UNIVERSIDAD DE VALLADOLID

ESCUELA DE INGENIERIAS INDUSTRIALES

Grado en Ingeniería Electrónica Industrial y Automática

Development of offline robot programming unit for tool position control

Autor:

Laiz Zamora, Mario

Responsable de Intercambio en la Uva

Marta Herráez Sánchez

Universidad de destino

Vilnius Tech

Valladolid, Junio 2025.

TFG REALIZADO EN PROGRAMA DE INTERCAMBIO

TÍTULO: Development of offline robot programming unit for tool position control

ALUMNO: Mario Laiz Zamora

FECHA: 3/6/2025

CENTRO: Faculty of Mechanics

UNIVERSIDAD: Vilnius Tech

TUTOR: Vytautas Bučinskas

Resumen en español (max 150 palabras)

El sistema de programación offline para robots (ORPU) desarrollado en esta tesis determina y define trayectorias de soldadura para entornos industriales, donde la suciedad es dominante. ORPU integra una unidad de medición inercial, un sensor de tiempo de vuelo y un microcontrolador ESP32. Este trabajo detalla su diseño e implementación, haciendo hincapié en los principios de funcionamiento y la ergonomía. El dispositivo registra el movimiento tridimensional, proporcionando datos precisos de posición y orientación para la generación de trayectorias. Estas trayectorias, construidas a partir de definiciones basadas en puntos, se introducen directamente en la programación offline del robot o pueden someterse a un procesamiento posterior. El proyecto aborda la integración del hardware y los algoritmos de adquisición de sensores, fusión de datos e interpolación de trayectorias. Los análisis estructurales y las pruebas de seguridad confirman la robustez y ergonomía del prototipo. Una evaluación económica demuestra la viabilidad comercial y el rápido retorno de la inversión.

Palabras clave: programación offline, IMU, sensor ToF laser, ESP32, data-fusion.

Abstract (max 150 words)

The offline robot-programming unit (ORPU) developed in this thesis determines and defines welding trajectories for dirty, dusty industrial settings. ORPU integrates an inertial measurement unit, a time-of-flight sensor, and an ESP32 microcontroller. This work details its design and implementation, emphasizing operating principles and ergonomics. The device records 3-D motion, delivering precise position and orientation data for trajectory generation. These paths, built from point-based definitions, feed directly into offline robot programming or can undergo post-processing. The project addresses hardware integration and algorithms for sensor acquisition, data fusion, and trajectory interpolation. Structural analyses and safety tests confirm the prototype’s robustness and ergonomic suitability. An economic evaluation shows commercial viability and rapid return on investment.

Keywords: offline robot programming, IMU, ToF laser sensor, ESP32, data fusion.

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY
FACULTY OF MECHANICS
DEPARTMENT OF MECHATRONICS, ROBOTICS AND DIGITAL MANUFACTURING

Mario Laiz Zamora

DEVELOPMENT OF OFFLINE ROBOT PROGRAMMING UNIT FOR TOOL POSITION CONTROL

Final Bachelor's Project

Study programme MECHATRONICS AND ROBOTICS,
Code 612H73002

Vilnius, 2025

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY
FACULTY OF MECHANICS
DEPARTMENT OF MECHATRONICS, ROBOTICS AND DIGITAL MANUFACTURING

APPROVED BY
Head of Department

(Signature)

Vytautas Bučinskas
(Name, Surname)

2025 05 28
(Date)

Mario Laiz Zamora

DEVELOPMENT OF OFFLINE ROBOT PROGRAMMING UNIT FOR TOOL POSITION CONTROL

Final Bachelor's Project

Study programme MECHATRONICS AND ROBOTICS,
Code 612H73002

Supervisor: prof., dr., Vytautas Bučinskas
(Title, Name, Surname) (Signature) (Date)

Vilnius, 2025

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

Mario Laiz Zamora, 20246957

(Student name and surname, Student ID)

Mechanics Faculty

(Faculty)

Mechatronics and Robotics

(Study programme, academic group)

DECLARATION OF AUTHORSHIP IN FINAL DEGREE PROJECT

18 May 2025

(Date)

I confirm, that my final degree project, which topic is Development of offline robot programming unit for tool position control

is written independently. The material presented in this final degree project is not plagiarized. Quotations from other sources used directly or indirectly are indicated in the literature references.

The final degree project was inspected by:

Vytautas Bučinskas

There is no contribution of other persons to the final degree project. I have not paid any statutory sums of money for this work.

Signature

MARIO LAIZ ZAMORA

(Name and Surname)

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY
FACULTY OF MECHANICS
DEPARTMENT OF MECHATRONICS ROBOTICS AND DIGITAL MANUFACTURING

Production and Manufacturing engineering study field
Mechatronics and robotics study programme,
State code 6121EX048

APPROVED BY
Head of Department
____
(Signature)
Vytautas Bučinskas
(Name, Surname)
____
(Date)

TASK FOR BACHELOR THESIS

13 February 2025 No. 2
Vilnius

For student Mario Laiz Zamora

Bachelor Thesis title: Development of offline robot programing unit for tool position control

Approved on ________________________________.

The Final work has to be completed by _____________.

TASK FOR FINAL THESIS:

Initial data:

Offline mode tool, operation time – 4 hours, weight – max. 300 g, size – max 300 mm length, microcontroller – ESP32, Sensors – IMU and ToF.

Explanatory part:
1. Introduction. Analysis of analogical devices. Substantation of the taken technical decision.
2. Calculations needed for the design process.
3. Description of the design and working principle. Electric-block scheme. Algorithm of management of device.
4. Work safety. General provisions and requirements for safe working and environmental protection. Work safety of specific devices.
5. Evaluation of economic indicators of the designed or upgraded device.
6. Final conclusions and recommendations.
7. Literature reference list.

Drawings:
1. General drawing of the device (1 sheet A1); 2. Assembly drawing of the device (node) (1 sheet A1); 3. Algorithm of management of device (0,5 sheet A1); 4. The work drawings of the chosen part (3 sheets A3); 5. Electric component composition (A3). 6. Economic indicators (0.5 sheet A1).

Supervisor .... prof. dr. Vytautas Bučinskas
(Signature) (Academic Title, Name, Surname)

Task accepted
……………………………………..
(Student‘s signature)
Mario Laiz Zamora
(Student‘s Name, Surname)
2025-05-02
(Date)

Vilnius Gediminas Technical University

Mechanics faculty

Mechatronics and Robotics department

ISBN ISSN

Copies No. ………

Date ….-….-….

Mechatronics and Robotics study programme bachelor (master) thesis.

Title: **Development of offline robot programming unit for tool position control**
Author **Mario Laiz Zamora** Academic supervisor **Vytautas Bučinskas**

Thesis language

X	Foreign (English)
	Lithuanian

Annotation

Šiame darbe sukurtas autonominis roboto programavimo įrenginys turi gebėti nustatyti ir apibrėžti suvirinimo trajektorijas pramoninėje aplinkoje, kurioje yra purvas ir dulkės. ORPU sistemą sudaro MEMS akcelerometras, lazerinis atstumo jutiklis ir ESP32 mikrovaldiklis

Šiame disertacijos darbe aprašomas išsamus ORPU projektavimas ir įgyvendinimas, daugiausia dėmesio skiriant veikimo principui ir prietaiso ergonominiam dizainui. Įrenginys fiksuoja trimačius judesius, tiksliai nustatydamas padėties ir orientacijos duomenis, reikalingus tiksliai trajektorijai generuoti. Šios trajektorijos, pagrįstos taškų duomenų apibrėžimu, gali būti tiesiogiai naudojamos pramoninėse programose programuojant robotus neprisijungus prie interneto arba joms gali būti taikomos tolesnio apdorojimo užduotys.

Projektas apima ne tik fizinį komponentų projektavimą ir integravimą, bet ir jutiklių duomenų rinkimo, duomenų sintezės ir trajektorijos interpoliavimo algoritmus. Išsamios struktūrinės analizės ir saugos bandymai patvirtina prototipo tvirtumą ir ergonomiškumą. Be to, ekonominis tyrimas rodo projekto komercinį gyvybingumą ir greitą investicijų grąžą.

Struktūra: įvadas, analogiškų konstrukcijų apžvalga, konkrečių mazgų analizė, projekto skaičiavimai, konstrukcijos ir veikimo principo aprašymas, darbo sauga ir aplinkosauga, ekonominiai skaičiavimai, išvados, nuorodos, Brėžiniai: bendras įrenginio vaizdas , surinkimo brėžinys, 3 detalių darbo brėžiniai, elektroninių komponentų struktūra, įrenginio valdymo algoritmas, ekonominiai skaičiavimai.

Disertaciją sudaro: tekstas be priedų, 34 paveikslai, 10 lentelių, 12 bibliografinių įrašų.
Pridedami priedai.

Reikšminiai žodžiai: neprisijungęs roboto programavimas, pramoninis robotas, IMU, ToF lazerinis jutiklis, ESP32, suvirinimo trajektorijos, ergonominis prototipas, duomenų sintezė, I2C protokolas.

Vilnius Gediminas Technical University
Mechanics faculty
Mechatronics and Robotics department

ISBN ISSN
Copies No. ………
Date ….-….-….

Mechatronics and Robotics study programme bachelor (master) thesis.

Title: **Development of offline robot programming unit for tool position control**
Author **Mario Laiz Zamora** Academic supervisor **Vytautas Bučinskas**

Thesis language

X	Foreign (English)
	Lithuanian

Annotation

The offline robot programming unit developed in this thesis must be able to determine and define welding trajectories in industrial environments where the dirt and dust predominate. The ORPU system consists of an inertial measurement unit, a time-of-flight sensor and a ESP32 microcontroller.

This thesis describes the detailed design and implementation of the ORPU, focusing on operational principle and device ergonomic design. The device captures three dimensional movements, accurately determining both positional and orientational data required for precise trajectory generation. These trajectories, based on data definition from the points, can be directly employed for offline robot programming in industrial applications, or they can be subjected to post-processing tasks.

The project covers not only the physical design and integration of the components but also the algorithms required for sensor data acquisition, data fusion and trajectory interpolation. Comprehensive structural analyses and safety tests validate the robustness and ergonomic design of the prototype. Additionally, an economic study demonstrates the project’s commercial viability and rapid investment return.

Structure: introduction, overview of analogous constructions, specific node analysis, project calculations, description of construction and operational principle, work safety and environmental protection, economic calculation, conclusions, references, Drawings: general view, assembly, 3 detail view, electronic component composition, algorithm of management of device, economic calculation.

Thesis consists of: 67 p. text without appendixes, 34 figures, 10 tables, 12 bibliographical entries.

Appendixes included.

Keywords: offline robot programming, industrial robot, IMU, ToF laser sensor, ESP32, welding trajectories, ergonomic prototype, data fusion, I2C protocol.

CONTENT

LIST OF PICTURES

LIST OF TABLES

INTRODUCTION

In contemporary industrial contexts, robots are progressively becoming a more prominent presence. Consequently, novel maintenance methodologies and programming techniques are emerging. Robots are especially prevalent in the production and automotive sectors, where they perform high-precision tasks (e.g. welding, placing fragile objects) and move heavy loads.

In the field of robot programming, fundamental techniques such as acquiring 3D points through testing are frequently employed. This necessitates the utilisation of a robotic unit within an industrial environment, thereby ensuring the elimination of any potential drift and the subsequent collection of the requisite points through experimental means. However, in new installations or instances where modifications are desired, the process can become more complex. Consequently, alternative methods for acquiring points and trajectories have emerged, obviating the necessity for robotic instrumentation in such determinations. Two potential avenues for investigation are as follows: firstly, the utilisation of software and simulators, which, despite their high computational cost, are capable of defining these trajectories in a virtual environment; secondly, the employment of digital devices and sensors, which offer the benefits of simplicity and precision in the definition of trajectories.

In industry, the concept of collaboration between the robot and the maintenance personnel has been established in order to enhance efficiency of the operation of the robotised facility. Consequently, these instruments, employed for tasks such as calibration and trajectory definition within the work area, enable maintenance personnel to oversee the operation of the robotised station with minimal training and in a relatively easy way. A further concept with considerable potential in the industrial sector is that of work by imitation. This approach allows the robot to learn from the operator, who brings all his experience to the task at hand.

This thesis will present the design and implementation of a prototype for defining trajectories in welding tasks. It will be a gadget used by maintenance personnel to define the paths where the robot will weld. The design should be ergonomically optimised for extended use by personnel, and sufficiently accurate to define the points of a weld bead. The prototype's development is driven by the objective of reducing the time spent by maintenance personnel waiting between different stages of a welding task, thereby enhancing the overall efficiency of the maintenance process.

As the industrial environment, and in particular the welding stations, is dominated by dust and dirt, different options should be considered for the design and implementation of the path creator, always taking into account the working characteristics.

1. OWERVIEW OF ANALOGIC CONSTRUCTIONS

1.1. Motion Capture and Augmented Reality

Since a decade ago, augmented reality has been introduced in the industrial sector, taking part in different ways of automatizing the factories, by using artificial vision. For this reason, it is proposed as a solution for this thesis, artificial vision will be used to determine the coordinates of the pen-shaped gadget, that will be manipulated by an expert welder, describing welding trajectories. Besides, this solution apart from facilitating the welding process, it prevents contamination and damage from the inhalation of toxic fumes by welding staff, due to the trajectories definition will be outside the working area.

For the description of the solution I will base myself on the study carried out by: Fabian Mueller, Christian Deuerlein, Michael Koch, called: **"Intuitive Welding Robot Programming via Motion Capture and Augmented Reality".** Throughout this subchapter, a brief summary of the operation will be made, with a detailed reference to a technology called Motion Capture**.**

At the beginning I should talk about MoCap Studio. it is a room containing a table and a clamping plate to fix individual sheets for the blank. The position of the clamping plate is referenced with a coordinate cross, consisting of several infrared (IR) markers. The whole room is being observed by four IR cameras, which are the main components of the MoCap system. The system is prepared with a special calibration tool by tracking the tool within the space near the table. The coordinate system has several measuring tips, which serve as calibration points for the pointing device. The exact position of the tips were already determined with a portable measuring arm using a FARO laser line scanner and the tool centre point (TCP) is precisely calibrated by repeatedly probing with the tip of the pointing device. The cross of the plate is relative to the original coordinate base of the MoCap system, so the plate can be rotated to any position to facilitate the user's work.

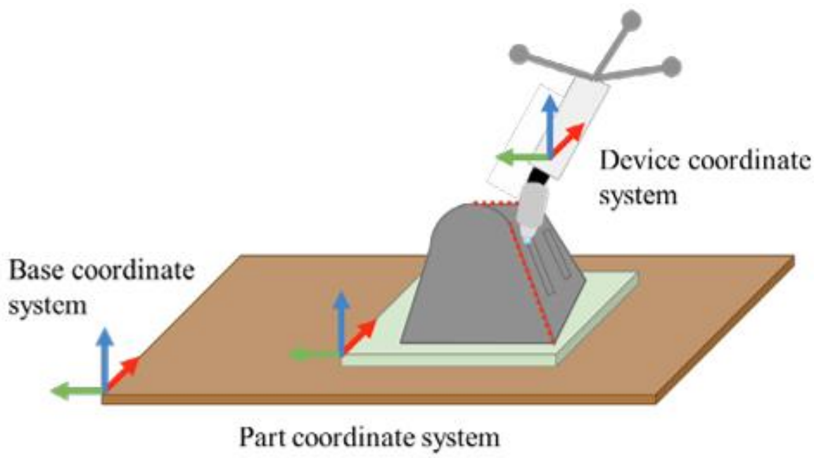


Fig. 1. Illustration of the different reference coordinate

(Fabian Mueller, Christian Deuerlein, Michael Koch, 2019)

Trajectories for the welds on the workpiece blank are recorded with the pointing device, whose spatial position is traced. Talking about the device: it should have the same size and shape as the welding gun that will be used later on the robot.

After recording, the trajectories are converted into an executable robot program. The second step takes place on the shopfloor and the program is executed by the robot on the blank. The generated program can be used to edit all blanks from the batch.

The third step Will be to masterize the trajectories save in the robot programme, by changing the different implementation options. The quality of those trajectories is influenced by the framerate of the recording and human influences while recording. The repetition-rate must be high enough to be able to reproduce the weld seam. An important aspect to keep in mind are small human-induced shaking movements, should not directly impact the robot path planning, as this makes the application less efficient and can also damage the mechanics in the long term.

