box:

	Solution 1	Solution 2	Solution 3
Sensor	Line Laser	Point Laser	LiDAR
Camera	Rolling Shutter Camera	Depth Camera	Global Shutter Camera
Control	Arduino	Raspberry Pi	ESP
Actuator	Linear Actuator	Linear Slider	
Movement	Camera	Camera with Laser	
Construction	3D Print	Aluminium Profile	Handmade
Software	OpenCV		
Reference	Ruler	Robot Version	Formula: Pixel-to-Cartesian Transformation

Table 4.1: Morphological box

4.1 Selection of Components and Solutions

Balancing the advantages and disadvantages of each variable, the following components and solutions were selected.

4.1.1 Sensor

Initially, a point laser was considered, but it provides very limited information. Another option was LiDAR (Light Detection and Ranging), which emits rapid laser pulses—usually in the infrared spectrum—and measures the return time to calculate distances with high accuracy. While LiDAR offers excellent precision, its cost is significantly higher than our budget allows. The chosen solution is a line laser, which projects a laser line at a fixed angle onto the ground. When captured by the camera, this provides sufficient height information at a much lower cost.

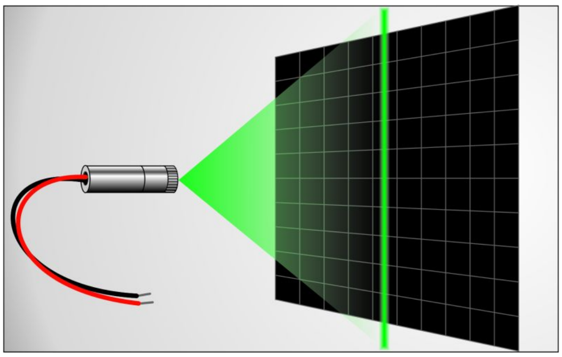


Figure 4.1: Line laser module GREEN 25mW, adjustable focus, insulated [Med21]. Source:https://www.lasershop.de/en/line-laser-module-green-25mw-adjustable-focus-12mm-housing.html

4.1.2 Camera

The Raspberry Pi 5, provided by the Chair of AgroMechatronics, is highly suitable for our project due to its programmability and efficiency. Along with it, we use a compatible global shutter Raspberry Pi camera, which is ideal for our task. A rolling shutter camera meets only the minimal requirements, as it works in static conditions but suffers from distortion when the robot is moving. Depth cameras could directly provide height information, but are excluded for economic reasons.

4.1.3 Actuator

There were two reasonable options for the actuator: a linear actuator and a linear slider. While their prices were comparable, the linear actuator was ultimately chosen because its dimensions were more suitable for our design.

4.1.4 Movement

Since the linear actuator has sufficient power, weight is not a concern. After discussion, we decided it would be more convenient and calculation-friendly to move both the camera and the line laser together.

4.1.5 Construction

Given that both a 3D printer and aluminium profiles are available in the lab, the construction requirements can be met using these provided resources.

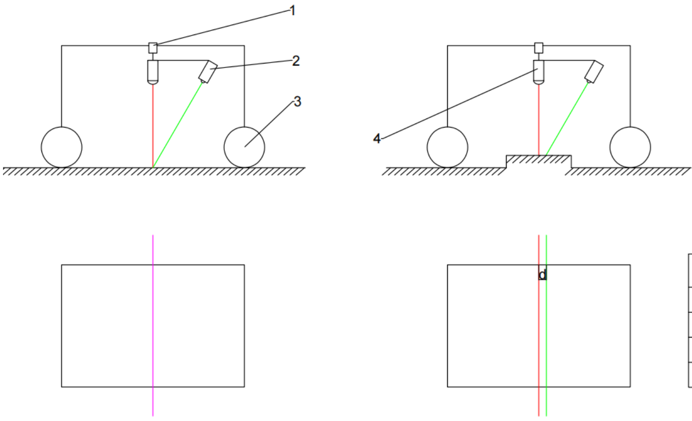
4.1.6 Software

OpenCV is the most suitable software within our knowledge base for mapping the real world to the camera's view and analyzing images to extract height information.

4.1.7 Reference

Due to the lack of precise feedback in the linear actuator's movement, establishing a pixel-to-Cartesian transformation formula may lead to inaccuracies. Placing a ruler in the camera's field of view to relate real-world Cartesian coordinates to image pixels was considered, but this approach complicated the construction design, made mounting more difficult, and sometimes obstructed the view. Ultimately, using a known-size reference object proved to be the simplest and most accurate method for achieving the transformation.

4.2 Final Concept



Equipments	
1	Line Actuator
2	Line Laser
3	Wheels
4	Camera

Figure 4.2: Final concept

As shown in Figure 4.2, the camera and line laser are mounted at the front of the robot. When the robot stops at a stop station, the laser projects a line onto the ground, and the camera captures an image containing the laser line.
In an ideal scenario,when the ground is level, the center of the laser line aligns perfectly with the center of the image captured by the camera.However, when the robot encounters uneven ground, this alignment is disrupted. The center of the laser line and the center of the image no longer coincide.
The distance between these two lines, labeled as 'd' in Figure 4.2, can be used to calculate the height variation of the ground surface.
As shown in Figure 4.3, the reference object and the line laser are positioned at the same level. This arrangement allows the relationship between real-world distance and pixel count in the captured image to be analyzed based on the known size of the reference object.

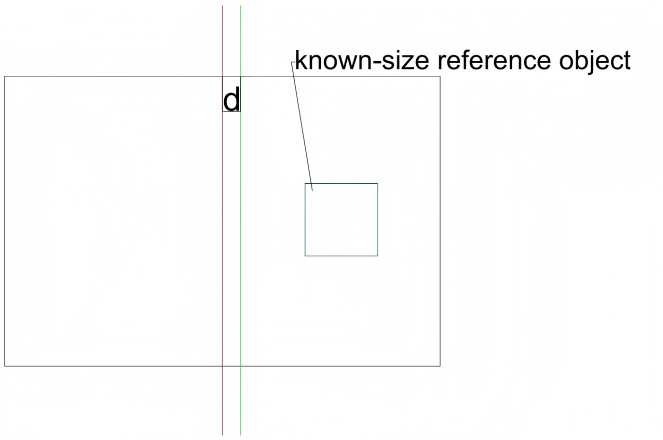


Figure 4.3: Pixel - distance calibration with a reference object

4.3 Preliminary Test

To ensure that the components operate correctly and do not interfere with subsequent steps, preliminary testing is necessary.
Figure 4.4 demonstrates that the camera and line laser function as expected.

Figure 4.4: Preliminary test 1

As shown in Figures 4.5 and 4.6, a gap exists between the laser line and the center of the captured image, and this gap increases when the robot faces taller objects. This observation provides evidence supporting the validity of the proposed concept.

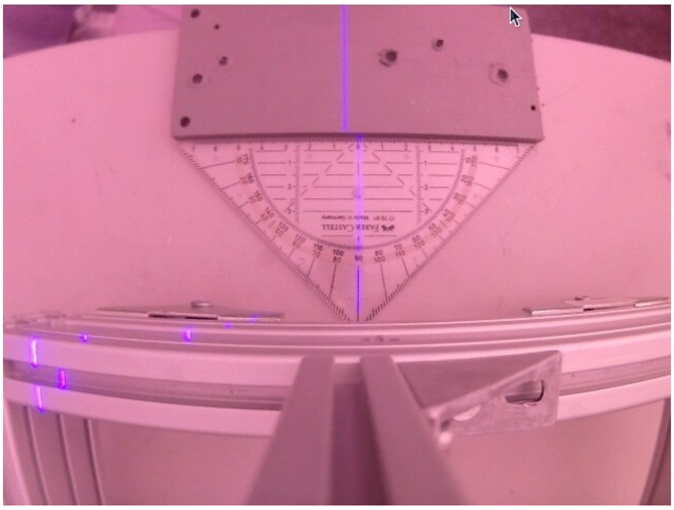


Figure 4.5: Preliminary test 2

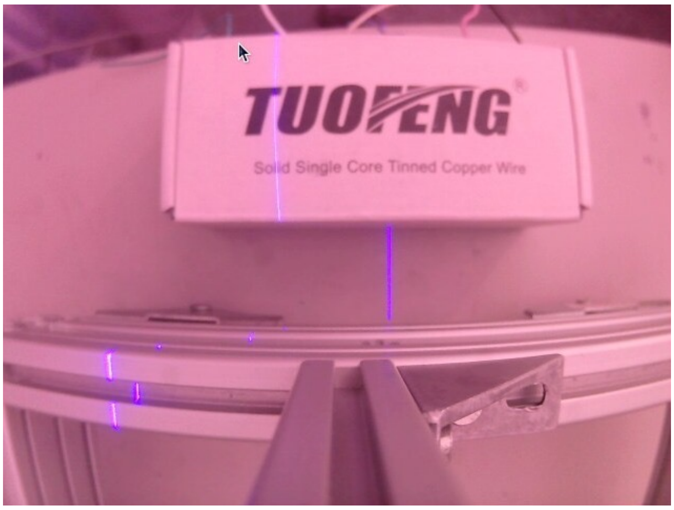


Figure 4.6: Preliminary test 3

5 Design

This chapter introduces the design of the robot structure and also the design and manufacturing process of the 3D printed components used.
In the end of this chapter you should write a specification for your solution, including interfaces, protocols and parameters.

5.1 Robot Structure and Design Concept

The design of the robot is based on the MARS robot that has been used on similar projects at ATB. Fortunately, a previous MARS development team created a robot structure that closely matches the requirements of this project. As a result, the existing structure was repurposed, with additional components added to fulfill the remaining project needs.
Figure 5.1 illustrates the robot design concept.

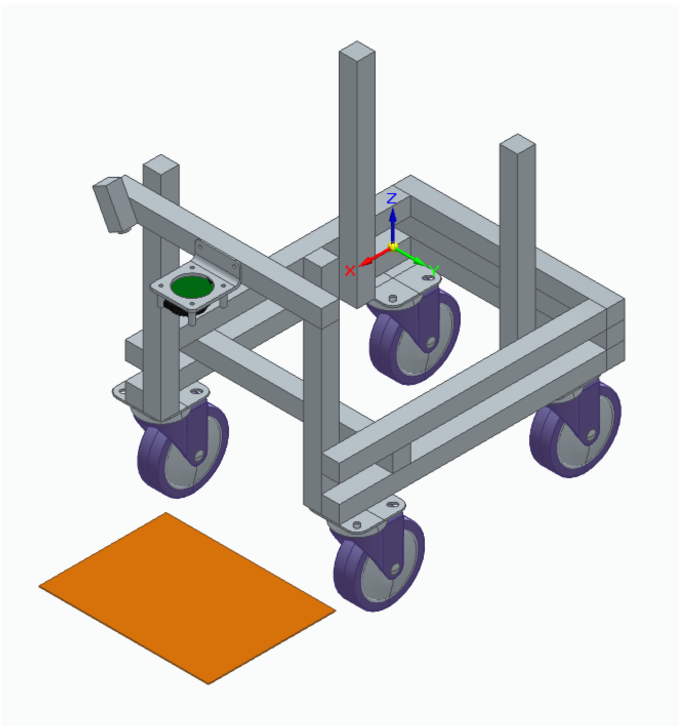


Figure 5.1: Robot design concept

In the initial design 5.1, the camera and line laser were mounted together on a horizontal bar as a single assembly. A vertical bar at the rear served both as a support for other

utilities and as a mounting point for the linear actuator. In this concept, the laser-camera assembly would be vertically adjustable. The linear actuator would be mounted horizontally and connected to the laser-camera assembly via a pulley system to redirect the motion. The main robot frame would be solely built using 20 × 20 mm I-type aluminum profiles.
However, due to shortages and availability issues with some aluminum profile hardware—such as the 20 × 20 mm sliders and joints—the robot design had to be adapted to use more readily available materials.
Figure 5.2 illustrates the robot design concept.

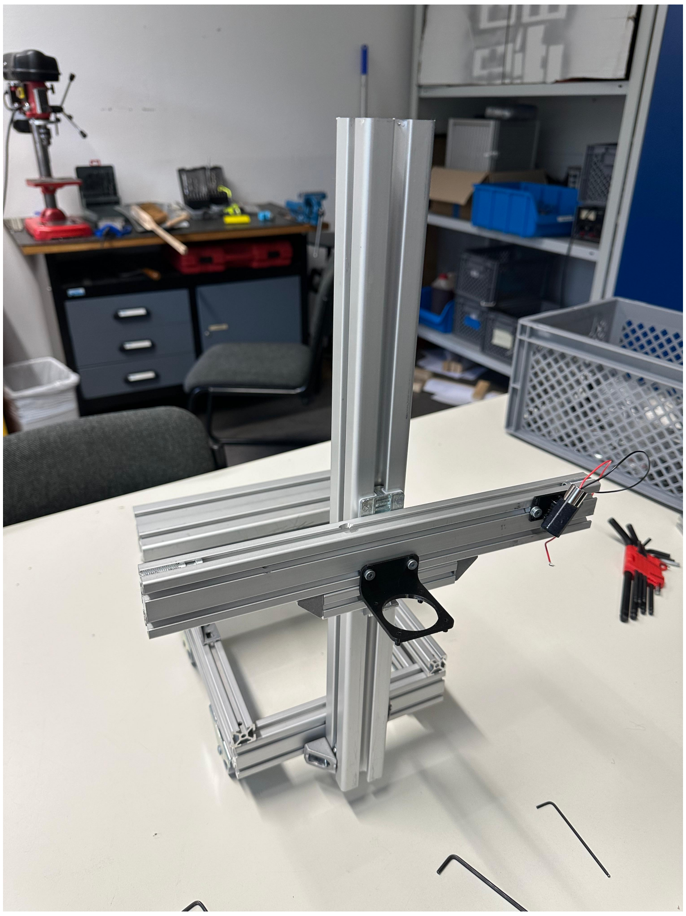


Figure 5.2: Robot body

In the updated design 5.2, the robot adopts a forklift-like structure. The main frame still uses 20 × 20 mm I-type aluminum profiles, while the vertical support beam is upgraded to a 40 × 40 mm I-type profile. This change was necessary because the vertical beam also serves as a rail for the horizontal laser-camera assembly, and the required slider is only available for the 40 × 40 mm profile. In this configuration, the linear actuator is mounted vertically on the vertical beam and connected to the horizontal laser-camera assembly via a pulley system.

5.2 3D-Models and 3D-Printing

Some components of the robot did not include mounting brackets, while others were not designed to be directly attached to the aluminum profile frame. To address this issue efficiently, one of the fastest, most cost-effective, and most flexible solutions was to design and fabricate custom mounts using 3D modeling and 3D printing. In this project, the 3D modeling was carried out using Siemens Solid Edge 2024, which allowed for precise dimensioning and easy adaptation to the existing robot structure. Once the designs were finalized, they were produced using a Bambu Lab A1 Mini 3D printer with PETG filament, chosen for its durability, strength, and resistance to environmental factors. This approach enabled the rapid creation of tailored parts that ensured proper fit, functionality, and ease of assembly.

5.2.1 Camera Bracket

The Raspberry Pi Global Shutter Camera does not include a mounting bracket that allows direct attachment to the aluminum profile frame. Furthermore, the camera module itself lacks any integrated mounting features, meaning a custom bracket had to be fabricated to attach directly to the camera's main board. To accommodate this, a 3D model was designed with standoffs to provide sufficient clearance for the ribbon cable.

Figure 5.3: Camera bracket 2. iteration

In the first iteration, the bracket was fully enclosed and served only to hold the camera securely in place. However, testing revealed that the camera could become significantly heated during operation, which reduced its performance. To address this issue, a small

5V cooling fan was integrated into the design to help maintain a stable operating temperature. This led to the second iteration of the bracket 5.3, which included an opening to serve as an air outlet, allowing active cooling while retaining structural stability. This version performed well for some time.
During extended and more intensive testing, a new challenge arose: a software-related requirement necessitated repositioning the camera further forward, beyond the original field of view of the robot. This change meant the bracket needed to be lengthened. However, considering the combined weight of the camera and cooling fan, extending the bracket increased the bending moment acting on the mounting point.
According to *Maschinenelemente* (18th Edition, Chapter 1, Section 1.3.3: *Festigkeitsgerechtes Gestalten*) [Hab], reinforcing such a component can be achieved by incorporating rib structures, which both reduce material usage and improve mechanical strength. Since the original bracket design did not include ribs, the bracket was redesigned and flipped to allow the integration of a reinforcement rib. The updated bracket design, as shown in Figure 5.4 and in Figure 5.5, effectively increased structural rigidity while accommodating the new camera position and cooling requirements.

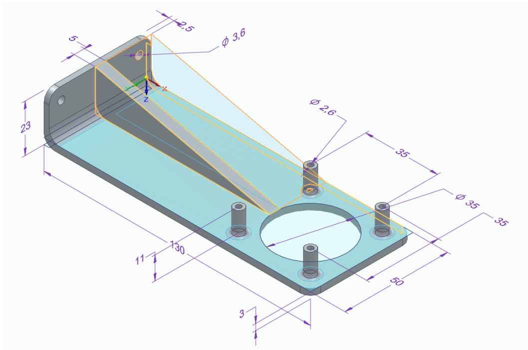


Figure 5.4: Camera bracket 3. iteration (design model)

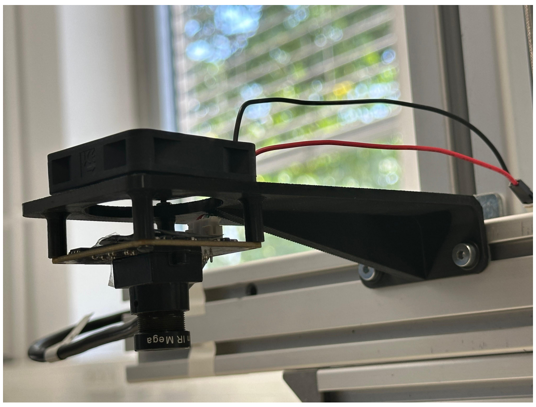


Figure 5.5: Camera bracket 3. iteration (manufactured)

5.2.2 Laser Bracket

The line laser provided for the project also did not include a mounting bracket, necessitating the fabrication of a custom bracket. The bracket was designed specifically to match the diameter of the laser, with the mounting interface to the aluminum profile incorporating a slotted bolt hole. This slot allowed the laser's angle to be adjusted during testing and calibration 5.6. The laser holder is set at a 45-degree angle relative to the bracket mount.