The global vision of the process is described in the following figure:

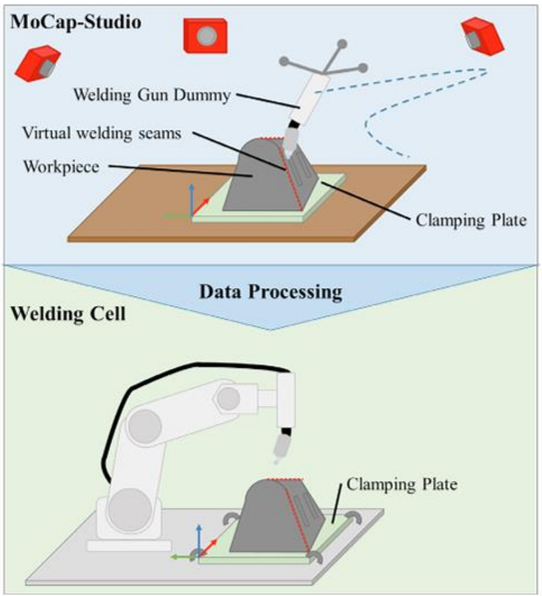


Fig. 2. Illustration of the whole process for AR robot welding

(Fabian Mueller, Christian Deuerlein, Michael Koch, 2019)

The three stages of the process are represented in the Figure, as a way of sum it up, first in the MoCap-Studio, the professional welding worker defines the virtual welding trajectory with the welding Gun Dummy, then the data is processed and become into the robot programme, finally in the welding cell, the robot will be the one who weld the object through the trajectory previously defined.

The tracking tool:

it is equipped with five passive infrared markers, which are captured by the MoCap system's four cameras to capture the position of it. In order to place the pivot point exactly into the tip of the tracking tool, all reference points were already measured with a portable measuring arm using a FARO laser line scanner. The reference points could be compared with the infrared markers from the MoCap system, and the pivot point could be repositioned in the tracking software.

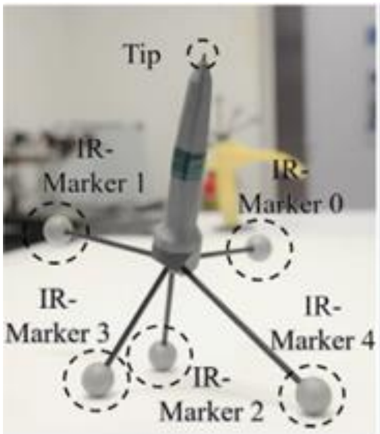


Fig. 3. Tracking tool

(Fabian Mueller, Christian Deuerlein, Michael Koch, 2019)

In the figure above the tracking tool is represented with the IR markers that will help the MoCap system to take the coordinates of the gadget’s tip.

The proposed solution offers several clear advantages. First, it allows expert welders to use their existing skills by programming robots with a pen-shaped device similar to a real welding gun. This makes the transition to automation more intuitive and reduces the need for extensive training.

Another significant benefit is safety. By capturing welding paths outside the hazardous area, the solution helps protect welders from toxic fumes. Additionally, the use of offline programming keeps production running smoothly by minimizing downtime. Also the precision of the MoCap system, combined with real-time visualization through augmented reality, makes it easier for welders to verify and adjust paths quickly, which leads to more accurate and consistent welds.

Despite its advantages, the proposed solution also has some drawbacks. One of the main challenges is the reliance on specialized hardware, such as the Motion Capture (MoCap) system with infrared cameras and markers, which can be costly and complex to set up. This might limit its accessibility for smaller businesses with limited budgets.

Involuntary shaking or slight errors during the recording of trajectories can affect the accuracy of the welding paths. This means that additional filtering and correction processes are required, which can add complexity and time to the setup.

Additionally, the need for frequent calibrations of the tracking device and the coordinate system can become time-consuming, potentially offsetting some of the efficiency gained from offline programming.

Lastly, while the solution simplifies the programming process, it may not be ideal for highly complex welding tasks that require advanced path planning and adjustments. This could limit its application in more demanding industrial scenarios.

1.2. Location based on UWB using Lidar Sensors (Tof)

Ultra-wideband (UWB) technologies are defined as a wireless communication system, it is based on the transmission of short-term radio frequency pulses with extremely wide bandwidth. Originally, it was developed for military applications, but nowadays it takes part in the industrial sector due to its ability to provide the exact location and, the device exhibits a high degree of immunity to interference, whilst simultaneously requiring a low level of operating power. In fact, UWB technology uses a wide frequency range.

Other part which involves this technology, is the development of Lidar Sensors. They use the time of light idea, which consists of the measurement of the time a laser lasts since it was sent. Through this, the sensor can know the distance to an object.

In this thesis a solution will be exposed to accurately define welding trajectories, a UWB-based localization system is proposed, which consists of three main components: the UWB emitter, UWB receivers, and a UWB coordinator.

UWB Emitter

The simulated tool (a laser gun) is fitted with the UWB emitter to transmit short duration radiofrequency pulses. These pulses will be used to determine the exact position of the tool.

UWB Receivers

For 3D triangulation to work accurately, the working environment should have at least four fixed UWB receivers.

The pulses transmitted by the emitter are captured by these receivers which measure the Time of Arrival (ToA) to derive distances. The receivers connect to a common processing unit (either a personal computer or a Raspberry Pi) to process the location in real-time.

UWB Coordinator

The UWB coordinator manages the connectivity of the receivers to the central processing unit (PC/Raspberry Pi). The main job is to make sure that all the pulses that are sent and received are timed the same so that the location data is correct. The system can determine the accurate location of the emitter in accordance with the differences between the arrival times of the pulses at the receivers by coordinating the timing information.

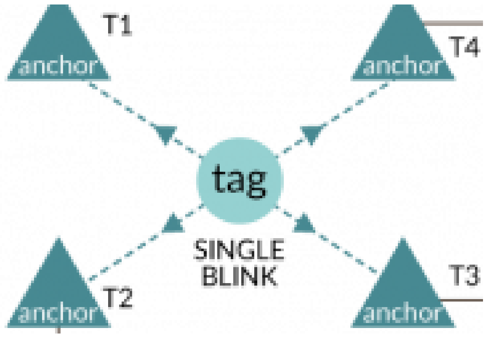


Fig. 4. Scheme of UWB system

(https://en.wikipedia.org/wiki/Ultra-wideband)

To accurately define welding trajectories using Ultra-Wideband (UWB) technology, there are three main localization methods: Time of Flight (ToF), Time Difference of Arrival (TDoA), and Angle of Arrival (AoA). Each method has its own way of determining the position of the tool in space, with distinct advantages and challenges.

1.2.1. Time of Flight (ToF)

The Time of Flight (ToF) method determines the position of an object by measuring the time it takes for a signal to travel from a UWB emitter to a receiver. In this approach, the emitter sends a short radiofrequency pulse, and the receiver records the exact time it takes for the pulse to arrive. By using the time recorded, the system can calculate the distance between the emitter and the receiver.

ToF is particularly effective for measuring direct distances in environments where line-of-sight is clear and straightforward. However, it requires precise synchronization between the emitter and the receiver to ensure the accuracy of the time measurements. This method works best for smaller areas, where maintaining synchronization is simpler and more reliable. Unlike other methods, ToF focuses on direct measurement of the travel time of a signal between two points rather than comparing the timing of multiple signals. Its simplicity in measuring direct distances makes it a practical option for straightforward setups, but it can become less accurate in larger spaces or environments with significant obstacles.

1.2.2. Time Difference of Arrival (TDoA)

The Time Difference of Arrival (TDoA) method determines the location of an object by comparing the difference in time at which a UWB signal arrives at multiple receivers. In this approach, a UWB emitter sends a pulse that is captured by several synchronized receivers positioned strategically around the workspace. Each receiver records the exact time the pulse arrives, and the system calculates the emitter's position by analyzing the differences in these arrival times.

TDoA offers a significant advantage over ToF by eliminating the need for the emitter to be synchronized with the receivers. Only the receivers need to be synchronized with each other, simplifying the setup and making it more suitable for larger areas. This method can provide high accuracy in three-dimensional space, even in complex environments with multiple receivers. The ability to use time differences rather than direct timing between emitter and receiver allows TDoA to offer enhanced precision and robustness against certain types of interference. Its reliance on multiple receivers also makes it more scalable for extensive industrial settings.

1.2.3. Angle of Arrival (AoA)

The Angle of Arrival (AoA) method determines the position of an object by measuring the direction from which a UWB signal arrives at a receiver. This approach requires each receiver to have an array of antennas capable of detecting the angle of the incoming signal. By analyzing the phase or time differences between signals received at different antennas, the system can determine the direction of the emitter relative to the receiver.

AoA is particularly useful when directional information is as important as positional accuracy, as it can provide both the location and the orientation of the emitter. However, this method is highly dependent on having a clear line of sight between the emitter and receivers, as obstacles can cause reflections that distort the angle measurements. The requirement for multiple antennas per receiver makes AoA more complex and costly compared to ToF and TDoA. Nevertheless, when combined with other methods, AoA can significantly enhance localization accuracy, especially in scenarios where understanding the direction of movement is critical.

To be clearer in the explanation of those different technologies the chart below shows principal characteristics of each method and the difference between them.

Table 1. Different UWB technologies

Aspect	ToF	TDoA	AoA
Synchronization Required	Emitter & Receiver	Receivers Only	Receivers Only
Number of Receivers Needed	One per measurement	At least Three (3D: Four)	Two or More (with antenna arrays)
Line of Sight Requirement	High	High	Very High
Accuracy	High	Very High	Medium to High
Complexity	Medium	Medium to High	High
Best Use Case	Short-range, simple setups	Large-scale, precise localization	Direction and orientation tracking

This UWB-based approach eliminates the need for additional sensors such as IMUs and simplifies the hardware architecture. The ability to capture precise 3D positions directly through the UWB system provides a robust and efficient solution for defining welding trajectories with cm-level accuracy. This method not only enhances the precision of path definition but also reduces the complexity of the overall system, making it a suitable choice for industrial applications.

On the other hand, this solution has many complications. First, it will be difficult to coordinate all the system described, and in a welding-environment where UWB can penetrate non-metallic obstacles, metallic surfaces can cause signal reflections and multipath effects, which may reduce localization accuracy. Besides, UWB modules and receivers are generally more expensive than other localization technologies such as IMUs and location sensors, which might increase the overall cost of the system.

Setting up UWB receivers requires precise calibration and positioning to ensure accuracy in 3D triangulation. For optimal accuracy, UWB requires a clear line of sight between the emitter and receivers. Blockages can degrade performance or cause temporary loss of signal. These situations are common in industrial environments so the calibration of this technology could take a lot of time, and it also requires real time system to process all the data acquire.

1.3. Stereo-based real-time 6-DoF work tool tracking

Nowadays robot programming requires the necessity of highly skilled personnel, as is the resultant prolonged periods of inactivity on production lines. In order to address these constrains, an innovative way for programming is proposed. It is based on human demonstration using a light-marker and artificial vision techniques.

For this idea, a light-marker is made by different colour LEDs, which are strategically placed on the faces of an icosahedron. This gadget is recorded at real time by industrial cameras which are synchronized to determine the position and orientation of the light-marker.

The system allows capturing trajectories in six degrees of freedom (6-DoF), including both the position and orientation of the marker, as an operator intuitively draws the welding paths. The captured data is processed to automatically generate a program for the robot, consisting of instructions and speeds adjusted according to the timestamps recorded during the demonstration.

For the description of the solution I will base myself on the paper carried out by: Marcos Ferreira, Paulo Costa, Luís Rocha, A. Paulo Moreira, called: **“Stereo-based real-time 6-DoF work tool tracking for robot programing by demonstration”.** Throughout this subchapter, a summary of the operations will be made, considering a little modification: instead of programming painting robot, this idea is become for welding robot.

Getting deeper in the solution, the device is based on a set of luminous markers (high-intensity LEDs) that enables video tracking using a minimum of two cameras. It is a simple but effective marker that delivers high-quality pose estimates. The shape of the marker and the choice of a singular pattern of colours for the LEDs are the key advantages to guarantee reliable and robust data from a human demonstration, which ultimately leads to a precise robot mimic.

Fig. 5. Prototype Design

(Marcos Ferreira, Paulo Costa, Luís Rocha, A. Paulo Moreira, 2014)

While one LED is enough to keep track of position (3D), to capture the other three degrees of freedom from orientation, at least three non-collinear LEDs are needed. Increasing the number of cameras around the working area can fight back pose estimation fail due to occlusions, but with increasing costs. So other way to achieve is increasing the number of LEDs to 20 visible-light (RGB). These are distributed in a special manner, based on the shape of an icosahedron, to provide an interesting set of properties that aid in constructive and algorithmic aspects:

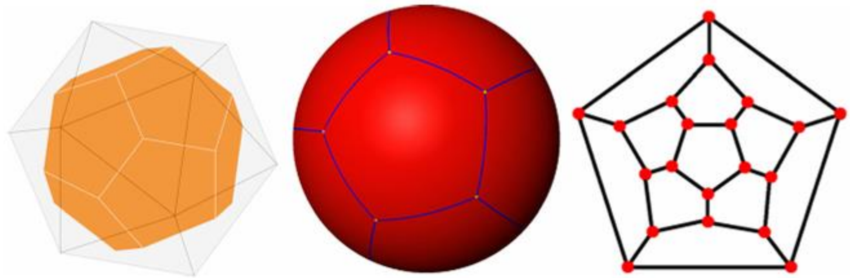


Fig. 6. The marker outline follows the icosahedron shape while the LEDs are positioned on the vertices of a dodecahedron that touch the face centers of the former

(Marcos Ferreira, Paulo Costa, Luís Rocha, A. Paulo Moreira, 2014)

1. Simple and Cost-Effective Manufacturing: The 3D model of the icosahedron can be easily printed, resulting in a lightweight and economical marker. Additionally, it allows the use of materials with different densities, balancing weight and mechanical robustness.
2. Space for Electronic Components: The shape of the icosahedron provides enough internal space to house PCBs and the components needed to control the RGB LEDs. The faces are ideal for attaching the PCBs and positioning the LEDs at the centre of each face.
3. Full Rotation Coverage: By placing the LEDs at the centre of each face, sufficient visibility is ensured at all times for the cameras, covering 360° rotations in every axis. This allows keeping the number of cameras to a minimum of two to achieve stereoscopy.
4. Symmetry and Separation of Position and Orientation: Being a regular polyhedron, the icosahedron allows a symmetrical distribution of the LEDs. This symmetry facilitates the separation of position and orientation calculations, as the solid centre remains invariant under rotation.
5. Ease of Position Estimation: Connecting the face centres of the icosahedron forms a dodecahedron, whose vertices lie on a sphere. Knowing the position of these vertices, the centre of the marker can be quickly calculated by fitting a sphere, simplifying the position estimation process.
6. Simplification of Orientation Estimation: The icosahedron/dodecahedron combination allows the spatial distribution of LEDs to be represented in a planar diagram called the Schlegel diagram. This diagram facilitates the identification of colour patterns, simplifying the orientation estimation of the marker.

1.3.1. Sincrovision technique

It implements a system of 3D acquisition based on stereoscopic vision synchronized with high intensity luminous markers. The key idea is to turn on the markers as soon as the cameras start acquiring image and turn them off after the camera exposure time has expired. It is well represented in the following scheme:

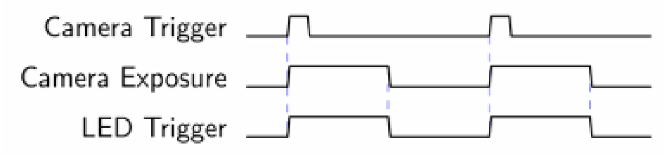


Fig. 7. A timing diagram depicting the synchronous image acquisition.

(Marcos Ferreira, Paulo Costa, Luís Rocha, A. Paulo Moreira, 2014)

To ensure that unwanted light is not captured, the lenses aperture is reduced to a minimal. This setup makes it possible to triangulate the individual markers' positions in space in a robust way, independently of lighting conditions in the scene thus ignoring most of the common noise sources in artificial vision applications.

1.3.2. Colour selection and position estimation

For this solution, the chosen colours are the primary and secondary ones. The prototype only uses 5 different colours but in a specific way and position to triangulate and obtain the coordinates and rotation of the tool. As I said before, the tool has a icosahedron shape with the LEDs incorporated in the middle of the faces creating a regular dodecahedron.

The LEDs could be grouped in groups of three, making a "Y" form. Using only five colours allows a quick identification of the marker orientation as soon as a Y Is completely visible in the images.