Figure 5.6: Line laser bracket 1. iteration (manufactured)

In the first iteration, the bracket was cracked during installation. This is caused by the actual diameter of the bracket is slightly smaller than the actual laser diameter due to a discrepancy caused by 3D printer dimensional tolerances 5.7.
In the second iteration, the internal diameter of the laser holder was increased to accommodate a more powerful replacement laser module with a larger housing. Additionally, the overall bracket geometry was refined — including increasing the width of the bolt slot — to enhance durability and installment process.

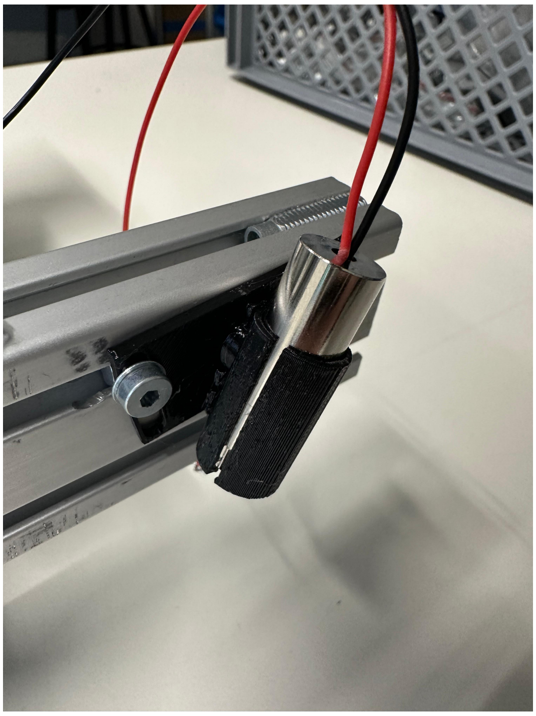


Figure 5.7: Cracked line laser bracket 1. iteration (manufactured)

In the third and final iteration, the bracket was extended to ensure the laser beam remained within the camera's capture area, accommodating the extended camera position as discussed in Subsection 5.2.1 as shown in Figure 5.8.

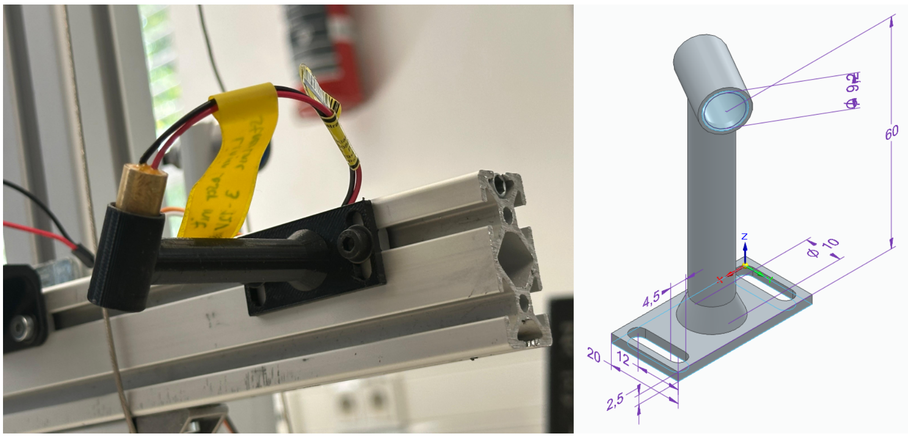


Figure 5.8: Line laser bracket 3. iteration (manufactured, left; design model, right)

5.2.3 Bearing Sleeve

Since the robot uses a bearing in the pulley system to transfer motion from the linear actuator to the camera–laser assembly, a bearing sleeve was required to provide a proper seating surface for the pulley cable. This sleeve ensures that the cable does not slip off the bearing during operation, thereby improving the stability of the pulley system 5.9.

Figure 5.9: Bearing sleeve (manufactured)

The design is a simple conical shape, inspired by a continuously variable transmission (CVT) pulley 5.10. This geometry helps keep the cable centered on the bearing while preventing it from slipping off. The bearing used is the S628 RS model, and the sleeve is designed to be press-fitted onto the bearing's outer race.

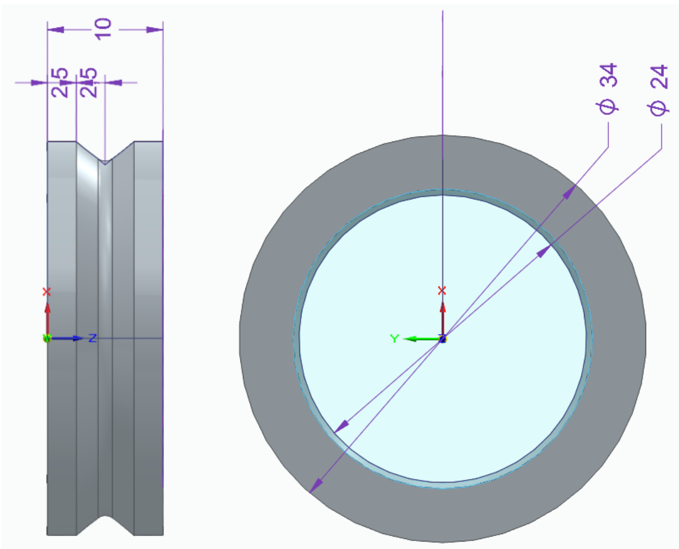


Figure 5.10: Bearing sleeve (design model)

5.3 Linear Actuator Configuration

As stated in 5.1, he initial design positioned the linear actuator horizontally toward the back of the robot to counterbalance the weight of the front-mounted assembly. However, during testing—and due to parts availability—the design was modified to a simpler configuration. In the revised setup, the linear actuator was mounted in line with the vertical beam/rail at the front of the robot. Because of height limitations for the camera–laser assembly, the actuator was connected to a pulley system using a metal cable. This arrangement increased flexibility in adjusting the vertical range of the camera–laser assembly, shown in Figure 5.11.

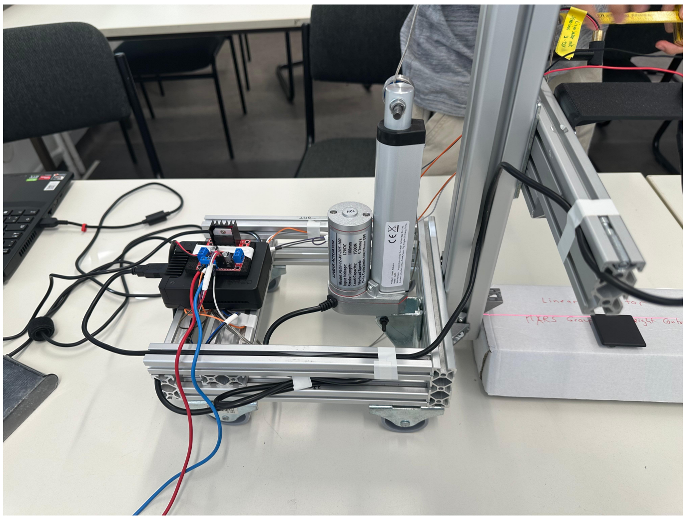


Figure 5.11: Linear actuator (installed)

5.4 Software Logic Design

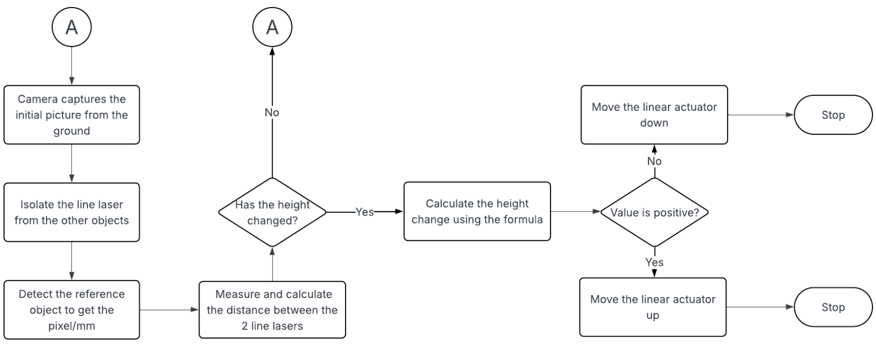


Figure 5.12: Software logic flowchart

The flowchart in Figure 5.12 illustrates the sequence of operations for the automated height adjustment system of the camera–laser assembly. The process begins with the camera capturing an initial image of the ground. This image is processed to isolate the line laser from other visual elements. Once isolated, a reference object within the frame is detected to determine the pixel-to-millimeter conversion factor.
The system then measures and calculates the distance between the two projected line lasers. Based on this measurement, it evaluates whether the height of the assembly has changed compared to the reference condition.
If no height change is detected, the system returns to the initial state, ready to start a new operation.
If a height change is detected, the system calculates the height difference using a predefined formula, which will be described in Section 6.2.4.
The resulting value is checked for its sign:

- If the value is positive, the linear actuator is moved upward.
- If the value is negative, the actuator is moved downward.

In both cases, the movement continues until the target position is reached, after which the system stops. The inclusion of adjustable laser angles ensures precise calibration throughout the process.

6 Implementation

This chapter describes the implementation of the electric configuration as well as the software implementation. The electric configuration will mainly illustrate the Raspberry Pi 5 cable connections and the software implementation will describe each of the robot's algorithm.