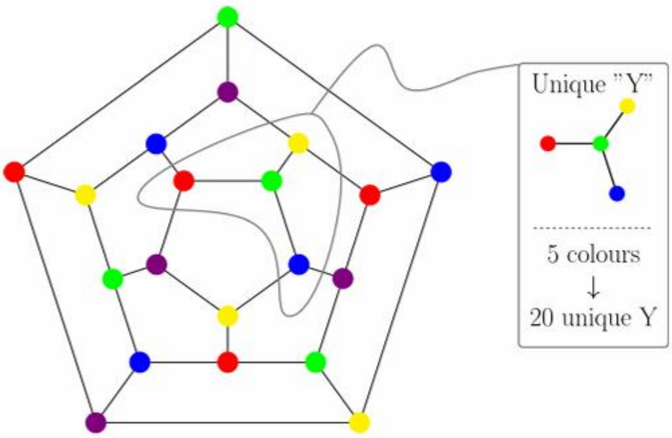


Fig. 8. colored dodecahedron

(Marcos Ferreira, Paulo Costa, Luís Rocha, A. Paulo Moreira, 2014)

With five different colours, there are 20 unique “Y”, as many as there are in the dodecahedron.

Fig. 9. Detection of a complete Y

(Marcos Ferreira, Paulo Costa, Luís Rocha, A. Paulo Moreira, 2014)

After explaining in detail the operation of the idea, some conclusions must be taken in account. This solution is quite easy to implement without an extra charge of costs, which makes perfect for small industries. It is also offered as a solution for acquiring the skill directly from the operators’ tasks, taking advantage of their experience in those environments and jobs. The used of pair of industrial cameras, which controlled the light-marker, instead of inertial and magnetic sensors reduced errors that appear with those sensors.

Apart from that, it has some negative points. The main problem is the dependence of the leds’ visibility. In industrial environments there are also places and objects with strange geometries, which reduce in a exponential way the precision of those cameras.

Talking about the cameras, colour detectors, in the paper they report so many errors during the process of colours classification. Those errors mixing with a complex way of calibration could affect to the accuracy of the coordinates.

In industrial places, dirty environments predominate. This could be a problem to the implementation of the light-marker and it also restricts the time of use of the gadget.

Finally, the last aspect to take in account is the materials that will be used during the paths defined process. Most of the pieces will be made of metal which produce lots of reflexes, affecting data acquisition.

1.4. Use of a IMU and a ToF

As a way to facilitate the industrial robots programming, a new idea turns up with the Programming by Demonstration (PbD). This option does not require specialised personnel or wasting time in re-programming and maintenance. The programming by demonstration makes the use of copycat robots possible to medium-size factories, improving their production and efficiency.

This revolutionary method has two possible directions to carry it out. The first one would be the use of industrial cameras that detect and follow staff's movements, then processing all data and transform into robot's trajectories. This solution, previously commented in above sections, could be complex to calibrate and will require high economical effort, despite that in some cases it would fail. Furthermore, in welding applications, the use of cameras would not be efficient due to high error percentage obtain from working in those dirty environments.

The other option to develop programming by demonstration are movement sensors that will be attached to the person who will define the paths. These sensors will provide data about the movement in three axis (x, y, z) and the rotations (roll, pitch, yaw), describing six degrees of freedom. Besides it is possible to add distance sensor to determine the points just aiming on them. The union of both sensor will facilitate the coordinates detection.

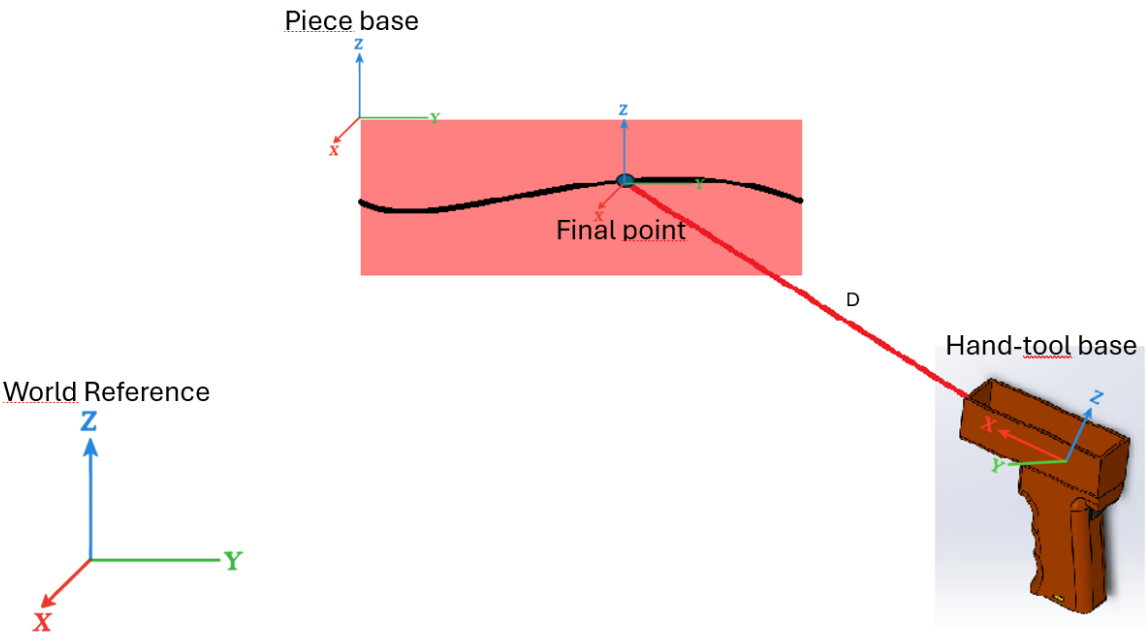


Fig. 10. Coordinates location and trajectory definition

This solution proposes to detect the movements by an inertial sensor which provides data about the acceleration from the three axis and its angular speed. This inertial sensor contains a built-in gyroscope and an accelerometer to obtain the measurements. Besides to complete the solution another sensor should be added, in order to determine the trajectory. This sensor should be able to determine distance in a range from 5 cm to up 4 meters, always with a strict accuracy. For this reason, a laser and a Tof sensor will be used to determine the distance between the IMU and the final points that compound the trajectory.

1.4.1. Inertial Sensor

The IMU sensor (Inertial measurement Unit) is an electronic device that measures and extract data about the movement of it. This unit combines different types of sensors that determine the orientation, acceleration and rotation in 3D space.

- Accelerometer: is the sensor in charge of obtaining data related with the lineal acceleration. It can determine it in (m/s^2) for each axis.
- Gyroscope: this sensor extracts measurements about the angular speed in the three axes, in degrees per second or radians per second.
- Magnetometer: depending on the type of the IMU this sensor might be optional. By measuring the Earth's magnetic field, it is able to obtain absolute orientation referring to absolute north.

The inertial measurement Unit will be in charge to determine the offset position by a double integer to lineal acceleration, and also the orientation of the prototype. With that data the controller will be able to capture the trajectory that the gadget has followed.

1.4.2. Laser Sensor (ToF)

The Laser Sensor is based on the Tof technology. This sensor is able to determine distance by counting the time a beam of light travels from the emitter and bounce off an object, then returns to the receptor. This sensor calculates the distance taking in account that the speed of the beam of light is the light's speed.

With this philosophy the laser sensor can detect obstacles and apport data about the distance to those obstacles.

For this solution the Laser sensor will be used to obtain the distance between the final point and the prototype as a way of taking the properties of every single point that define the trajectory.

1.5. Substantiation of the decision

During the first subchapter of this thesis many solutions for describing welding trajectories for robots have been exposed. Most of them use industrial cameras as the hardware solution that combine with artificial vision and augmented reality to determine the trajectory's points. But in welding environments it might not be the ideal solution due to the complex way of calibration and the high economic effort it should be.

From this thesis point of view, an ideal solution should be that one which combines simplicity with high precision and low cost. For that reason, all the solutions based on cameras will not be effective and developed. Therefore, the other ideas are UWB technology and the IMU + Laser Sensor.

Firstly, as it was mentioned before, UWB technology might be so expensive if you want to have high level of accuracy, due to the number of transmitters and receivers the studio should have. This technology also presents a challenge in welding environments due to signal interferences and electronic noise. Besides, working with UWB (ultra-WideBand), in some cases multipath effects will appear due to the metallic surfaces.

As with the previous options this technology calibration will generate lots of headache adjusting it. So after exposing the difficulties and problems that will carry out other solutions, it is time to stablish the solution that will be developed along this thesis.

An inertial measurement unit combines with a Laser sensor (ToF) to determine coordinates will have so many advantages. In contrast to artificial vision and augmented reality, the use of those sensors will carry out in a less computational difficulties, which means that a mid-range microcontroller will be able to obtain data with low latency. Also the sensors of the idea selected do not depend on changes in lighting and environmental noisy conditions, and it is robust against reflexes. One important point to take in account is the high cost of the augmented reality technology and its high energetic consumption.

Now, if the final solution is compared with the UWB technology, there are also some advantages. As it was said before, the economic effort would be the first disadvantage of this technology. Apart from that the final solution will provide higher accuracy near to mm than the UWB, that it is needed to determine welding points. An important aspect is about the data obtained: the final idea gives 6 degrees of freedom from the point, but the UWB technology only gives the coordinates in the 3D space (x, y, z).

While technologies such as AR or computer vision are ideal for complex visual inspection tasks, advanced detection, or enriched visual interfaces, and UWB excels in longer-range positioning with lower accuracy (such as equipment localization in factories or remote asset tracking), the combination of IMU and ToF sensors is more precise, simpler, and more efficient for defining detailed local trajectories.

2. OVERVIEW OF SPECIFIC NODES

2.1. Inertial Measurement Unit

With the presentation of the solution, Inertial Measurement Unit was described in a brief way. For this subchapter, IMU will be shown in detail, and some commercial sensors will be provided.

An Inertial Measurement Unit (IMU), also known as an Inertial Reference Unit (IRU) or Motion Reference Unit (MRU), packs a 3-axis accelerometer and a 3-axis gyroscope, making it a 6-axis IMU. Some also include a 3-axis magnetometer, turning them into 9-axis IMUs. Together, these sensors measure specific force, angular rate, and magnetic fields around the device, providing a comprehensive picture of its motion.

2.1.1. Accelerometer

Accelerometers are devices that gauge and relay specific forces, including mechanical, quartz, and MEMS accelerometers.

Mechanical accelerometers can achieve in-run bias stabilities less than 1 µg but are mainly used in navigation-grade applications due to their size and cost.

Quartz and MEMS accelerometers offer in-run bias stability ranging from 1000 µg to 1 µg, covering various performance categories. With high precision and stability, they are often employed in industries where accurate measurement of acceleration is essential.

In IMUs, the accelerometers often use MEMS technology, which stands for microelectromechanical systems.

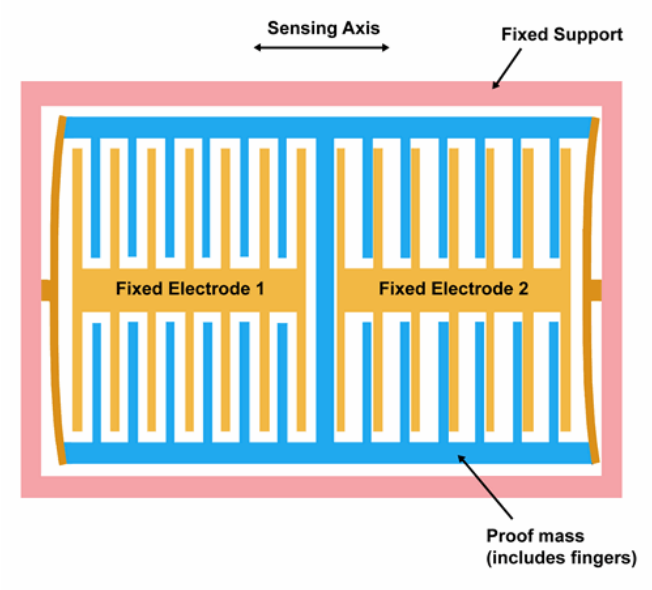


Fig. 11. Accelerometers design

(https://siliconsensing.com)

These accelerometers have a tiny mass connected to a reference system by a spring. This setup allows them to measure how fast something is speeding up or slowing down. They keep track of the mass's movement using capacitors, and special electronic components.

When the accelerometer is not moving, the mass creates a specific capacitance, like a baseline, showing no acceleration. But when there's acceleration, the mass moves, and this changes the capacitance.

The accelerometer then measures this change electronically, adjusts it for accuracy, and processes the data to figure out how much acceleration is happening.

2.1.2. Gyroscope

Gyroscopes in an IMU measure angular velocity, indicating how fast and in what direction something is rotating. There are various types of modern gyroscopes, including mechanical gyroscopes, fiber-optic gyroscopes (FOGs), ring laser gyroscopes (RLGs), and quartz/MEMS gyroscopes.

Quartz and MEMS gyroscopes find applications in consumer, industrial, and tactical markets, while fiber-optic gyroscopes cover all performance categories.

Ring laser gyroscopes have in-run bias stabilities ranging from 1°/hour to less than 0.001°/hour, suitable for tactical and navigation grades.

Mechanical gyroscopes, the highest-performing, can achieve in-run bias stabilities of less than 0.0001°/hour.

MEMS gyroscopes, commonly used, rely on the Coriolis effect (a phenomenon describing forces when an object moves in a rotating frame of reference). In a typical Coriolis MEMS gyroscope, a vibrating proof mass is attached to a reference frame, inducing a secondary vibration perpendicular to the drive axis when rotated. This secondary vibration sensed through changes in capacitance, provides a signal proportional to the Coriolis force and the sensed rotation.

2.1.3. Magnetometer

A magnetometer is a device that measures the magnetic field, including its strength and orientation. Some magnetometers measure magnetic dipole moments, which involve closed loops of electric current or pairs of poles. Various magnetometers work by aligning with magnetic fields, canceling forces through the Hall effect, magneto induction, or magnetoresistance.

IMUs without a magnetometer can determine 6 degrees of freedom by relying exclusively on accelerometers and gyroscopes to track motion. These sensors effectively measure basic orientation, but tend to experience drift over time because of inherent errors in the gyroscopes. Therefore, this type of IMU is ideal for applications where simple orientation data is sufficient.

Conversely, IMUs with a magnetometer include an additional sensor that measures Earth's magnetic field, substantially enhancing accuracy in determining heading. This integration significantly improves precision. Nevertheless, careful calibration is required after installation to minimize errors caused by static magnetic interference, especially when precise directional accuracy is essential. This makes IMUs with magnetometers particularly suitable for applications demanding accurate orientation and navigation data.

2.1.4. Commercial IMUs

There are many commercial producers of inertial measurement units, due to their application on different sectors. Their characteristics also depends on the parameters and functions they must achieve and work with.

Some IMU's producers are: Analog Devices, InvenSense, Bosch Sensortech…that develop sensors for daily life projects. There are other companies that investigate the use of IMUs in a medical and military aspect, but for this thesis they wouldn't grab the spotlight.

Besides, there are cheap Arduino sensors which have compatibility with Arduino controller and they are easy to use and connect. Furthermore, for this thesis, an Arduino IMU will be used. As it was presented above, there are different types of IMUs, with 6-dof and with 9-dof, but for simplify the controller process and bearing in mind that the improvement is not much, the selected IMU will be 6-dof.

To sum up the selection process, for the thesis an IMU will be needed with the following characteristics:

- Easy to use and connect
- Compliant with Arduino
- 6-dof
- Low Cost

So as a final decision, **MPU-6050** will be the best option.

2.2. Time of flight Sensor

Laser Sensor is an electronic device that detects the distance to the nearest object. Most of the laser sensor are based on the time of flight statement. The main hardware needed to determine the distance, should be: emitter, receiver, counter and an internal microprocessor to calculate the control algorithm.

2.2.1 Time of Flight

TOF is an absolute distance detection technology, where the sensor emits calibrated near-infrared light, which is reflected upon encountering an object. By calculating the time or phase difference between light emission and reflection, the sensor converts it into distance information about the captured scene, thus generating depth information.

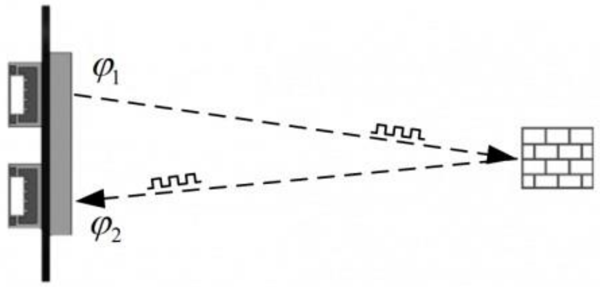


Fig. 12. Description of ToF technology

(https://www.waveshare.com/tof-laser-range-sensor-b.htm)

Compared to stereo vision and 3D structured light approaches, TOF offers advantages such as longer working distances, broader applicability, and higher accuracy at longer distances. Therefore, it is commonly used in applications such as proximity detection of individuals, obstacle avoidance for robots, and automatic focusing in cameras. However, in outdoor environments, near-infrared light from sunlight can affect the measurement accuracy of the module.

2.2.2. Commercial Laser Sensors based on ToF

In the commercial world some companies develop each own Laser Sensor based on time of flight technology. Most of them vary according to the distance they should measure and also the communication protocol with the controller.

STMicrolectronics develops the VL53L0X and VL53L1X, with infrared light and the range evolves between 2 and 4 meters. They have millimetric accuracy what makes ideal for precise proximity detection, and they use the I2C protocol to transmit data.

The company Benewake come up with TF-Luna and TF-Mini. They have higher-range measurement, about 8 to 12 meters, but the accuracy begins to decrease (between mm and cm). This specific sensor is affected by direct solar light, which generates a derive in the accuracy. It is one of the best options to movil robotic applications due to the compatibility with UART and I2C protocols.

Waveshare also develops its own Laser sensor based on ToF technology. This option is quite similar to previous ones, but combines the best characteristics of each sensor. It is cheaper than the TF-Luna, and its prize-efficiency is better.

As a conclusion, the commercial search is ended with the selection of the sensor. As it was said before, waveshare's sensor is the best option from the ones presented above. It is able to communicate with different controllers and it also has its own software to change some parameters and characteristics to personalize the process of taking data.

So as a final decision, **Laser Sensor (ToF) from Waveshare** will be the best option.

2.3. Controller ESP32

As in all projects, a device that controls data and is in charge of processing the information extracted from the sensors to become legible, is needed. There are many types of controllers depending on their processing characteristics and other parameters, also taking into account the economical cost.

Arduino Controllers are one of the best options, in case cheap controller with enough functions is required. They are able to use different types of protocols, ways of transmitting, and have enough number of pins for medium-size projects.

In particular, Esp32 is a range of chip microcontrollers developed by Espressif Systems. The main features of ESP32 include wireless connectivity, high-speed processing, low power consumption, extensive memory, and built-in security.

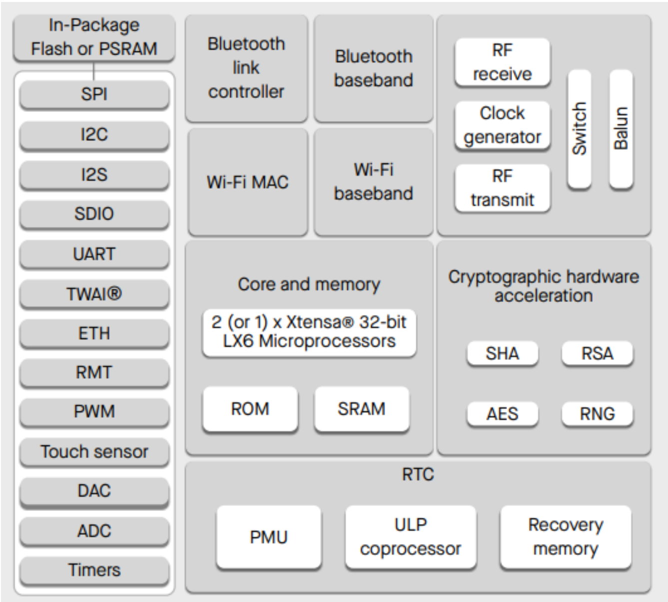


Fig. 13. Functional Block diagram

(https://www.espressif.com/sites/default/files/documentation/esp32_datasheet_en.pdf)

2.3.1. Features

In this subsection the controller's characteristics are presented. They will be divided into sections following reasoned order.

1. **Wireless Conectivity**

Wi-Fi: IEEE 802.11b/g/n, up to 150 Mbps (2.4 GHz), supports multiple simultaneous modes (Station, SoftAP, Promiscuous).

Bluetooth: Version 4.2 (Classic and BLE), transmission power up to +9 dBm, sensitivity up to -94 dBm, multi-connection support, audio capabilities (CVSD, SBC).ç

2. **CPU and Memory**

Xtensa LX6 microprocessor, single or dual-core up to 240 MHz.

Internal Memory: 448 KB ROM, 520 KB SRAM, additional RTC SRAM (16 KB).

3. **Clocks and Timers**

Internal calibrated 8 MHz oscillator, external crystal oscillator (2-60 MHz), RTC oscillator (32 kHz). Two 64-bit timers, watchdog timer included.

4. **Peripherals and Interfaces**

ADC SAR (12-bit, 18 channels), two DAC channels (8-bit).

UART (3), SPI, I²C, I²S, Ethernet (IEEE 1588), CAN interface (ISO 11898-1).

16-channel PWM for LED control, Motor PWM, Remote-control module (RMT).

5. **Powe Management**

Low power modes (Active, Deep-sleep, ULP).

Deep-sleep mode consumption around 10 µA, ULP coprocessor.

6. **Security Features**

Secure boot, flash encryption, OTP memory (1024 bits).

Hardware acceleration for AES, SHA-2, RSA, ECC, RNG.

2.3.2. Application for the controller

Along this thesis, the functional process of the prototype will be described, and the "brain" of the gadget will be the Esp32 controller. It will oversee taking the data that sensors share with it, then that information must be processed and finally the controller will store the processed data to describe the sequence of points from the path.

Firstly, the communication with the sensors would be the initial problem. Using Esp32 the inertial unit and the laser sensor will be able to communicate through data communication protocol. The controller also is the master which controls the slaves to determine which one transmits data.

After the acquisition of data, it is the turn to process the information. The controller should apply some mechanism to process the data from both sensors, determine the step time when the acquisition was carried out and store the correlated data in its memory.

3. CALCULATION OF PROJECT

The principal idea of the project is obtaining the coordinates from the trajectory's points. The sensors' measurements will be collected and processed to carry out that task. With the raw data it is impossible to take any conclusions in account, so this calculation section is important to understand why the sensors have been chosen and how the data will be transformed into legible information to create trajectories.

3.1. Define position of tool from reference

Before extracting data from sensors, let's talk about how the process is carried out. To determine the coordinates from points is important to have a reference point from which the coordinates are based. The reference is a point that will be significant to achieve successful results in the trajectories definition.

Firstly, the user should aim with the hand-tool to this reference, in this stage the controller will save the parameters as initial conditions. The process to save the point is done using a button that is pressed when the operator wants to save the reference point.

Going deep technically, the physical reference point is marked in a specific coordinate that will be useful for the further definitions. Then, when the time for trajectories definition comes up the user will aim with the hand-tool looking with accuracy that the laser light is on the marked point, and the gadget is without movement drifts. Finally, the reference button is pressed, and the controller will take data in "inverse cinematic model".

3.1.1. Data acquisition from reference

The controller is in charge of asking for data to the sensors. When the reference button is activated, it is time to extract data from the reference point. As it was said before, the information from the position of the hand-tool and the distance will make the controller able to determine the real position of reference point. For this section, It is important that the device is completely static in order to not make mistakes. If this initial task goes wrong or with unexpected accuracy, the device will not be able to define the coordinate points correctly.

The inertial unit in this section will provide the orientation of the gadget, and the laser sensor the distance from the IMU to the reference point. What makes difficult this task is to obtain a zero value in the offset from the acceleration signal.

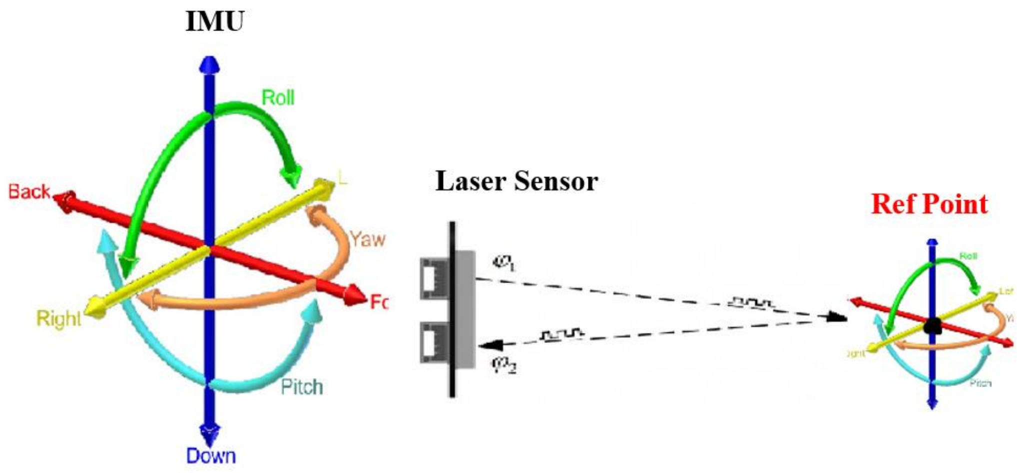


Fig. 14. Coordinates scheme

What it was previously named as inverse cinematic model, is the system's task from which the controller determines the position of the reference point taking advantage of the feedback from the reference button, and reading data from the sensors. Knowing the coordinates from reference point beforehand, the controller is able to correct the errors and derives in the sensor's measurements. This process is essential to obtain well-defined trajectories.

3.2. Move horizontally

Once the benchmark is defined, the gadget is able to be moved along the horizontal axe freely, as method to reach the initial position from the reference one. When the device moves, the controller doesn't save the points it goes through, because the save-points button is not pressed. It is important to highlight the horizontal movement, because the inertial unit will detect the rotation about that axe due to the gravity force, but it couldn't detect the rotation in the rest of the axis. Once the tool aims to the initial point, we move to the following subchapter.

3.3. Define interest points position

In this stage the user should place the laser pointer in the initial point of the trajectory. After that the second button (that one which is programmed for trajectories definition) is pressed. At that time the controller begins asked for data to both sensors and also it relates the information with the extra variable: time. Finally, what the controller has, when the definition task ends, is a vector with this shape:

$$[\boldsymbol{ax_i} \quad \boldsymbol{ay_i} \quad \boldsymbol{az_i}\,; \quad \boldsymbol{\omega_i} \quad \boldsymbol{\theta_i} \quad \boldsymbol{\varphi_i}\,; \quad \boldsymbol{d_i}\,; \quad \boldsymbol{T_i}\,] \qquad \textbf{(Ec. 1)}$$

Explain what measures are in the data vector and where they come from more in detail. Firstly, the three first variables are the linear acceleration in each axe, the inertial unit gives this information, in particular the accelerometer. Then, there are three angular speeds, one for each axe, given also by the inertial unit, but in this case by the gyroscope.

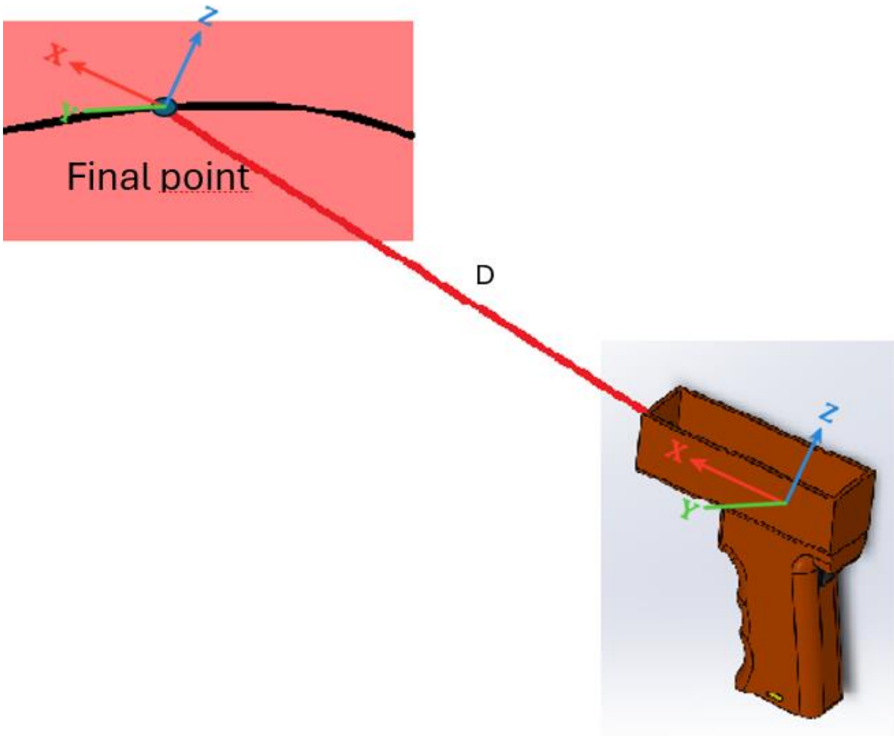


Fig. 15. Scheme of point definition

What is exposed by d_i is the distance between the device and the point to be defined. It is determined by the laser sensor, and it could also be thought as an extension of an axe. The final parameter is the time. As the vector is determined, the completely information is saved in a matrix composed by one vector for each timestamp.

3.4. Store positions as trajectory for robot's tool

As it was previously mentioned the controller (ESP32) is in charge of storing the data. That information at the beginning will be stored in a software variable (flash memory from the controller) and then, a sending task takes place. This task sends the information saved in that variable to the computer in charge of the processing task. The values stored in the pc will be in a chart shape, making easily to analyse and process to later create robot's trajectory. The final task is related with understanding and processing the information stored in pc.

It is important to explain step by step the task of store, share and process data. There are 2 devices involved: the controller ESP32 and the computer. Firstly as it was mentioned, the controller obtains the data and stores it in its flash memory, then it must share with the computer. To carry out this process the controller can share the information through wifi or using a microsd, these options will be discussed in the following subchapter.

The task of processing data meets some drawbacks. Firstly, to create the trajectories, the information needs to be about the position of the points, not the acceleration. It occurs the same with the angular speed, to create trajectories it is needed the euler angles.

In order to extract positions the linear acceleration will undergo a double integration:

$$\boldsymbol{x_i = \iint ax_i\, da} \qquad \textbf{(Ec. 2)}$$

Until the position of the IMU is known, it will be multiplied by the vector done from the distance between the IMU and the final point that will have the following shape:

$$[\, \boldsymbol{d}_{\mathrm{i}},\ \ \mathbf{0},\ \ \mathbf{0}\,] \qquad \textbf{(Ec. 3)}$$

To transform to the reference global base. Besides, to obtain the euler angles (roll, pitch, jaw):

$$\boldsymbol{\delta = \int \omega_i\, d\omega} \qquad \textbf{(Ec. 4)}$$

After the pre-processing task is done, the data is actually ready for the obtaining trajectories task. To this model, the trajectories shape will be as splines, because they are smooth and easy-to export trajectories for robotics programs.

The process of creating them from the information extracted from the pre-processing task, will be helped by a simple python program that is in charge of interpole the data into a spline:

Table 2. Program to obtain spline coordinates

```
from scipy.interpolate import CubicSpline

# Interpolación independiente para cada eje
spline_x = CubicSpline(T, X)
spline_y = CubicSpline(T, Y)
spline_z = CubicSpline(T, Z)

# Evaluar la trayectoria suavizada
T_smooth = np.linspace(T[0], T[-1], 1000)
X_smooth = spline_x(T_smooth)
Y_smooth = spline_y(T_smooth)
Z_smooth = spline_z(T_smooth)
```

The final results will be saved in 3 variables, one for each coordinate, that show the evolution of the coordinates along the time.

3.5. Data sharing

This is subchapter presents the options to develop and carry out the task of share the information between the controller and the computer, which is in charge of processing the data to determine points for the robot. There are many options for data transmission, like Wifi, Bluetooth, or using a microsd, depending on the size of data and the way of save. For selecting one of the options is important to make some calculations about the amount of measurements. The different measurements are:

- Accelerations in each axe: 3 variables double integer type
- Linear speed: 3 variables double integer type
- Distance of Laser Sensor: 1 variable double integer

This amounts to the sum of 28 bytes for each timestamp. Besides the timestamp or a number to order the measurements is necessary, so the size could reach about 32 bytes for each timestamp of information.