6.1 Electrical Design

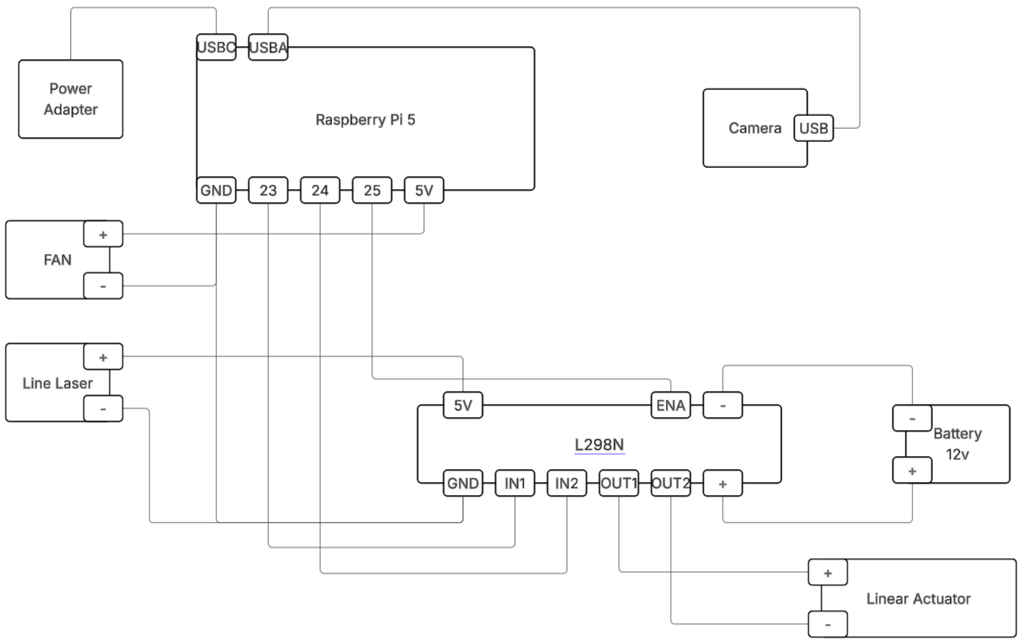


Figure 6.1: Circuit diagram

6.1.1 Power Supply

- A power adapter supplies 5 V to the Raspberry Pi 5 via its USB-C port.
- The 12 V battery powers the L298N motor driver and the linear actuator.
  - The positive terminal of the battery is connected to the +12 V input of the L298N.
  - The negative terminal of the battery is connected to the GND of the L298N.

6.1.2 Raspberry Pi 5 to L298N Motor Driver Connections

- GND of Raspberry Pi 5 is connected to GND of L298N to share a common ground.
- GPIO 23 → IN1 of L298N (controls motor direction).
- GPIO 24 → IN2 of L298N (controls motor direction).
- GPIO 25 → ENA of L298N (enables motor and allows PWM speed control).

6.1.3 L298N to Linear Actuator

- OUT1 → Positive terminal of the linear actuator.
- OUT2 → Negative terminal of the linear actuator.

6.1.4 Line Laser Wiring

- Positive terminal of the line laser is connected to the 5 V enable pin of the L298N.
- Negative terminal of the line laser is connected to the GND of the L298N.

6.1.5 Cooling Fan Wiring

- Positive terminal of the fan is connected to the 5 V pin on the Raspberry Pi 5.
- Negative terminal of the fan is connected to the GND of the Raspberry Pi 5.

6.1.6 Camera Connection

- The camera connects to the Raspberry Pi 5 via a USB-A port.

This configuration allows the Raspberry Pi 5 to control the linear actuator via GPIO pins through the L298N driver, while powering auxiliary components like the cooling fan and line laser from its own 5 V rail.

6.2 Software Design

6.2.1 Color Detection

The first step in getting the robot to calculate the distance between the laser is to be able to detect the line laser itself. Since the library used here is mainly based on OpenCV, which is primarily a library used for computer vision, the simple approach is to use a color detection algorithm to isolate the line laser from the other objects detected by the camera.

The program starts by analyzing the given image. The read analyzed is then converted from RGB to HSV value. HSV values have a more robust color detection, since HSV has 3 main components of detection which are Hue (color), Saturation (intensity of color)

and Value (brightness). The values can be adjusted easily to match what is required. For example, the hue can be adjusted based on what color is needed, such as red (0-10 or 160-180) and the Saturation and Value can be adjusted accordingly since the color has been detected.
To fully isolate the line laser from the image, the HSV values are then combined in the mask, to ensure the overlapping parts are marked as white and the non overlapping parts are marked as black.

6.2.2 Distance Calculation

The distance calculation algorithm's purpose is to find the distance between the laser from the previous spot to the elevated spot. How this is done is by using the color detection algorithm to isolate the laser from its surroundings as well as calculating its coordinate systems.
The initial concept is similar to the color detection algorithm. Instead of one picture, two pictures are taken on different positions. The line lasers are first converted to HSV and masked to get the isolated line laser. The program then searches for the contours of the masks to find the centroid of both lasers. Finally, the centroids are then subtracted to find the distance between both lasers in pixels.

6.2.3 Object Reference Size Detection

The object reference size algorithm has one of the more important role to get the calculation precise. The object that is used as referenced has to be chosen properly to ensure the algorithm can detect it properly. Firstly, a non-red colored object is preferred to not disrupt the color detection algorithm. Secondly, a normally shaped object such as a square or circle is best for an easier calculation. In this case, a black colored square object is used as the reference object.
The main objective of the algorithm is to get the pixel per cm of the object. Since the object is a square, the object's length can be determined by its horizontal or vertical length. First, the program finds all of the contours of all the objects in the image. The contours are then filtered by its area within a certain threshold. Once it is filtered, the algorithm calculates the midpoints of each edge and then the euclidean distance between the points to get the horizontal and vertical distance in pixels. With the known size of the object as well as the pixel size of the object, the pixel per cm can be calculated.

6.2.4 Laser Distance to Height Conversion

The laser distance to height conversion is a simple algorithm which calculates the conversion from laser distance to height required for adjustment. The calculation is given by this formula:

$$h = l * tan(61.39^\circ) \tag{6.1}$$

Where h is the height change and l is the distance between the line lasers in mm. The angle here is measured between the projection of the line laser to the ground and the beam that holds the line laser. By using the formula, the height of the linear actuator can be adjusted accordingly

6.2.5 Linear Actuator Movement

This is the main algorithm which coordinates all of the previous calculation. Once the previous algorithm are done calculating, the final distance between the line lasers are then converted to the height change. If the height change is positive, the linear actuator goes up and the system goes down and if the height change is negative, the linear actuator goes down and the system goes up.
The final overall pseudo code of the algorithm can be seen in the following pseudocode.

Algorithm 1 Distance Control algorithm

```
while program is running do
    isolate the line lasers
    calculate the distance between the line lasers
    get the pixel/cm measurement from the object reference
    convert laser distance to height
    adjust the linear actuator to the height needed
end while
```

7 Evaluation

In this chapter, the implementation of the robot and each individual parts will be evaluated. Based on the requirement list, each point is evaluated according to each robot component.

7.1 Camera Testing

The first component to be tested is the camera. Most of the algorithms are highly dependent of the picture taken by the camera. In this section, the color detection, object size, and distance between laser calculations will be evaluated.

7.1.1 Color Detection

Color detection plays a key role in calculating the distance between each line laser. During testing, color detection using HSV values is highly sensitive to different lighting conditions. As stated in the previous chapter, the HSV values take into account not only the color(Hue), but also the saturation as well as the value (brightness) of the surroundings. With each changing variables such as the background color and brightness of the environment, each values have to be adjusted accordingly. The following images show the effect of lighting on color detection.

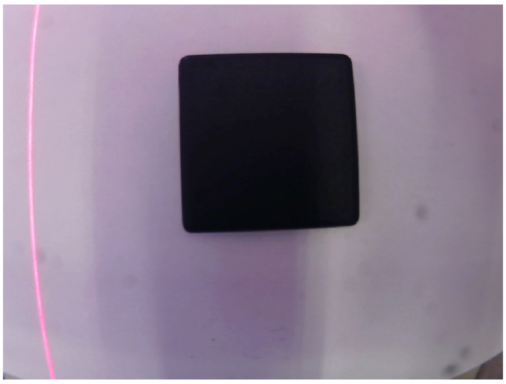


Figure 7.1: Image taken in bright lighting

Figure 7.2: The mask of the image

Both cases used the same HSV values which are (140,58,200) for the lower red values and (180,255,255) for the upper red values. In Figure 7.3, the lighting of the room is switched off which causes the camera to detect a lot more noise than the condition where the lights are switched on.

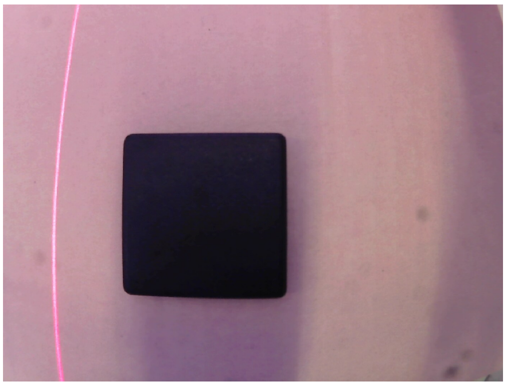


Figure 7.3: Image taken in dim lighting

Figure 7.4: The mask of the image

Due to the nature of the sensitivity of the color detection, the environment of the picture taken has to be taken into consideration heavily for a consistent outcome.