Furthermore, it is necessary to determine the amount of measurements for a trajectory creation and the maximum range of time for points determination. For a trajectory creation is supposed to be not longer than 5 minutes which means 300 seconds. If information is captioned each 0,25 seconds, there will be:

$$300 * 4 = 1200\ timestamps$$

Concluding with the amount of data, if for each stamp 32 bytes are needed:

$$1200 * 32\ bytes = 38{,}4\ Kbytes$$

The maximum amount of data will be 38,4 Kb, which means that microsd will not be good option for the information sharing because most of them have five times that size, and the way the data is sharing is not quite comfortable for the operator, to extract the card and introduce to the computer each time the data wants to be processed. The other options are using Wifi or Bluetooth. The controller esp32 is able to share information and also receive through them, so maybe both might be good options.

3.6. Sensor data fusion

The sensor data fusion is a technology that combines the information coming from multiple sensors to obtain an accurate and coherent estimation from the system status. Its use helps reducing uncertainty, correcting individual mistakes and incrementing system's reliability.

In a navigation system like the one is presented in this thesis sensors do not directly measure position. They measure related quantities, such as accelerations, angular speeds or distances. To obtain position and orientation, you have to process and integrate that data, and that's where accumulative errors, noise, and drift problems arise.

This is where fusion comes in: instead of blindly relying on a single sensor, the combination of several sensors is strategical to get the best out of each.

Going Deeper in detail, the inertial unit, as it was studied before, will provide measurements about the position and orientation of the hand-tool device. That is not enough for the development of welding trajectories, because the definition tasks will become more difficult to carry out. In this case using a distance sensor like the laser sensor, will provide with the distance between the gadget and the final point to easily create those trajectories. With this overview, in this case the laser sensor is useful to determine final points just aiming on them.

One important detail to take into account, is the timestamp. Time will be the robust variable that combines the measurements from each sensor to the instant of time in which that values are extracted. To develop the sensor data fusion in a rugged, accurate and effective way, TIME will be the main character from the data acquisition and analysis.

Also a new problem appears: obtain data from different sensors in the same timestamp. The controller should be able to develop multitasking behaviour and manage concurrent data acquisition. There are different means of taking data from sensors like using I/O connections, or using some specific data protocols. Nowadays mostly commercial sensors use protocols as a way of data sharing with the controller due to the speed and high accuracy of the data transmission.

The laser sensor from waveshare and also the inertial imu MPU6050 from Adafruit are compatible with the main protocols Arduino esp32 is able to work with. There are various options that can be used depending on the characteristics of data transmission. One of them is the I2C protocol.

I2C protocol, inter-integrated circuit, is a communication protocol that allows multiple devices, such as sensors, microcontrollers, and peripherals, to communicate with each other over a two-wire bus.

- Serial clock line (SCL): This line carries the clock signal, which is generated by the master device to synchronize data transfer between devices.
- Serial data line (SDA): This line carries the actual data being transferred between the master and slave devices.

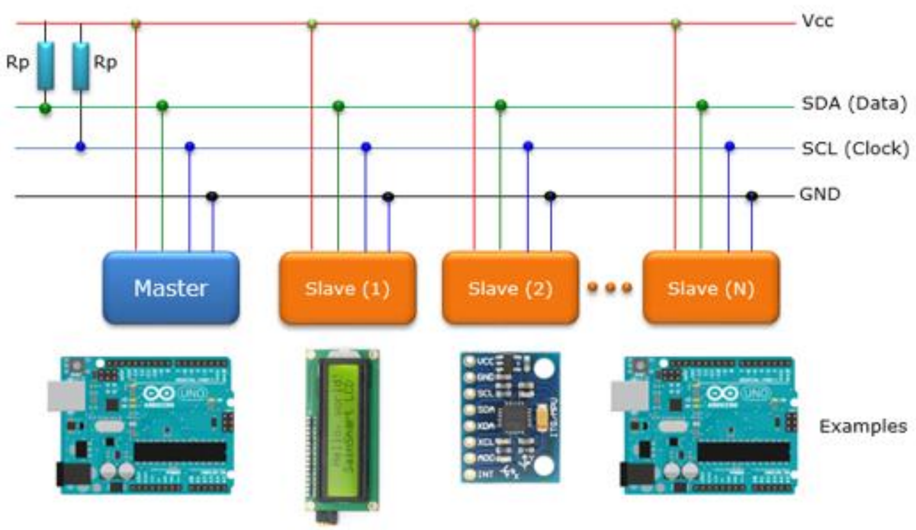


Fig. 16. I2C connections

(https://controlautomaticoeducacion.com/sistemas-embebidos/arduino/bus-comunicacion-i2c/)

Data transfer over I2C happens in a master-slave relationship, where there is one master device that controls the clock signal and initiates communication with one or more slave devices. The communication process in I2C begins with the Start Condition, where the master device pulls the SDA line low while the SCL line remains high. This signals the start of communication.

Next, the Addressing phase occurs. After the start condition, the master sends the address of the slave device it wishes to communicate with. The address is typically 7 or 10 bits long, and the slave device listens for its specific address. A 7-bit address can accommodate up to 128 unique devices on the bus. Following the addressing, the Read/Write Operation takes place. A single bit is transmitted to indicate whether the operation is a read (1) or write (0).

In the Data Transfer phase, data is transferred byte by byte. Each byte is followed by an acknowledgment (ACK) bit, where the receiving device (either the master or slave) must acknowledge each byte by pulling the SDA line low.

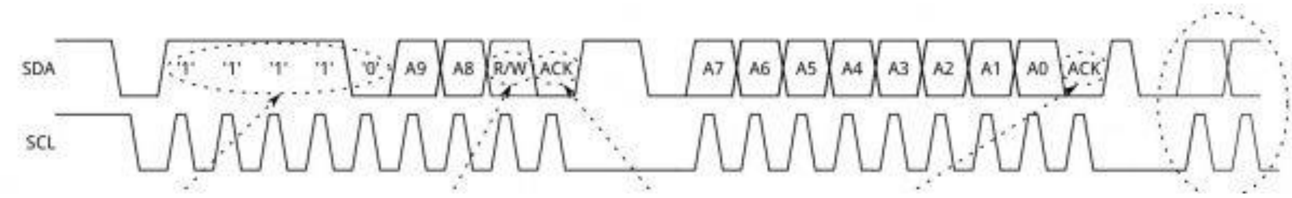


Fig. 17. I2C protocol data transmission

(https://adichip.net/tienda/protocolo-i2c/)

Finally, after the data transfer is complete, the master issues the Stop Condition by pulling the SDA line high while the SCL line is high. This signals the end of communication.

3.6.1. Data fusion example

To represent the data fusion, is preferable to explain how does it works using example codes. In this case the data fusion comes up between the inertial unit and the ToF sensor. The main idea is to extract measurements from each sensor at same time using different I2C buses to carry out it with parallelism. To do that, the buses should be initialized:

Table 3. I2C bus initialization

```
TwoWire I2C_MPU   = TwoWire(0);   // Bus I2C dedicado al MPU6050
TwoWire I2C_Laser = TwoWire(1);   // Bus I2C dedicado al sensor láser

#define MPU_SDA_PIN   21
#define MPU_SCL_PIN   22

#define LASER_SDA_PIN 19
#define LASER_SCL_PIN 18
```

The data fusion is carried out with two functions in charge of data acquisition, one for each sensor. The process is to determine the timestamp of data acquisition and then the measurement representation through the terminal output:

Table 4. Data reading from sensors

```
// Obtener el timestamp
unsigned long timestamp = millis();

// Lectura de la distancia desde el sensor láser TOF
readLaserDistance();

// Lectura de datos del MPU6050
sensors_event_t a, g, temp;
mpu.getEvent(&a, &g, &temp);
```

The data fusion frequenty is controlled by a function in charge of determining the acquisition time due to an input value and the time counter.

```
Timestamp: 298592 ms
MPU6050 - Aceleración (m/s^2): X=2.77  Y=-4.36  Z=7.93
MPU6050 - Giroscopio (rad/s): X=-1.54  Y=0.16  Z=0.00
Sensor Láser TOF - Distancia: 84 mm
```

Fig. 18. Output data that should be shared

As it is shown in the figure above, the output gives the measurements in each timestamps from the different sensors, with a post processing signal to make the task synchronized. The main idea of data fusion is to reach the final results, in this case point coordinates determination, using synchronized sensors that measure different variables to reach the final results.

3.7. Power supplied overview

Every electronic device used in this prototype are efficient-consuming devices. That means that every sensor and the main controller (ESP32) shall be supplied with low-rate voltage. The perfect combination for these parameters is small lithium batteries with low-rate voltage and high long-lasting life. Most of Arduino accessories work with range between 3,3 volts and 5 volts. Using a DC current battery around 5 to 7 volts, it will be able to supply every single electronic device from the prototype.

The main question is, how many time it will last; with a electric calculation it is easy to know the operational time between charges.

The controller is connected to 5 volts, and its consumption depends on the actual mode: if it is in IDLE mode, the consumption is around 47,6mAh, but if it is using the DualCore mode it will consume 81,3 mAh. If the controller is slept the consumption is despicable. In case the Esp 32 is working with wifi tasks, the typical power consumption is between 150 to 200 mAh, with maximum peak consumption up to 500 mAh.

Talking about the sensors the consumption in normal behaviour will appear in the datasheets. Firstly, the inertial unit selected (MPU6050) has a consumption about 4 mAh according to the specifications when it is connected to 3,3 volts. Then the laser sensor (in particularly from Waveshare) its datasheet shows a consumption around 290mW connected to 5 volts.

Taking advantage of the output supply from the controller, the sensors are connected to them. To sum up the consumption of the whole electronical part it is possible to make an scheme:

$$\mathbf{(81,3\ mA * 5V) + (3,3V * 4\ mA) + 290\ mW = 709,7\ mW} \quad \textbf{(Ec. 5)}$$

The medium consumption is 709,7 mW. In the case 800mAh battery is used that provides 7,4 volts, the working life of the prototype will be around 8 hours which means it could be able to be used along the working time of a day.

There are different cases of consumption depending on the task carried out by the controller. The sensors usually have the same power expenditure along the task of measuring, so the device which might change the consumption will be the controller Esp32. In the worst scenario the power consumption could be:

$$\mathbf{(200\ mA * 5V) + (3,3V * 4\ mA) + 290\ mW = 1,3\ W} \quad \textbf{(Ec. 6)}$$

To develop this thesis the controller will work without the Wifi mode activate, so the usual consumption will be the presented in Ec. 5, except in the case of data transmission when the Wifi turns on and the consumption will reach to 1,3 W. this should be taking in account to determine the battery cycles and the operating time between charges.

4. DESCRIPTION OF THE CONSTRUCTION AND OPERATIONAL PRINCIPLE

4.1. Position and accuracies

As it is mentioned in previous chapters the process of extract the raw data could be easy, but it is necessary to process it in order to understand and obtain final results that determine and place the coordinates from the sequence of points that describe the trajectories. The raw information from the sensors is saved and share by the microcontroller in a way of matrix. Using data fusion, the information correlates with the linear acceleration and angular speed in each axe, and the linear distance between the prototype and the final point due to the combination of the inertial unit and the time of flight sensor.

Firstly the raw data from the sensors has to be processed and correlated with the coordinates system of the hand-tool device. As it was shown in the calculations through an easy operation it is possible to obtain the value of movement in mm in the three axis by a double integration, using the reference point as initial value. Besides, the angles (roll, pitch, yaw) can be obtained from the integration of the angular speed.

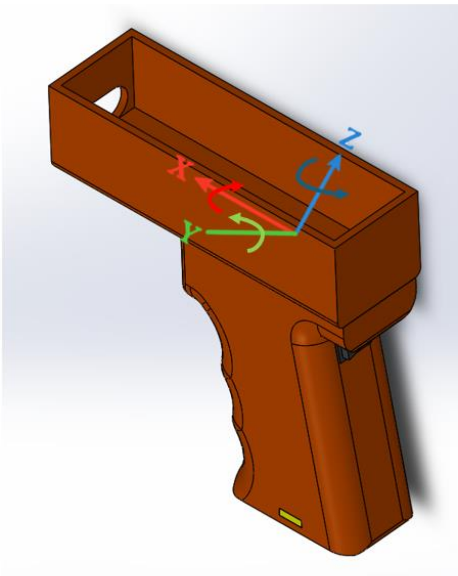


Fig. 19. 3D coordinates and euler angles given by processing raw data from IMU

Secondly, when the coordinates of the hand-tool device are defined, always in relation to the reference point, the information given by the ToF sensor is useful. This sensor gives measurements of linear distance in only one axe. For this case, the value of distance will be an extension of the value in the X axe given by the inertial unit data.

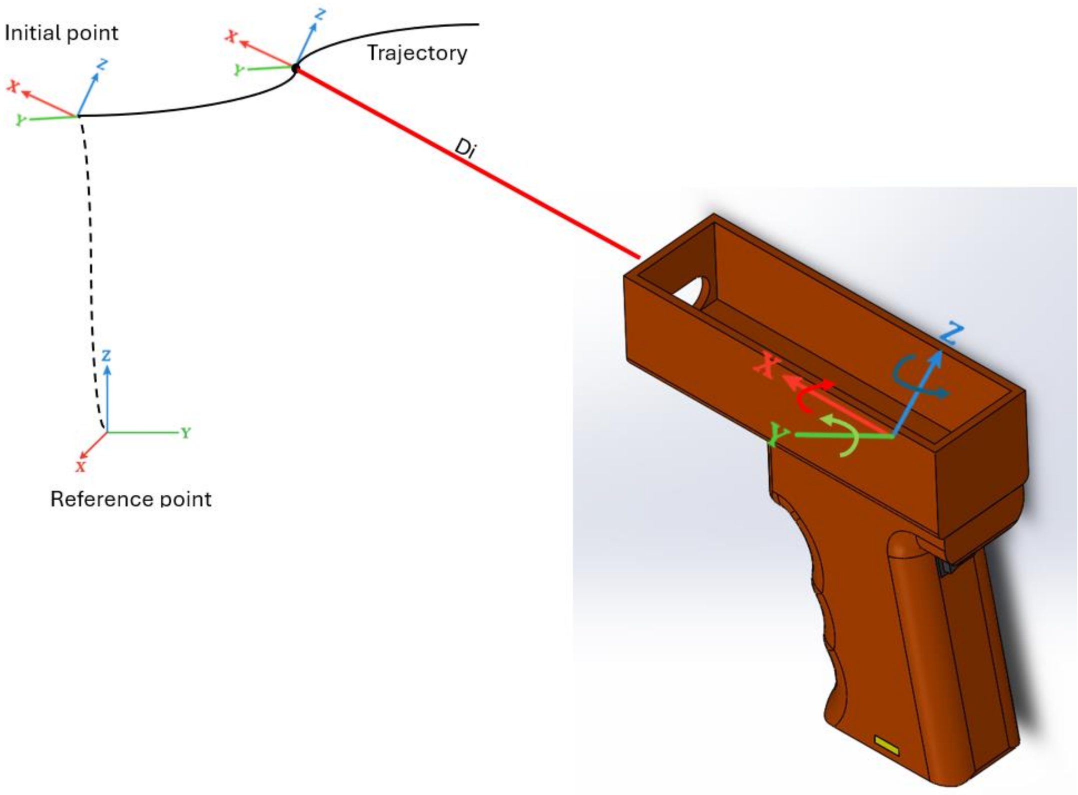


Fig. 20. Representation of Tof sensor measurement to define points related to the reference point

Finally as it is represented in the image above, by data fusion, the gadget is able to define the reference point and thereafter the trajectory definition task could be carried out. As it can be observed, the relationship between the coordinates systems of each point and basis are make in a simple way, using rotation matrix to reach the orientation of the coordinates. It is important to define this relations to have every single point referenced to world system coordinates.

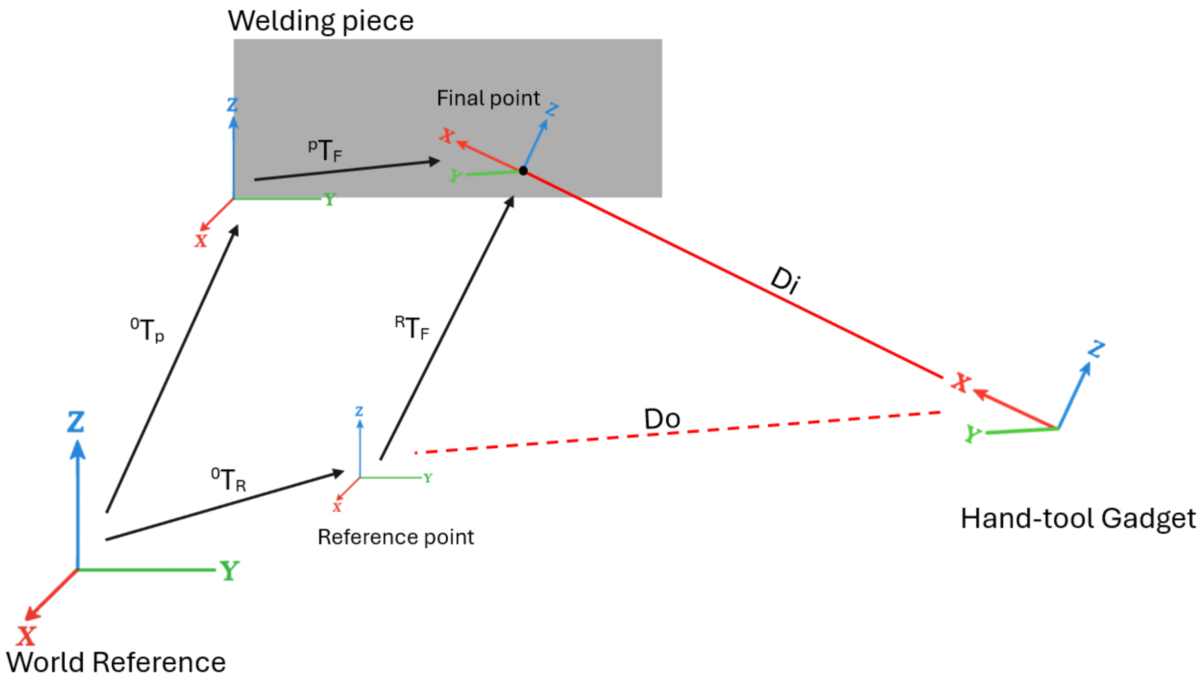


Fig. 21. Transformation matrix representation

This figure represents the transformation matrix that complete the relationship between the world reference and the final point coordinates. there are two possible paths to reach the final point but in this case the principal use will be: $^{0}T_{R}$, $^{R}T_{F}$.

To reach the final point through the other path, the information about the position of the welding piece in the scenario should be measure. Also it is needed in every single point the coordinates of the points from the origin of the welding piece basis. That is not the idea when the device should facilitate the trajectories definition. The process of this task consists of determining the measurements of the sensors in the reference point (this is a point previously defined and the relationship with world reference is known). Then the prototype could know the position of the final point due to the relation with the reference point.

4.1.1. Sensor accuracy

The sensor accuracy is an essential characteristic for determining the well value of the measurements. Along this subsection the accuracies of the prototype's sensors will be determined and the demonstrated with some experimental procedures.

The MPU6050 (inertial unit) is composed of accelerometer and gyroscope. Both of them are able to set the range of variables depending on their used, which means different accuracies for each range. Firstly the accelerometer range can be set between ±2g, ±4g, ±8g o ±16g, This accuracy means that it can measure accelerations within these ranges with a resolution of approximately 0.000061g for the lowest range.

Table 5. Accelerometer accuracy related with range

Range	Resolution (unts per g)	Accuracy (g)
±2g	16384	0.000061g
±4g	8192	0.000122g
±8g	4096	0.000244g
±16g	2048	0.000488g

The highest accuracy is achieved in the ±2g range, which is ideal for detecting small variations in acceleration, such as the movement of a hand or subtle changes in tilt. As you increase the range, the resolution decreases, making the accelerometer less accurate, but capable of measuring higher accelerations.

Also the range of the gyroscope can be adjusted between ±250, ±500, ±1000 o ±2000 degrees per second. For the lowest range the accuracy resolution is approximately 0.0076° per second.

Table 6. Gyroscope accuracy related with range

Range	Resolution (unts per °/s)	Accuracy (°/s)
±250°/s	131	0.0076°/s
±500°/s	65.5	0.0152°/s
±1000°/s	32.8	0.0304°/s
±2000°/s	16.4	0.0608°/s

Although its accuracy decreases with higher ranges, the gyroscope is capable of measuring angular velocities even in very fast movements. Within the range of ±250°/s, the instrument demonstrates a high degree of accuracy, rendering it optimal for systems that necessitate precise measurements at low rotational speeds. However, by switching to higher ranges, such as ±2000°/s, the gyroscope can measure faster movements, but with reduced accuracy. This may be less problematic if the system does not require absolute accuracy.

The time of flight sensor from Waveshare, indicates the specifications about the accuracy in the datasheet of the sensor. Besides, this sensor also requires to take into account FOV (field of vision) degree, which is around 1 to 2 degrees. The accuracy of this sensor depends on the distance range: between 0,1 to 2 meters the typical accuracy is 2 cm. in this case the resolution is about 1 mm. in the range of longer distances, from 2 meters to 15 meters, the measuring accuracy changes into 2% value of measurements. For this application the typical operation mode will be in the first range so the tof sensor accuracy will be around 2 cm.

It must be noted that there is another significant issue to consider, the error between the laser pointer and the tof sensor pointer.

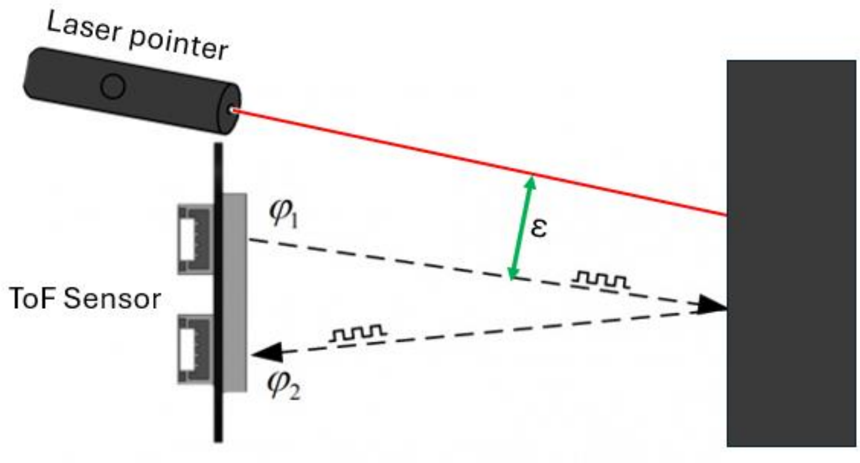


Fig. 22. Representation of Error between laser pointer and Tof Sensor

As it is shown in the figure above, the position of the laser pointer could be quite difficult to calibrate due to the layout, so the way to match both pointers might be changing the angle of the laser pointer. Besides, the position of the laser point could vary from the tof sensor point due to the distance to the surface. The laser pointer must be calibrated by experimentation, changing the accuracy of matching according to the tasks will be carried out.

4.2. Safety test for gripping

The test for gripping is a way to confirm that the prototype will support the forces done by the worker when the defining trajectories task will be carried out. To simbolise the gripping from a human, some pressure forces are defined. The value of the forces seems to be the maximum case: catching force from a gymmer person (0,25MPa). This case is extremetely to understand if the device will be deformed.

To represents the gripping test, the Von misses tension graph is ideal for it.

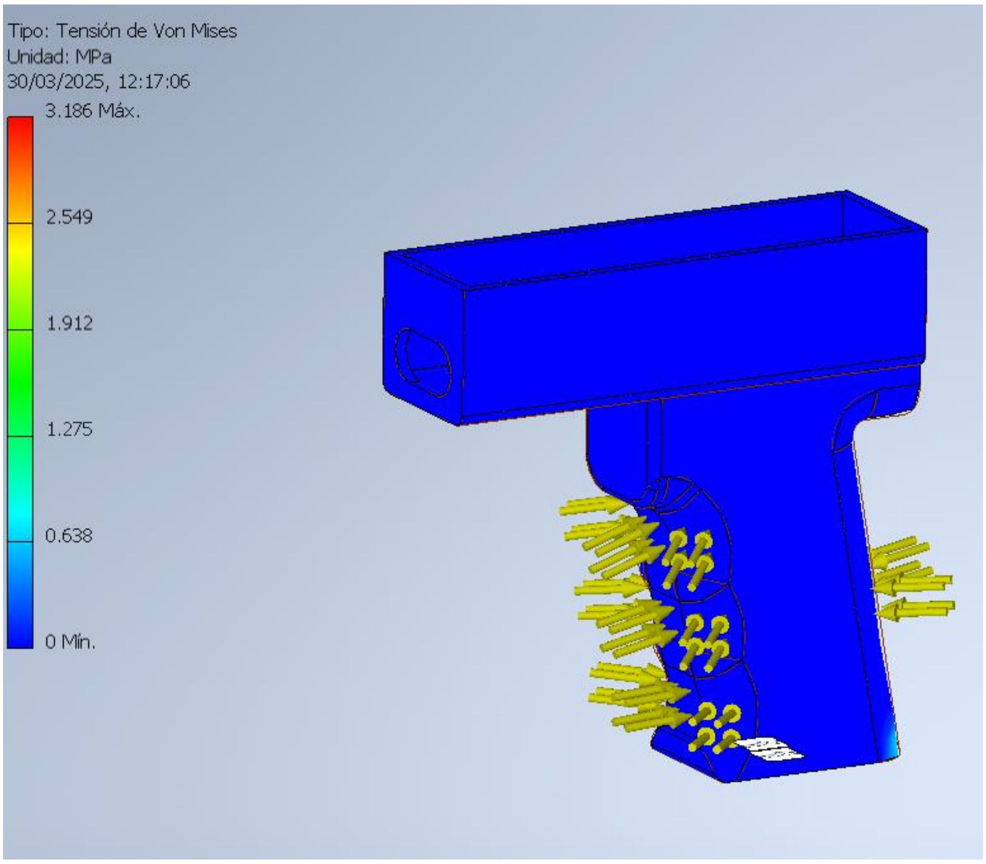


Fig. 23. Test for catching (Von Mises)

Taking in account the use of plastic material come from the 3d printed, like PLA or ABS, the device is completely build on it. As the Von Misses tensions show, the prototype from a structural point of view is stable. The forces are only focus on the handle of the device, but it is seemed to be robust and sturdy.

The study can be completed with the safety coefficient about the test for gripping

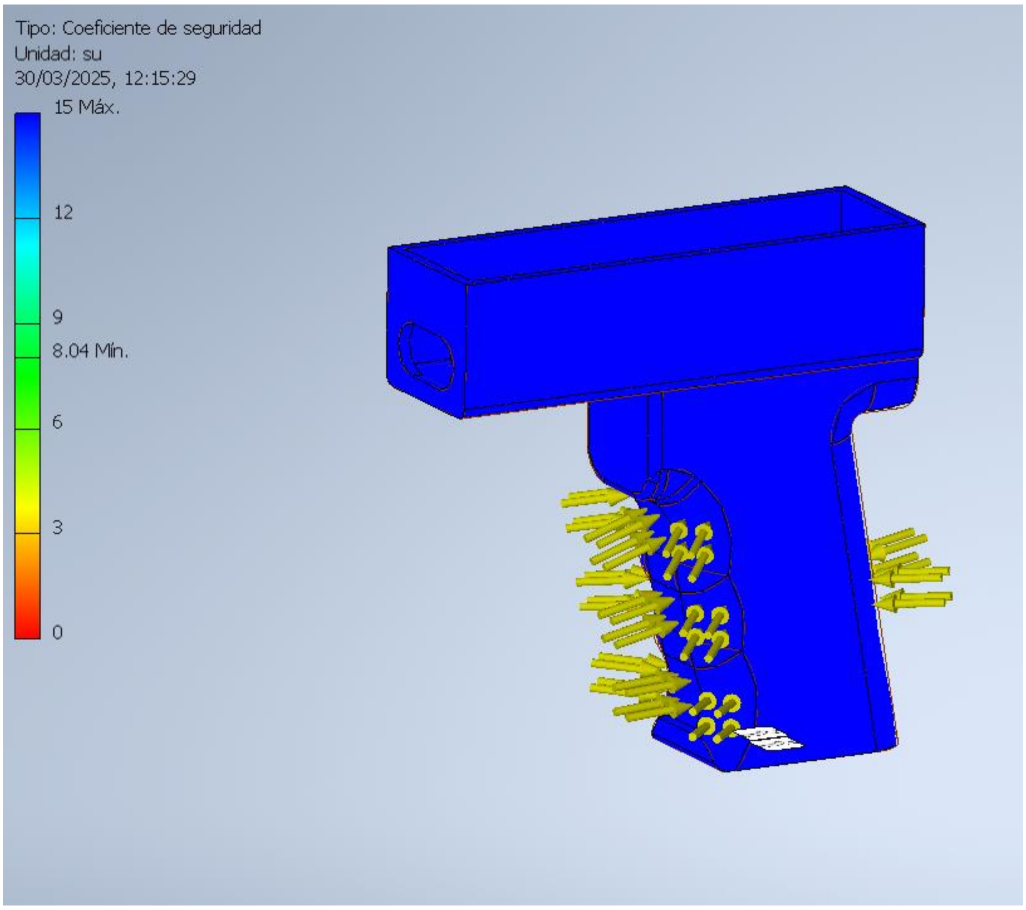


Fig. 24. Safety coefficient in gripping test

The figure shows the safety coefficient analysis through gripping conditions. It is obtained by the relation between the yield stress of the material and the Von Misses tension. In the simulation the minimal coefficient is around 8,04 which means that the stress for the catching is lower than the elastic limit of the material used.

The dark blue around all the structures means a higher value of the safety coefficient, which reinforces the validity of the design from a structural point of view, confirming that the grip of the device does not compromise the integrity of the prototype or create critical areas of potential failure.

4.3. Safety test for drop

One of the most prevalent failure scenarios for handheld devices is their accidental descent from an operational height. A structural analysis was thus conducted in order to ascertain the resistance of the prototype to a vertical drop from a height of 1 metre. The primary objective of this study is to ascertain whether the design is capable of absorbing the impact energy without compromising its structural integrity.

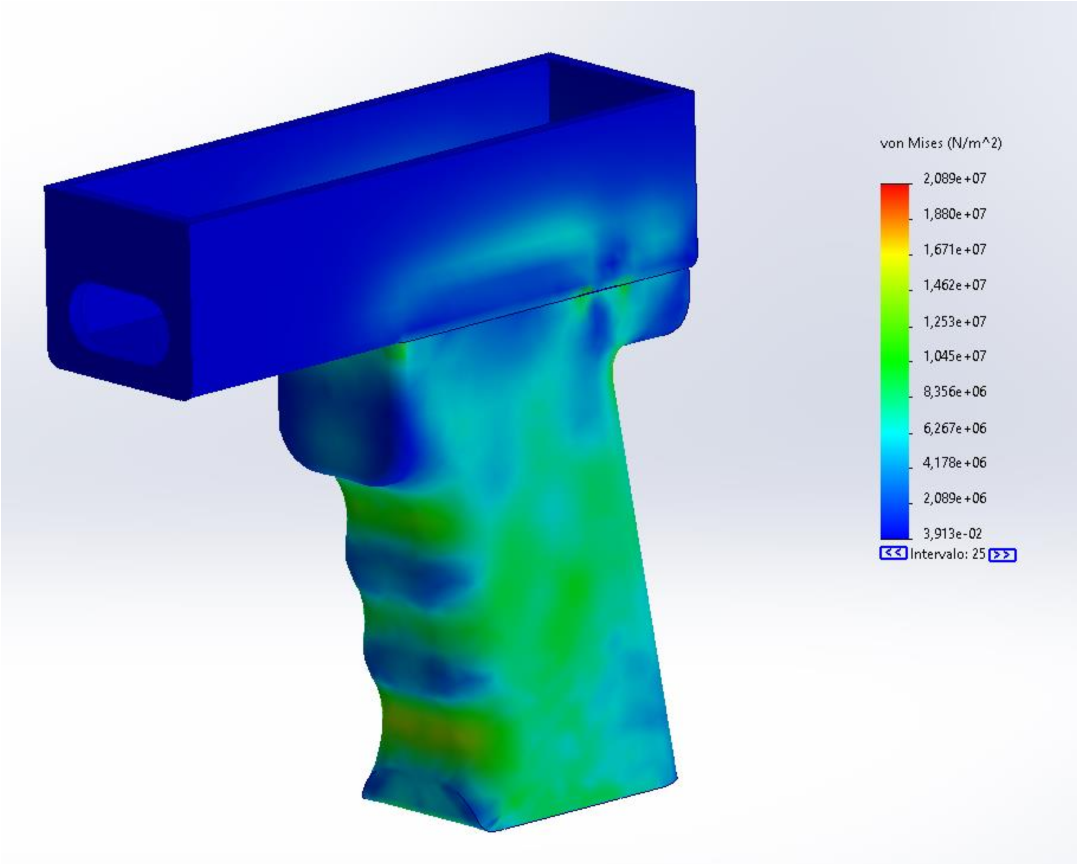


Fig. 25. Drop test from 1 meter high (Von Mises)

The figure shows the results from a simulation in terms of Von Misses. The highest value reached is 20,89 MPa, located in the union between the handle and the rest of the body of the prototype. This area due to the sudden change of geometry, represents an area where stress forces are concentrated.