7.1.2 Object Size Calculation

The object size algorithm encounters a similar problem during testing. Due to the nature of the algorithm, the object itself has to be larger than other objects within the image for an easier detection. In 6.2.3, it has been elaborated that the algorithm filters any area smaller than a certain threshold in order to filter any unwanted small objects.

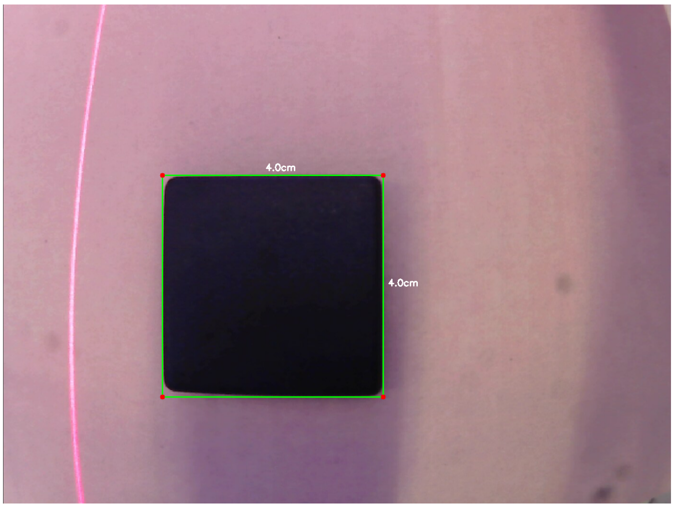


Figure 7.5: Camera capturing the reference object size

With the known size of the reference object, the size of the object is instantly recognized by the algorithm and finally getting the pixel per cm of the object accurately.

7.1.3 Distance Between Laser Calculation

In this section, the accuracy of the distance between the line laser is evaluated. The outcome for the distance between line laser calculation is compared to the actual distance between the line lasers.

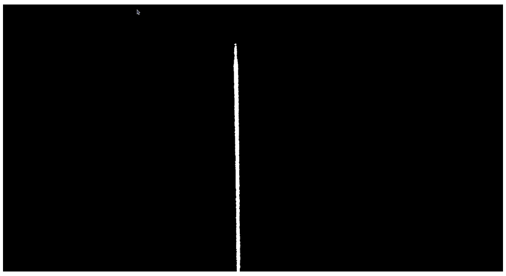


Figure 7.6: First line laser visualized

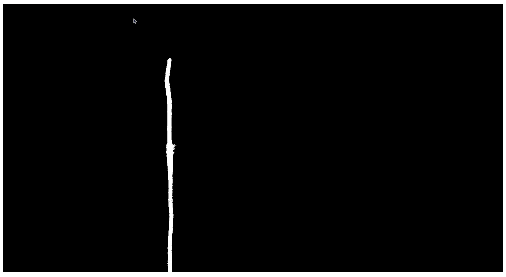


Figure 7.7: Second line laser visualized

No	Measured distance in cm	Pixels/cm	Distance in pixels	Calculated distance in cm
1	3	86,8	231	2,667
2	3,9	125.5	503,2	4,01
3	3	93	262	2.82

Table 7.1: Data taken for the distance algorithm

As seen from Table 7.1 , some of the data calculated and measured have some noticable differences. Some of these misaccuracies came from many potential problems such as the camera warping. Due to the camera warping, the placement of the reference object and the distance between the camera and the reference object, they influence the calcualtion of the object reference size. Take these two images as an example: The closer the object

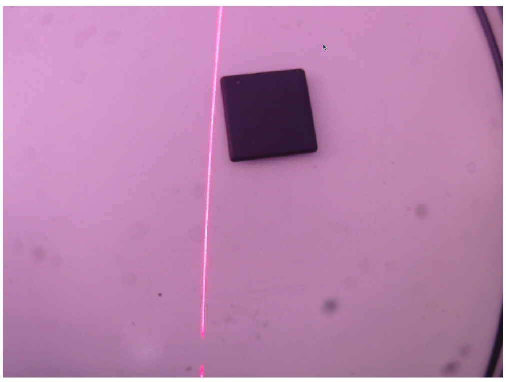


Figure 7.8: Further reference object

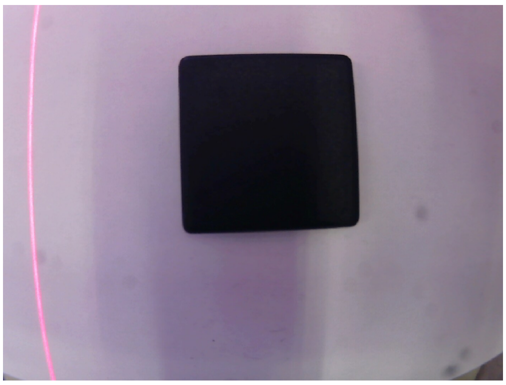


Figure 7.9: Closer reference object

and the farther the object is from the center of the camera, the more warped it becomes. This affects the calculation of the distance between the lasers

7.2 Linear Actuator Testing

Given that the linear actuator speed have different variables affecting the speed, the speed of the linear actuator has to be measured. A simple test is conducted where the distance is measured and the time it takes to travel between two points is given within the program.

$$speed = \frac{distance}{time} \tag{7.1}$$

Thus, the speed from the linear actuator is calculated as 4,3 mm/s.

7.3 Overall Component Testing

In the following section, the robot is tested as a whole. Since the whole system is not fully automated, the test will simulate the case as if it is a closed loop system. To do this, different objects with different heights are placed after each adjustment and evaluated. Then, the overall accuracy of the algorithm is compared to the actual height adjustment needed.

No	Starting height in cm	End height in cm	Height difference in cm	Actual height in cm
1	7,8	3,2	4,6	5
2	3,2	7,9	4,7	5
3	7,9	7,1	0,8	0,8
total			10,1	10,8

Table 7.2: Closed loop system data simulation

As seen from table 7.2, as the robot keeps on adjusting itself, the error will accumulate over time, leading to a possible problem that could be encountered when applied in the actual field. As stated from the previous evaluation, this problem occurs due to mainly the algorithm calculating the distance between the line lasers.

One other noticeable factor that affects the calculation of the height change is the varying speed of the linear actuator. Due to the angle between the linear actuator and the metal string, the linear actuator's movement have varying speed depending on the angle between the linear actuator and metal string. These minor inaccuracies, though small individually, compound over time and contribute to the overall error.

From Figure 7.10 it shows that the accuracy gets better as more attempts are added. However, this only simulates the small part of the testing and the fluctuation could also mean that the accuracy can increase over time as more attempts are added.

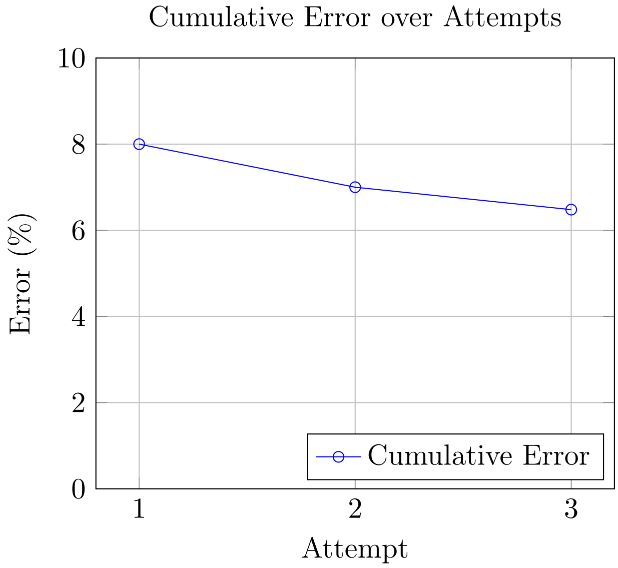


Figure 7.10: Cumulative Error Percentage vs Attempt Number

7.4 Requirements Evaluation

The project's overall requirements will be evaluated to demonstrate that all goals have been achieved. The first requirement was that the robot must maintain a constant height of 10 cm above the ground. This has been fulfilled by the algorithm's design. The robot starts at an initial position of approximately 20 cm above the ground, and whenever a height change is detected, the program automatically adjusts to keep the robot at the target height for as long as it operates. As a result, this requirement is met.
The second requirement was that the laser must be clearly visible for the camera to detect it. While this has been achieved, there are some limitations. Although the camera can detect the line laser, its red color makes it difficult to distinguish from the surrounding environment. Initially, a blue laser was considered because it would be easier to detect, but due to safety concerns—blue lasers are more hazardous to human eyes. Hence, the decision to use red line laser is made.
The third requirement was that the project should not exceed a budget of 50 Euros. Unfortunately, this was not fulfilled. The initial goal was to stay under 50 Euros, but the total cost ended up being 61,02 Euros. The most expensive components were the linear actuator (18,32 Euros) and the line laser (18,60 Euros), while the remaining parts were significantly cheaper, each costing around 5–6 Euros.

7.5 Time Management Evaluation

All of the deadlines are met. When the schedule was first made during the initial stages of the project, it was a rough estimate on how long each component will be tested. Most of the component's schedule were shifted due to some being finished faster than it was originally thought and some longer due to some constraints such as group meetings being delayed. At the end of the testing phase, the project was also continued to be tested as a closed system loop. This, however, did not affect the scheduled dedadline, since the closed loop system was never a requirement in the first place, but only as an additional simulation to reflect the actual scenario on the field.