Furthermore, it is evident that the load transmission is progressive, with the transmission starting from the base of the handle and culminating at the uppermost point of the device. As the initial impact is absorbed by the lower areas, a green-yellow hue is exhibited, indicative of forces ranging from 10 to 15 MPa. As the impact propagates upwards through the structure, the stress levels undergo a corresponding decrease.

In conclusion if the principal material for build the prototype is 3d printed plasctic, like PLA or ABS, the elastic limits are around 50-60 MPa. As the safety drop test shows, the prototype could afford a drop from 1 meter with a max rate of 20,89 MPa in some points of its structure. The prototype will never reach the elastic limit if it is thrown form normal-medium distance to the floor.

4.4. Detail design

The design of the prototype is a challenge to achieve all the required features, such as ergonomics for prolonged use, easy printing of parts using a 3D printer, and protection of the electronic components against drops or shocks. After the test task, the design has some upgrades and it shows like this:

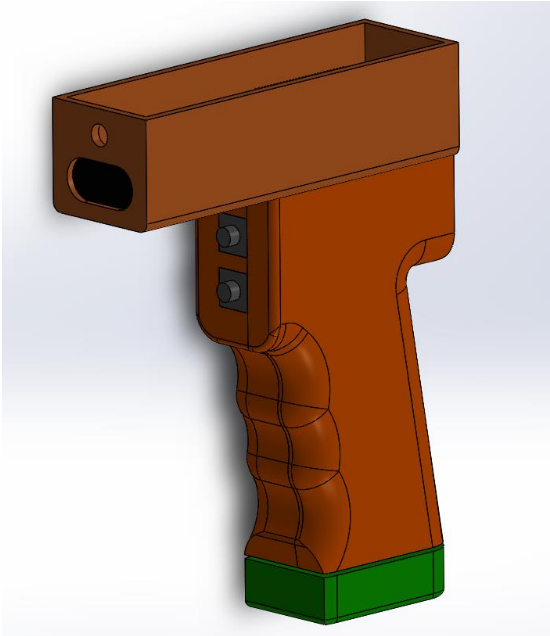


Fig. 26. Final prototype design

Once we have the general view of the prototype, it is time to go into detail. to do so, we can start with the description of the buttons and pushbuttons, defining their functionality. In the part where the trigger of the gun would normally be located, we find 2 buttons exactly the same, one to determine the reference point and the other to define the acquisition of the trajectory. Their position allows them to be manipulated by both right-handed and left-handed users, without any restrictions.

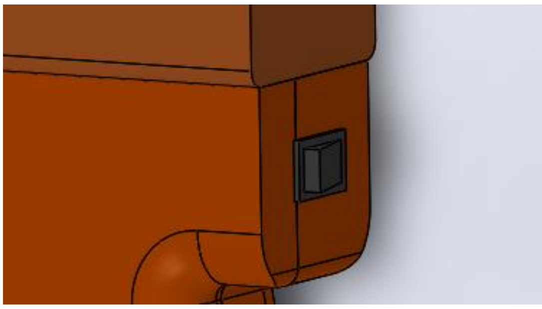


Fig. 27. General Switch

Lastly, on the back of the device, there is a switch button that turns the device on or off, acting as a general switch.

4.4.1. Battery extraction

The way the battery is attached may remind of a gun charger. The idea is a quick connection and disconnection, which facilitates the exchange between batteries, and secure and fixed so that there are no cuts in the power supply of the device. Therefore, it was decided to use magnetic connectors for the connection of the battery. Thanks to the magnetism the charger will not fall out of the device and is easy to remove by hand force.

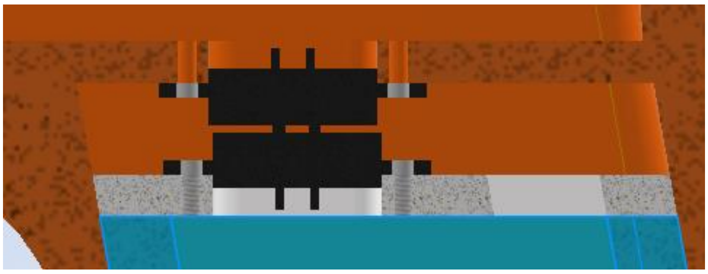


Fig. 28. Magnetic Connectors

The connection is safe from an electrical point of view, as the magnets will guide each connector to its counterpart, and there is no option of a reverse connection thanks to the angled design of the charger and the inside of the handle.

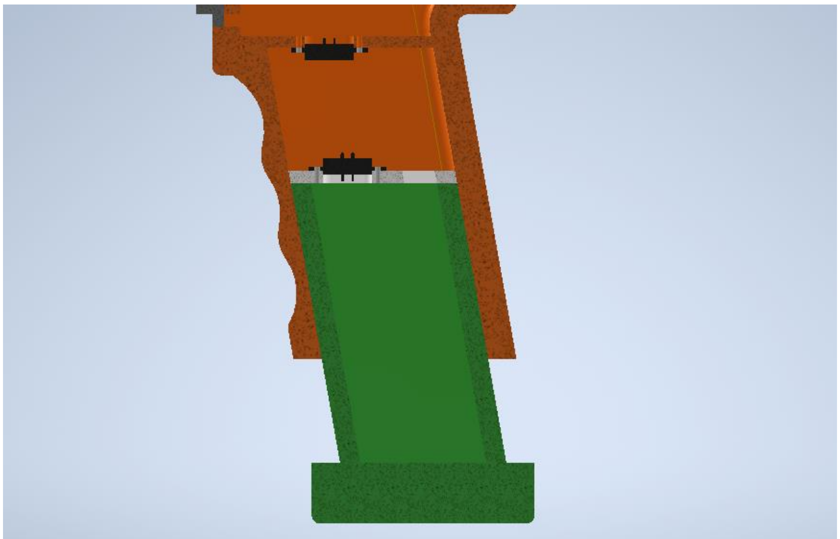


Fig. 29. How charger is inserted into the device

It is evident that the charger is equipped with its own stopper, thus ensuring that the magnetic connection is not subjected to strain or deterioration. Furthermore, it is imperative to insert the battery into the charger prior to affixing the cover, thereby enclosing the battery within an encapsulation.

This cover is designed with a perforation, enabling the battery to be charged without the need to disassemble the encapsulation.

4.4.2. Electronic devices' envelope

As it was shown previously, the battery is inserted into the handle, so the rest of the electronic devices must have its own space. For this prototype the devices are located into a 3d printed case, which will be screwed to the handle, and also has an opening for conduct the cables. For the first design the case will not have the cover, due to adjustments in the electronic connections and also in case the microncontroller could transfer data through the usb wire.

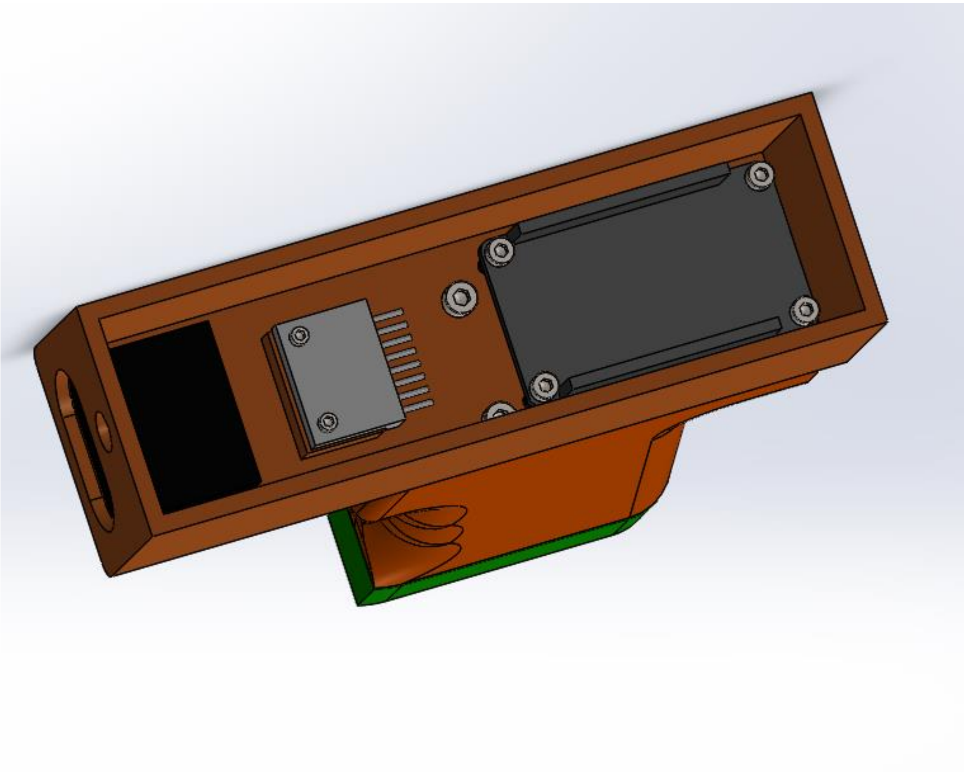


Fig. 30. Overview of electronic device dispose

All electronic devices are attached to the case with ISO screws and can be added rubber nuts to protect them from parasite charges. the esp32 is not in contact with the surface of the case but is slightly raised to allow the cables to pass through the opening underneath. On the other hand, the MPU6050 (inertial unit) is anchored to a bed made solid to the case, and the ToF sensor is directly anchored by two screws to its encapsulation. The laser pointer would be placed above the said sensor so that the error would be the minimum when measuring and pointing.

4.5. Electric Scheme

All electronic devices with their connections will be presented in this subsection. The prototype has simple electric lines due to the use of dc supply. Every single electronic device works with 5 volts.

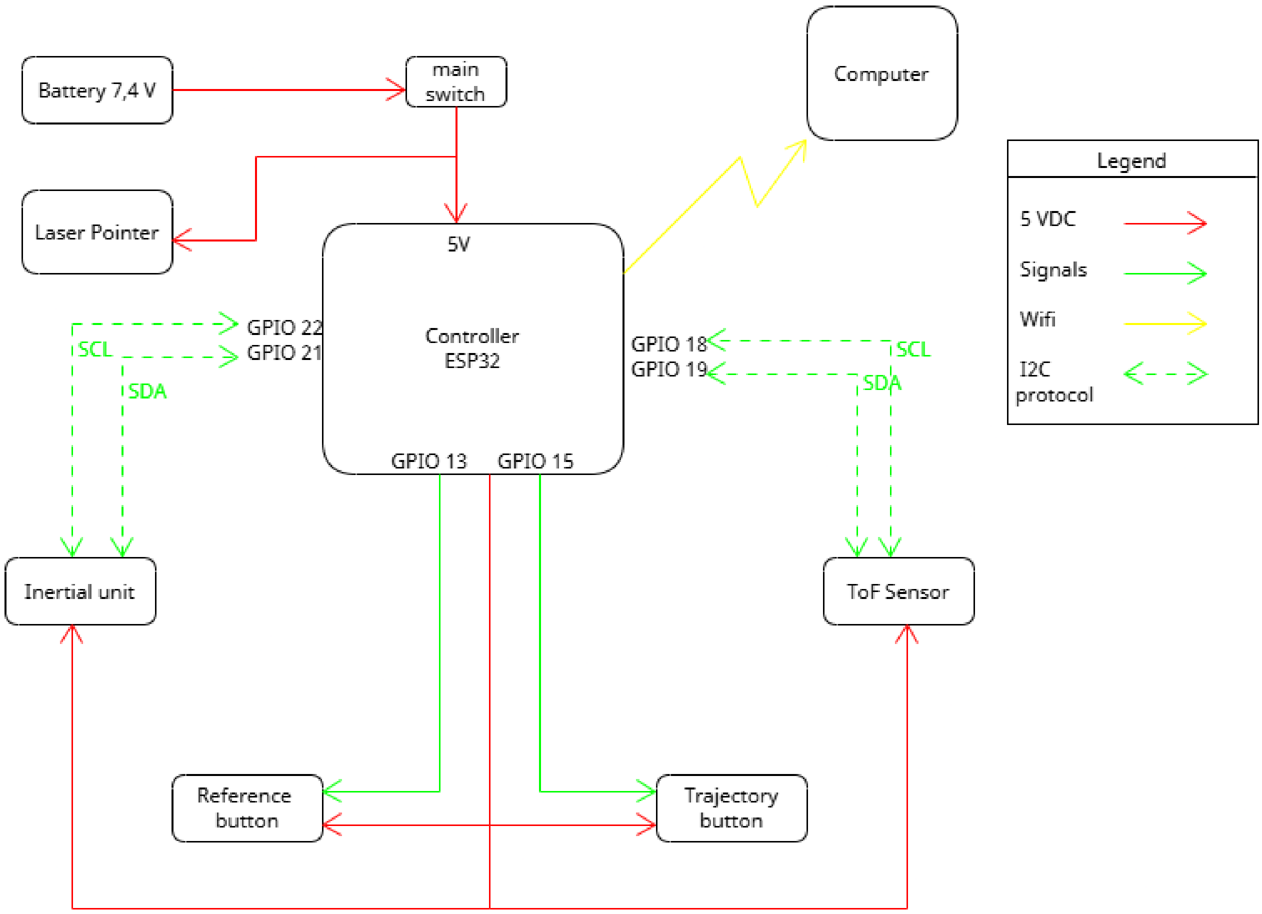


Fig. 31. Electrical-block scheme

As it is represented, there are different types of connection depending on the colour of the lines. The lines in red represent the power supply to every single device, in this case using 5-volt dc. It is built in an easy way, because the battery supply the microcontroller and can be switched on or off by the main switch. Then the controller is also in charge of transmitting the power supply to the rest of devices like sensors and buttons.

There is another option to supply the electronic construction without using the battery. The Esp32 can be connected with the usb-c port to the current and its operation should be the same. The idea of using the battery is to have the electronic compose independent from the wire connection, facilitating the movements of the prototype when the trajectory definition is carried out.

The green lines represent the way of transmitting signals. There are two types, dotted lines simbolised the way of transmitting signals through the I2C protocol, and the continuous lines are simple signal like the ones the controller receive from the status of the buttons. Going deeper on the lines from the protocol I2C, there are 2 lines. One is used to synchronised the data transmission with the signal of the clock, and the other line is used to transmit the data, in all directions: from controller to sensor and viceversa.

The protocol lines are represented in two different buses, one for each sensor due to the capacity of the microcontroller ESP32 to control 2 buses at the same time. It will enhance the data transmission and the data acquisition from different sensors at the same time.

Finally, the transmission between the controller and the computer will be done using Wifi as the mean of transport for the data. It is represented in a yellow line to understand how data can be transferred but there is no physical wire to do it.