8 Conclusion and Future Work

8.1 Conclusion

Overall, the project successfully achieved distance control when the robot encountered obstacles or uneven ground, with an error margin of approximately 6,5%.

8.2 Recommendations for Future Work

Although the robot can maintain a constant distance, several areas could be improved in the future. First, the linear actuator powered by direct electricity lacks sufficient accuracy. A feedback control system could be integrated in the next stage, provided that the solution remains cost-effective so it is affordable for farmers. Second, distortion at the edges of the camera's field of view causes significant negative impact on measurement accuracy. Third, the mounting method of the linear actuator should be improved; in this project, the connection between the linear actuator and the sensors (camera and line laser) uses a fixed pulley and steel cable mechanism, which is not sufficiently precise. In addition, the color and power of the line laser have a considerable influence on both measurement performance and eye safety, as the implemented line laser in this project is highly dependent on the ground color and environmental conditions. Finally, machine learning could be applied in the future to establish the relationship between image pixels and real-world dimensions.

TU Berlin Chair Agro Mechatronics Prof. Dr.-Ing. C. Weltzien	**Requirements List** **for Modul** **Mobile Working Robotic Systems**	**Order No.:** SoSe-2025-1-3(Group No.) **Team Members:** **Susanto, Sebastianus Dustin** **Li, Yurong** **Liauwangsa, Georgius Kenneth**

No.	Date:	Origin	D/R (F/W)	Requirements	Specification – Data Minimum Fulfilment	STANDARD Fulfilment	Ideal Fulfilment	Unit [mm]
				Equipment				
D01		SDS	D	Line Laser	1	1	1	unit
D02		SDS	D	1 Raspberry Pi Camera	2	2	5	MP
D03		SDS	D	Raspberry Pi 5				
D04		SDS	D	Linear Actuator				
				Process Requirements				
P01		SDS	D	Budget should not exceed 50 €	35	35	30	€
P02		SDS	D	The robot must always be a minimum of 10 cm above ground	15	10	10	cm
P03		SDS	W	Robot has to function in daylight conditions				
P04		SDS	W	Robot minimum speed of 1 km/h	2	3	4	
P05		SDS	W	Robot needs to have warning lights during the process				
P06		SDS	D	Laser has to be visible enough to be detected by the camera				
				Functional Requirements				
F01		SDS	D	Distance measurement accuracy	2	1	1	cm
F02		SDS	W	Picture taken per 10cm distance traveled	10	10	10	cm
F03		SDS	W	Take picture as the robot is moving				
F04		SDS	D	Adjustment of the camera and laser	Per Stop		While moving	
				Safety Requirements				
S01		SDS	D	The laser has to be safe for humans				
S02		SDS	W	Robot electronics has to be safe from dirt and dust				

Type of Requirements: D = Demands (F-Forderungen), R = Request (W-Wunsch, “nice-to-have”); Short name members: SDS = Sebastianus Dustin Susanto

Replaces version: From: *First version:* Responsible:		**Version:** 2 **Date:** 05.05.2025 **Page** 1 of 1

Projektplan *für die* *MARS*

Erzeugnisnummer XXXXXXXXXXX
Anlagenteile XXXXXXXXXXX
Projektleiter C. Weltzien & T. Schütte
Projektstart 4/23/2025
Heute 8/13/2025
Liefertermin 8/13/2025

Version: **1.0**

Projektstatus
100%

Berechnungsfelder
Meilensteine
Auszufüllende Felder
Fixtermine (Einzeleingaben)
Fixtermine pönalisiert
Fragen

M = Maßzeichnung
D = Material - Dispo
U = Fertig.-Unterl. (1.Teil)
F = Fertig.-Unterl. (2.Teil)
B = Material - Bereitst.
E = Fertigungsende
A = Fertigungsabnahme
L = Lagereingang MP

KW 17 4/21/2025 | **KW 18** 4/28/2025 | **KW 19** 5/5/2025 | **KW 20** 5/12/2025

M D M D F S S M D M D F S S M D M D F S S M D M D F S S M

	Aufgabe	Bearbeiter	Start	Dauer AT	Ende	Fortschritt	Status
1	Concept Phase	offen	4/23/2025	22	5/14/2025	100%	Abgeschlossen
1.1	Project Goals	offen	4/23/2025	1	4/24/2025	100%	Abgeschlossen
1.2	Requirement List	offen	4/24/2025	1	5/4/2025	100%	Abgeschlossen
1.3	Time Schedule	offen	4/24/2025	1	5/4/2025	100%	Abgeschlossen
1.4	Function Structure	offen	4/28/2025	1	5/7/2025	100%	Abgeschlossen
1.5	Concept of Solution	offen	5/1/2025	1	5/14/2025	100%	Abgeschlossen
1.5	Concept Presentation	yurongli	5/14/2025	1	5/14/2025	100%	Abgeschlossen
2	Design Phase	offen	5/14/2025	30	6/11/2025	100%	Abgeschlossen
2.1	Mounting Design	offen	5/14/2025	14	5/28/2025	100%	Abgeschlossen
2.1.1	*Mount Draft*	offen	5/14/2025	4	5/18/2025	100%	Abgeschlossen
2.1.2	*3D Design*	offen	5/18/2025	6	5/24/2025	100%	Abgeschlossen
2.2	Software Design	offen	5/14/2025	18	6/1/2025	100%	Abgeschlossen
2.3	Budget and lists of parts to buy	offen	5/14/2025	14	5/28/2025	100%	Abgeschlossen
2.4	Components Tests	offen	5/21/2025	21	6/11/2025	100%	Abgeschlossen
2.5	Design Presentation	Georgius Kenneth Liauwangsa	6/11/2025	1	6/11/2025	100%	Abgeschlossen
2.6	Assembly	offen	6/12/2025	7	6/19/2025	100%	Abgeschlossen
3	Testing Phase	offen	6/12/2025	34	6/17/2025	100%	Abgeschlossen
3.1	Obstacle testing	offen	6/12/2025	7	6/19/2025	100%	Abgeschlossen
3.2	Modification	offen	6/19/2025	7	6/25/2025	100%	Abgeschlossen
3.3	Field testing	offen	6/25/2025	7	7/2/2025	100%	Abgeschlossen
3.4	Optimization	offen	7/2/2025	7	7/9/2025	100%	Abgeschlossen
3.4.1	Live adjustment	offen	7/9/2025	7	7/16/2025	100%	Abgeschlossen
3.5	Final Presentation	Sebastianus Dustin Susanto	7/17/2025	1	7/17/2025	100%	Abgeschlossen
4	Dokument Phase	offen	8/13/2025	100	8/13/2025	100%	Abgeschlossen

Projektplan *für die* *MARS*

Erzeugnisnummer	XXXXXXXXXXX		Berechnungsfelder = Versand
Anlagenteile	XXXXXXXXXXX	Version: 1.0	Meilensteine = Montage - Service
Projektleiter	C. Weltzien & T. Schütte		Auszufüllende Felder = Inbetriebnahme
Projektstart	4/23/2025	Projektstatus	Fixtermine (Einzeleingaben) = Lieferung zum Kunden
Heute	8/13/2025	100%	Fixtermine pönalisiert
Liefertermin	8/13/2025		Fragen

KW 21 5/19/2025 — KW 22 5/26/2025 — KW 23 6/2/2025 — KW 24 6/9/2025

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	Aufgabe	Bearbeiter	Start	Dauer AT	Ende	Fortschritt	Status
1	**Concept Phase**	offen	4/23/2025	22	5/14/2025	100%	Abgeschlossen
1.1	**Project Goals**	offen	4/23/2025	1	4/24/2025	100%	Abgeschlossen
1.2	**Requirement List**	offen	4/24/2025	1	5/4/2025	100%	Abgeschlossen
1.3	**Time Schedule**	offen	4/24/2025	1	5/4/2025	100%	Abgeschlossen
1.4	**Function Structure**	offen	4/28/2025	1	5/7/2025	100%	Abgeschlossen
1.5	**Concept of Solution**	offen	5/1/2025	1	5/14/2025	100%	Abgeschlossen
1.5	**Concept Presentation**	yurongli	5/14/2025	1	5/14/2025	100%	Abgeschlossen
2	**Design Phase**	offen	5/14/2025	30	6/11/2025	100%	Abgeschlossen
2.1	**Mounting Design**	offen	5/14/2025	14	5/28/2025	100%	Abgeschlossen
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2.1.2	***3D Design***	offen	5/18/2025	6	5/24/2025	100%	Abgeschlossen
2.2	**Software Design**	offen	5/14/2025	18	6/1/2025	100%	Abgeschlossen
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3.4	**Optimization**	offen	7/2/2025	7	7/9/2025	100%	Abgeschlossen
3.4.1	**Live adjustment**	offen	7/9/2025	7	7/16/2025	100%	Abgeschlossen
3.5	**Final Presentation**	Sebastianus Dustin Susanto	7/17/2025	1	7/17/2025	100%	Abgeschlossen
4	**Dokument Phase**	offen	8/13/2025	100	8/13/2025	100%	Abgeschlossen

Projektplan *für die MARS*

Erzeugnisnummer	XXXXXXXXXXX		Berechnungsfelder
Anlagenteile	XXXXXXXXXXX	Version: 1.0	Meilensteine
Projektleiter	C. Weltzien & T. Schütte		Auszufüllende Felder
Projektstart	4/23/2025	Projektstatus	Fixtermine (Einzeleingaben)
Heute	8/13/2025	100%	Fixtermine pönalisiert
Liefertermin	8/13/2025		Fragen

KW 25 /16/2025 · KW 26 6/23/2025 · KW 27 6/30/2025 · KW 28 7/7/2025 · KW 7/14

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	Aufgabe	Bearbeiter	Start	Dauer AT	Ende	Fortschritt	Status
1	**Concept Phase**	offen	4/23/2025	22	5/14/2025	100%	Abgeschlossen
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4	**Dokument Phase**	offen	8/13/2025	100	8/13/2025	100%	Abgeschlossen

Projektplan *für die MARS*

Erzeugnisnummer	XXXXXXXXXXX		Berechnungsfelder
Anlagenteile	XXXXXXXXXXX	Version: 1.0	Meilensteine
Projektleiter	C. Weltzien & T. Schütte		Auszufüllende Felder
Projektstart	4/23/2025	Projektstatus	Fixtermine (Einzeleingaben)
Heute	8/13/2025	100%	Fixtermine pönalisiert
Liefertermin	8/13/2025		Fragen

	Aufgabe	Bearbeiter	Start	Dauer AT	Ende	Fortschritt	Status
1	Concept Phase	offen	4/23/2025	22	5/14/2025	100%	Abgeschlossen
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2.1.2	***3D Design***	offen	5/18/2025	6	5/24/2025	100%	Abgeschlossen
2.2	Software Design	offen	5/14/2025	18	6/1/2025	100%	Abgeschlossen
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2.6	Assembly	offen	6/12/2025	7	6/19/2025	100%	Abgeschlossen
3	Testing Phase	offen	6/12/2025	34	6/17/2025	100%	Abgeschlossen
3.1	Obstacle testing	offen	6/12/2025	7	6/19/2025	100%	Abgeschlossen
3.2	Modification	offen	6/19/2025	7	6/25/2025	100%	Abgeschlossen
3.3	Field testing	offen	6/25/2025	7	7/2/2025	100%	Abgeschlossen
3.4	Optimization	offen	7/2/2025	7	7/9/2025	100%	Abgeschlossen
3.4.1	Live adjustment	offen	7/9/2025	7	7/16/2025	100%	Abgeschlossen
3.5	Final Presentation	Sebastianus Dustin Susanto	7/17/2025	1	7/17/2025	100%	Abgeschlossen
4	Dokument Phase	offen	8/13/2025	100	8/13/2025	100%	Abgeschlossen

KW 29	KW 30	KW 31	KW 32	KW 3
/2025	7/21/2025	7/28/2025	8/4/2025	8/11/20
D F S S	M D M D F S S	M D M D F S S	M D M D F S S	M D M

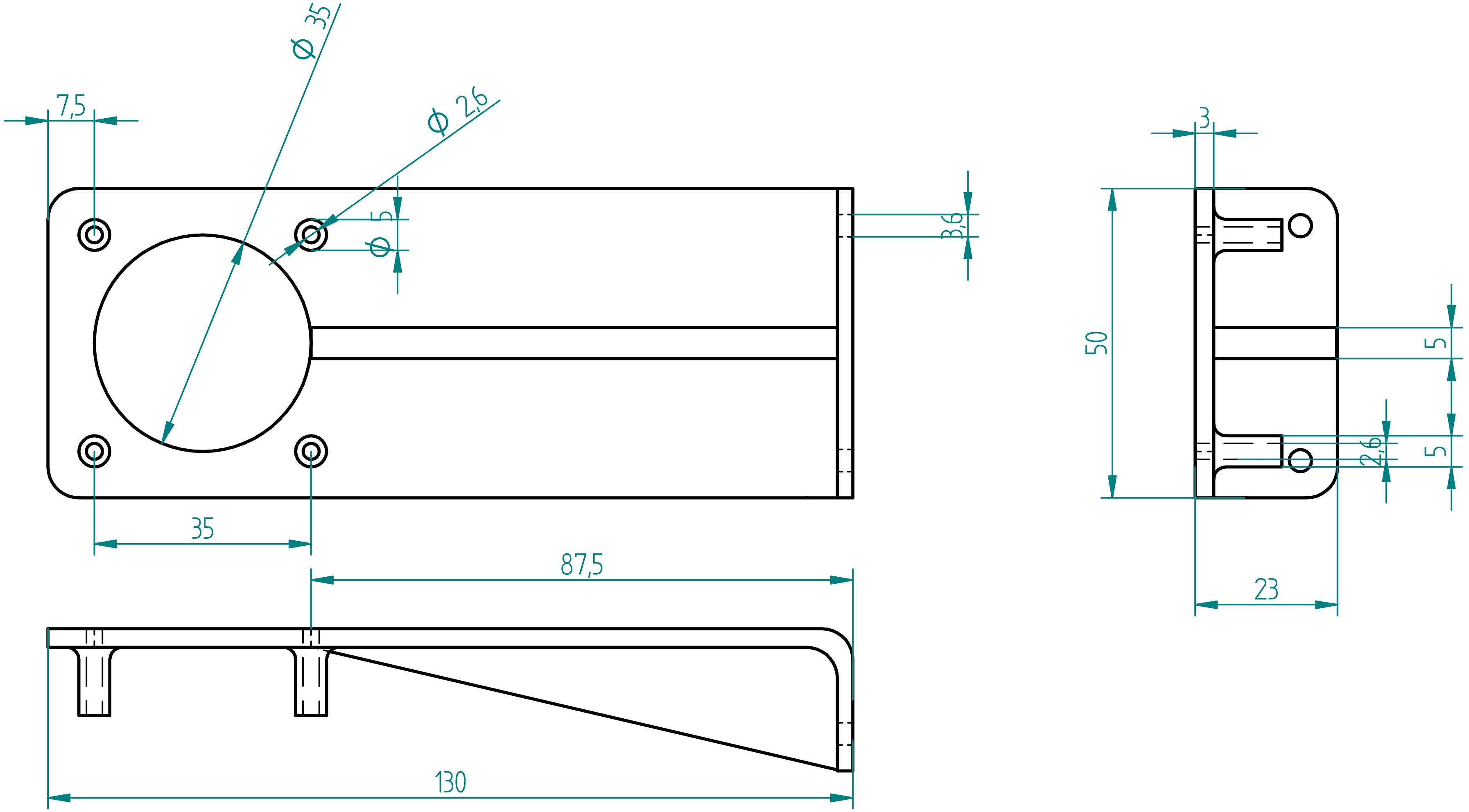
Projektplan *für die MARS*

Erzeugnisnummer	XXXXXXXXXXX		
Anlagenteile	XXXXXXXXXXX	Version:	1.0
Projektleiter	C. Weltzien & T. Schütte		
Projektstart	4/23/2025	Projektstatus	
Heute	8/13/2025	100%	
Liefertermin	8/13/2025		

Berechnungsfelder
Meilensteine
Auszufüllende Felder
Fixtermine (Einzeleingaben)
Fixtermine pönalisiert
Fragen

33
025

	Aufgabe	Bearbeiter	Start	Dauer AT	Ende	Fortschritt	Status
1	Concept Phase	offen	4/23/2025	22	5/14/2025	100%	Abgeschlossen
1.1	Project Goals	offen	4/23/2025	1	4/24/2025	100%	Abgeschlossen
1.2	Requirement List	offen	4/24/2025	1	5/4/2025	100%	Abgeschlossen
1.3	Time Schedule	offen	4/24/2025	1	5/4/2025	100%	Abgeschlossen
1.4	Function Structure	offen	4/28/2025	1	5/7/2025	100%	Abgeschlossen
1.5	Concept of Solution	offen	5/1/2025	1	5/14/2025	100%	Abgeschlossen
1.5	Concept Presentation	yurongli	5/14/2025	1	5/14/2025	100%	Abgeschlossen
2	Design Phase	offen	5/14/2025	30	6/11/2025	100%	Abgeschlossen
2.1	Mounting Design	offen	5/14/2025	14	5/28/2025	100%	Abgeschlossen
2.1.1	***Mount Draft***	offen	5/14/2025	4	5/18/2025	100%	Abgeschlossen
2.1.2	***3D Design***	offen	5/18/2025	6	5/24/2025	100%	Abgeschlossen
2.2	Software Design	offen	5/14/2025	18	6/1/2025	100%	Abgeschlossen
2.3	Budget and lists of parts to buy	offen	5/14/2025	14	5/28/2025	100%	Abgeschlossen
2.4	Components Tests	offen	5/21/2025	21	6/11/2025	100%	Abgeschlossen
2.5	Design Presentation	Georgius Kenneth Liauwangsa	6/11/2025	1	6/11/2025	100%	Abgeschlossen
2.6	Assembly	offen	6/12/2025	7	6/19/2025	100%	Abgeschlossen
3	Testing Phase	offen	6/12/2025	34	6/17/2025	100%	Abgeschlossen
3.1	Obstacle testing	offen	6/12/2025	7	6/19/2025	100%	Abgeschlossen
3.2	Modification	offen	6/19/2025	7	6/25/2025	100%	Abgeschlossen
3.3	Field testing	offen	6/25/2025	7	7/2/2025	100%	Abgeschlossen
3.4	Optimization	offen	7/2/2025	7	7/9/2025	100%	Abgeschlossen
3.4.1	Live adjustment	offen	7/9/2025	7	7/16/2025	100%	Abgeschlossen
3.5	Final Presentation	Sebastianus Dustin Susanto	7/17/2025	1	7/17/2025	100%	Abgeschlossen
4	Dokument Phase	offen	8/13/2025	100	8/13/2025	100%	Abgeschlossen



	NAME	DATE
DRAWN	1-3	12.08.2025
CHECKED		
ENG APPR		
MGR APPR		

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN MILLIMETERS
ANGLES ±X.X°

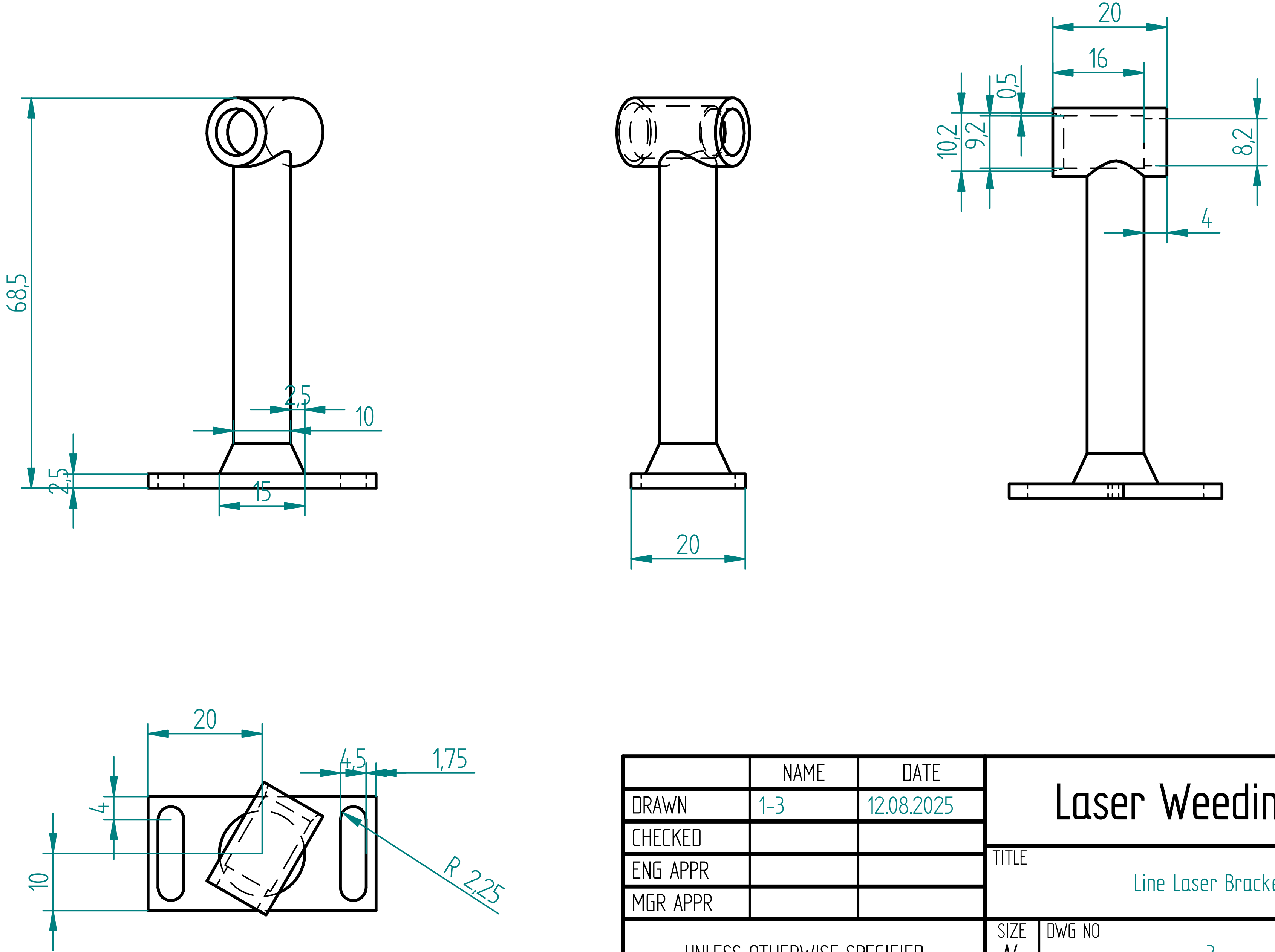
Laser-Weeding 1-3

TITLE
Camera Bracket

SIZE	DWG NO	REV
A4	1	3

FILE NAME: Final Design

SCALE: 1:1 | WEIGHT: 23g | SHEET 1 OF 1



	NAME	DATE
DRAWN	1-3	12.08.2025
CHECKED		
ENG APPR		
MGR APPR		

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN MILLIMETERS
ANGLES ±X.X°

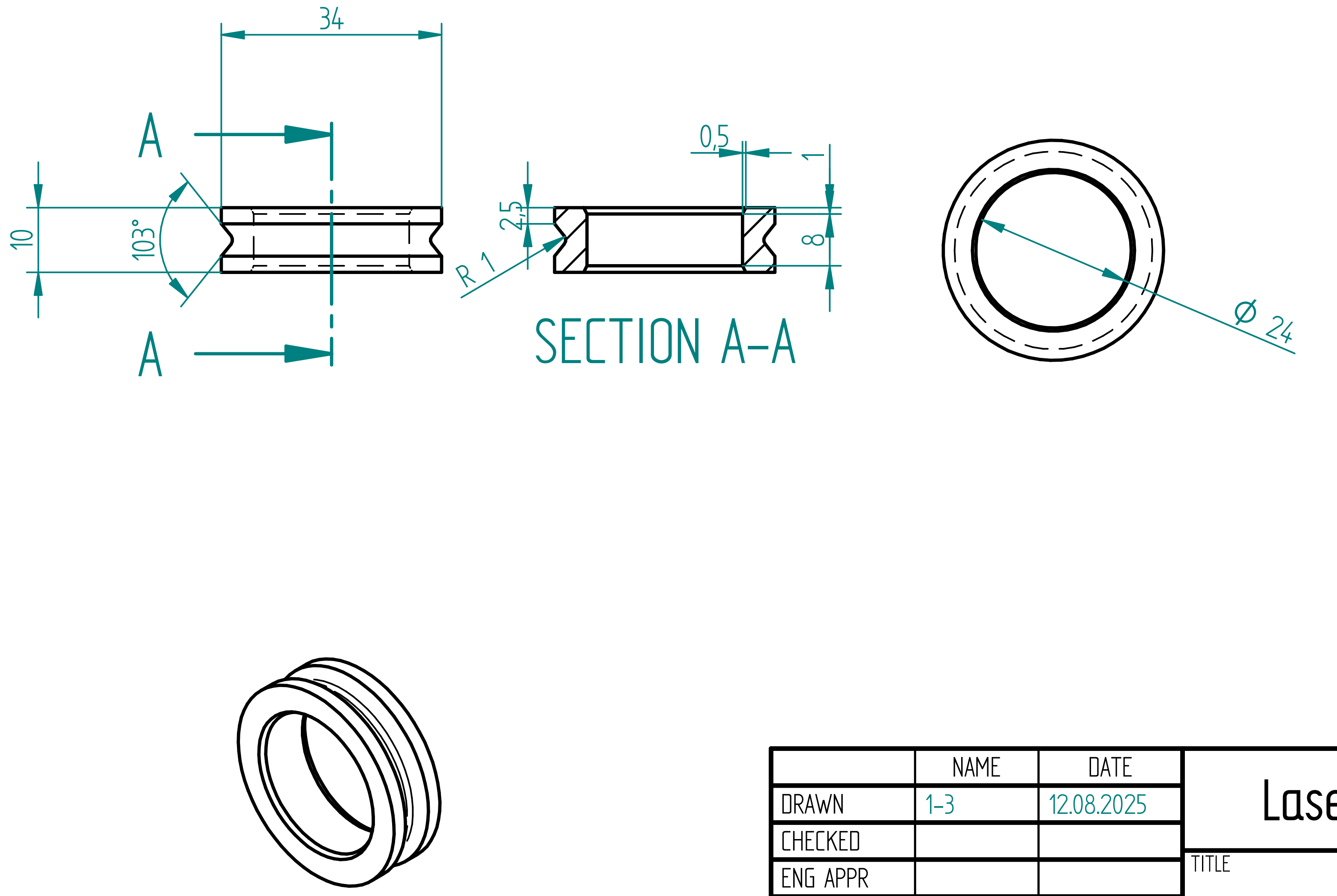
Laser Weeding 1-3

TITLE
Line Laser Bracket

SIZE	DWG NO	REV
A4	3	3

FILE NAME: Draft 1

SCALE: 1:1 | WEIGHT: 7,12g | SHEET 1 OF 1



	NAME	DATE
DRAWN	1-3	12.08.2025
CHECKED		
ENG APPR		
MGR APPR		

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN MILLIMETERS
ANGLES ±X.X°

Laser Weeding 1-3

TITLE
Bearing Sleeve

SIZE	DWG NO	REV
A4	2	1

FILE NAME: Draft 1

SCALE: 1:1	WEIGHT: 4g	SHEET 1 OF 1

Bibliography

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