4.6. Algorithm of management of device

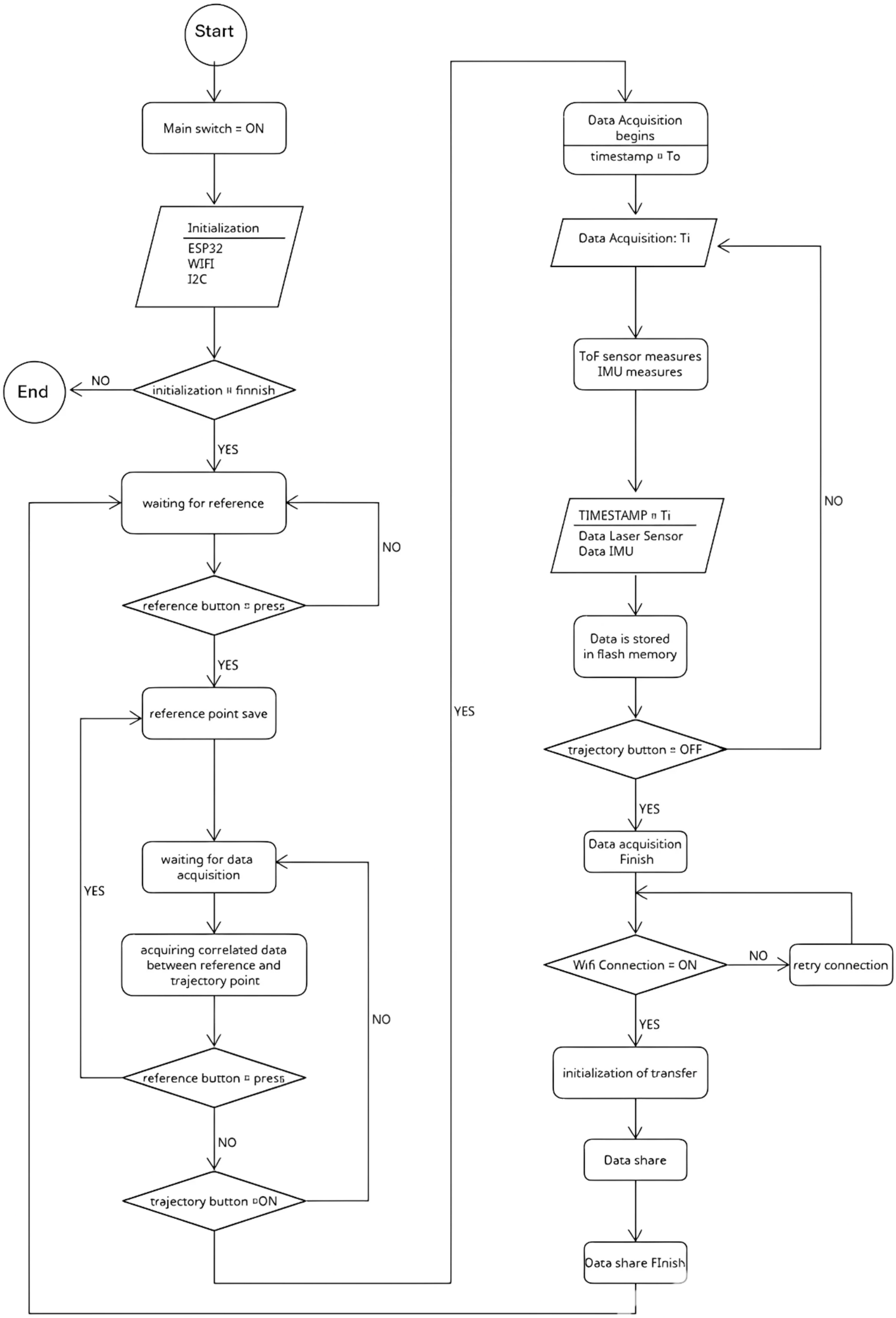


Fig. 32. Algorithm of management

The controller task begin when the main switch is on and allow the battery powers every electronic devices. In that moment the controller starts the initialization process, searching the connection of the sensors and also running the wifi connection. The first steps of running the I2C protocol include the scanning tasks and communication between the sensors and the controller to interact how the data flow will be. When every single step of the initialization process is done it is time to begin with the loop tasks, in wrong case the device gives an error about the initialization to be checked.

The first stage of the loop task is the determination of reference point. To do that the controller will wait until the operator aim the reference dot and in that time the reference button is pressed. When that happens the controller asks sensors about measurements to save them and the reference point is saved. Then, it is possible that the user can determine the reference point again just by pressing the reference button before introducing the trajectory definition task.

The second step of the loop task is the data acquisition for trajectory definition. This stage begins when the trajectory button is pressed. In that moment, the controller determine the first timestamp and time starts to run out. The ToF sensor and inertial unit measure at the same timestamps in a parallelism way. The controller receive the measurements and relates them with the timestamp, then they are stored in Esp32's flash memory. The task finishes when the trajectory button is no longer pressed.

Finally the third stage of the loop is the data transfer. In this case the are many options due to the different means of transfer data the Esp32 provides. Using Wifi, data can be transferred to a computer for post processing stages. To carry out it the wifi connection must be initialized, and in case it isn't on the controller will be able to retry it. Apart from that, when the connection has been stablished the transfer is initialized and through wifi protocol the controller will share data sequentially. When this stage has been finished, the algorithm will be retake at waiting for reference stage and the cycle is completed.

5. WORK SAFETY

5.1. General provisions and requirements for safe working and environmental protection

Before integrating any prototype into a working environment or its utilisation for manual guidance and robot programming purposes, it is essential to evaluate the associated safety risks and implement preventive measures. Even if the device is intended for educational or experimental use, it is imperative that it complies with fundamental safety principles. This is to ensure that electrical hazards are avoided, the user's physical integrity is protected, and reliable system operation is ensured.

In this section, the safety criteria adopted during the design and implementation of the system are outlined, with a focus on electrical protection, ergonomic handling and all based on different european standards.

To ensure the safety of the operator and protect the integrity of the electronic components, the system has been designed with low-voltage operation in mind. The prototype is powered using voltages that do not pose a direct risk to human health, like 3.3V and 5V lines, which are typical for microcontrollers such as the ESP32 and the sensors used.

5.2. Work safety on ESP 32

The ESP32 microcontroller acts as the central unit for data processing, sensor reading, and communication in the developed prototype. Although it is a low-voltage device, specific precautions must be taken when working with ESP32-based systems to ensure both operator safety and long-term hardware reliability. Some aspects must be taking in account to enhance the safety to operate with this microcontroller:

1. The ESP32 operates at 3.3V logic levels and is typically powered through a regulated 5V input via USB or external supply. Under no circumstances should higher voltages be applied directly to its I/O pins, as they are not 5V-tolerant.
2. To avoid electrical damage, a regulated power source is used. In case of battery-powered configurations, voltage regulators or step-down converters ensure the ESP32 receives a stable voltage within its safe operating range (typically 3.0–3.3V on VCC).
3. All sensors and peripherals connected to the ESP32 share a common ground (GND) to prevent floating voltages and ensure signal integrity.
4. When powering peripherals such as Laser Sensor or IMU from the ESP32's output pins, current draw is carefully evaluated to avoid overloading the onboard voltage regulators.

5. During prototyping and manipulation of the board, standard ESD-safe practices are followed to avoid damage to sensitive microcontroller pins. These include grounding oneself before handling the ESP32 and avoiding contact with pin headers when powered.
6. Care is taken to avoid accidental entry into the ESP32's bootloader mode, which can occur if GPIO0 is pulled low during reset. Connections to critical pins are reviewed and kept consistent with manufacturer recommendations.
7. In the final prototype, the ESP32 is housed within a protective casing to avoid accidental short circuits, mechanical damage, or exposure to environmental contaminants such as dust or moisture.

These considerations, most of them focus on the electrical problems, must be taking into account by the operators when the prototype will be built or upgraded. the microcontroller Esp32 is also included in the euro standard regulations, where the manipulation and electric control of the device is explained in detail:

5.3. Work safety with Battery

The prototype is powered by a 7.4V removable battery pack, integrated in a manner similar to a pistol charger for ease of replacement. Although this improves usability, it also introduces specific safety challenges related to both the electrical and mechanical characteristics of lithium-based batteries.

To ensure safe operation and handling, some conditions must be taken in account by the operator and also by the builder of the device:

1. Mechanical locking mechanism: The battery is designed to be inserted and removed using a guide-and-lock system that ensures correct polarity alignment and prevents accidental disconnection or short circuits during handling.
2. Switch for electrical disconnection: for disconnect the battery from the rest of electronic devices, the main switch is included acting as a isolator switch at small scale.
3. Safe charging practices: The battery must be charged using a dedicated Li-ion/LiPo charger compatible with 2S configurations. Charging must always be done under supervision and on a non-flammable surface to reduce the risk of thermal runaway.
4. The battery area is thermally isolated from components that may generate heat, such as the microcontroller, and sensors.

The act of connecting or disconnecting the battery by the operator must always be carried out on the basis that the disconnector has been switched off to protect the system from undesirable static charges and the operator from small discharges.

5.4. work safety of positioning laser

The laser pointer integrated in the prototype is used as a visual aid for defining welding trajectories with precision. Despite operating at low power (typically Class 1 or 2), laser devices pose specific risks to both the operator and the environment if not used responsibly. The following precautions must be respected to ensure safe use:

1. The laser should not be directed at reflective surfaces such as mirrors, polished metals, or glass. Reflected beams retain the same potential for injury as the direct beam and can cause unexpected hazards.
2. Devices such as binoculars, telescopes, or microscopes must not be used to observe the laser. These instruments can focus the beam, greatly increasing the risk of ocular injury even with low-power lasers.
3. The laser must never be aimed at people or animals. Direct exposure to the eyes can cause temporary visual disturbances or, in extreme cases, irreversible retinal damage.
4. The laser pointer should include an activation control (e.g., a pushbutton) that only powers the beam during actual use. Leaving the beam active unnecessarily increases the risk of accidents.
5. The device should be labeled with its laser class, wavelength, and power rating. Users must be informed of the potential risks and trained in its correct handling, even in non-industrial settings.

6. ECONOMIC CALCULATION

The device for trajectory definition developed along this thesis should be studied in a economic and profitable way. Therefore, a chart with the material cost of the elements involved in the prototype has been made, to show the quantity of them that are required to assemble it. It represents quantities for the production of one hand-tool trajectory definition.

Table 7. Material Costs

Number	Item	Quantity	Price per unit (€)	Sum (€)
1	Esp 32 microcontroller	1	5,27	5,27
2	inertial unit MPU6050	1	1,4	1,4
3	ToF sensor Waveshare	1	23	23
4	Laser pointer KY-008	1	1,65	1,65
5	Magnetic Connectors (2 pins)	1	2,59	2,59
6	Push button Arduino 12x12	2	0,4	0,8
7	2-pin SPST rocker switch T85 KCD1-101	1	0,99	0,99
8	Socket head cap ISO 4762 M1,6 x 4	4	0,648	2,592
9	Socket head cap ISO 4762 M3 x 10	4	0,162	0,648
10	Socket head cap ISO 4762 M2,5 x 16	4	0,648	2,592
11	Socket head cap ISO 4762 M1,6 x 8	4	0,267	1,068
	TOTAL (EUR)			**42,60**

After that is preferable to make an analysis of the cost per unit produced. In this section, all cost will be review, fix ones and variable ones. Due to the fact that the envelope of the gadget and the structural part is made by 3D printer plastic ABS, a 3D printer will be necessary with an accuracy about 0,01 mm. Nowadays some professional models are around one thousand euros but in particular for this task with high accuracy the chosen one is about 1100 €. The idea is that it will have a payback time of 5 years and will be active along the working days, giving as a result of amortization cost per unit of 0,11 €. The type of plastic used to this application must be structurally flexible and it should protect the electronic components, ABS (Acrylonitrile Butadiene Styrene) is the best option. 1 kg of ABS is priced at 18 €.

Apart from that, it is necessary to assemble the different parts of the device. An operator is needed to perform this task, and also to adjust the printer before the 3D printing takes place. This will take about 15 minutes, and the assembly operation should not last more than 20 minutes. If the salary of the operator is 15 €/h, the cost associate to the pre-printing adjustment is 3,75 €, and the cost of the assembly task is 4,5 €.

An important aspect to take into account is the renting premises. In Vilnius, not in the main downtown, it is estimated an amount of 1200 € per month. After a research, the currently cost in Vilnius for the kilowatt is 0,20 €. The 3d printer has an average consumption around 0,16 KWh, so the cost per hour will be 0,032.

Table 8. Fix and variable costs

ABS cost (€/Kg)	**18**
light cost (€/KWh)	0,2
Average consumption (KW)	0,16
light cost per hour(€/h)	0,032
Operator hourly cost (€/h)	15
Preparation time for piece (h)	0,25
Post-production time (h)	0,3
Cost operator per piece (€/piece)	**3,75**
Assembly cost (€/piece)	**4,5**
3D printer cost (€)	**1100**
Amortization time (years)	5
Active days per year (days)	250
Active hours per day (h)	8
Amortization cost (€/h)	**0,11**
Local Renting (€)	1200
Time for produce 1 unit (h)	9,05
Units per month	17
Cost local per unit (€)	**70,59**

After detailing the different types of cost and defining them, it is calculated the cost for 3d printed pieces, due to its importance in the production process. Going deeper, the pieces have been studied in detail to know their properties and also improve the printing process. It is possible to calculate the ABS plastic consumption, the electricity, and amortization of the printer. The printed pieces are made with a 25% density, to decrease time and costs. Another way to improve the printing task is to print several pieces at the same time. The final cost of printed pieces is 21,39 €.

Table 9. 3D printed pieces cost

Printed pieces	electronic case	battery envelope	battery envelope cover	handle left part	handle right part	**TOTAL**
weight (g)	53	55	2	56,4	79,81	246,21
Printing time (h)	2,5	2		4		8,5
ABS cost (€)	0,954	0,99	0,036	1,015	1,437	4,432
Electric cost(€)	0,08	0,064		0,128		0,272
Labour cost (€)	3,75	3,75		3,75		11,25
Amortization cost (€)	0,275	0,22		0,44		0,935
SUM (€)	5,06	5,02	0,04	5,33	1,44	**16,89**
Assembly (€)						4,5
TOTAL						**21,39**

Finally, the total cost of the hand-tool trajectory definition production is calculated. As a result, to manufacture one unit the resulting total cost is 129,4 €. At this price is necessary to add the profit will be obtained for each unit. The selling price will be set at 160 €. That gives a benefit of 30,60 €. That is a benefit of 20%. The table below shows at a glance what has been explained:

Table 10. Cost per unit produced

Cost per unit	**EUR**
Material	42,60
Electric	0,272
Labour	15
Amortization	0,935
Local renting	70,59
Net profit	30,60
Total cost without profit	**129,40**
Selling price	**160,00**

Based on this data, the economical estimation can be done per unit manufactured.

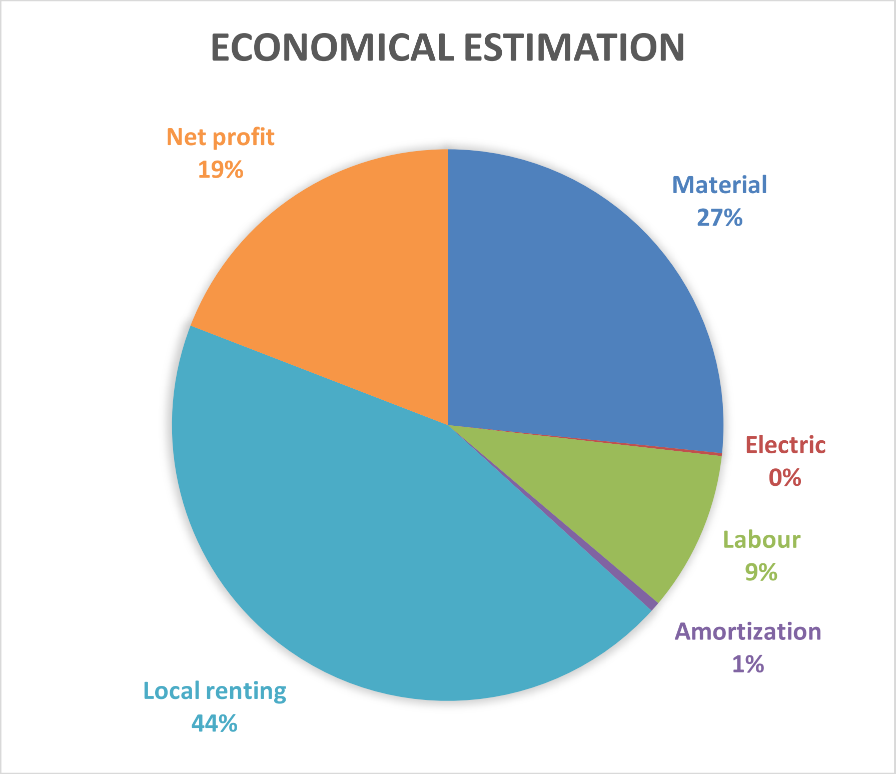


Fig. 33. Economical estimation per unit

The payback period is then calculated. For the purpose of this study, the profit obtained per unit sold has been considered. It has been determined that the cost is equivalent to that which is generated by the production of the unit. The following equations have been employed to model profit. The following cost data is presented: In this equation, q denotes the quantity of units sold.

$$\boldsymbol{Cost\ (q) = 1200 + 129,4 \cdot q} \qquad \textbf{(Ec. 7)}$$

$$\boldsymbol{Profit\ (q) = 160 \cdot q} \qquad \textbf{(Ec. 8)}$$

The intersection point will be the result of matching both equations. This intersection point is noted as the point which profit begins to be made on the product manufactured. The number of units necessary to reach this point is 40.

$$\boldsymbol{1200 + 129,4 \cdot q = 160 \cdot q} \qquad \textbf{(Ec. 9)}$$

$$\boldsymbol{q = 39,21 \approx 40}$$

The cost and profit match at the value of 6400 €.

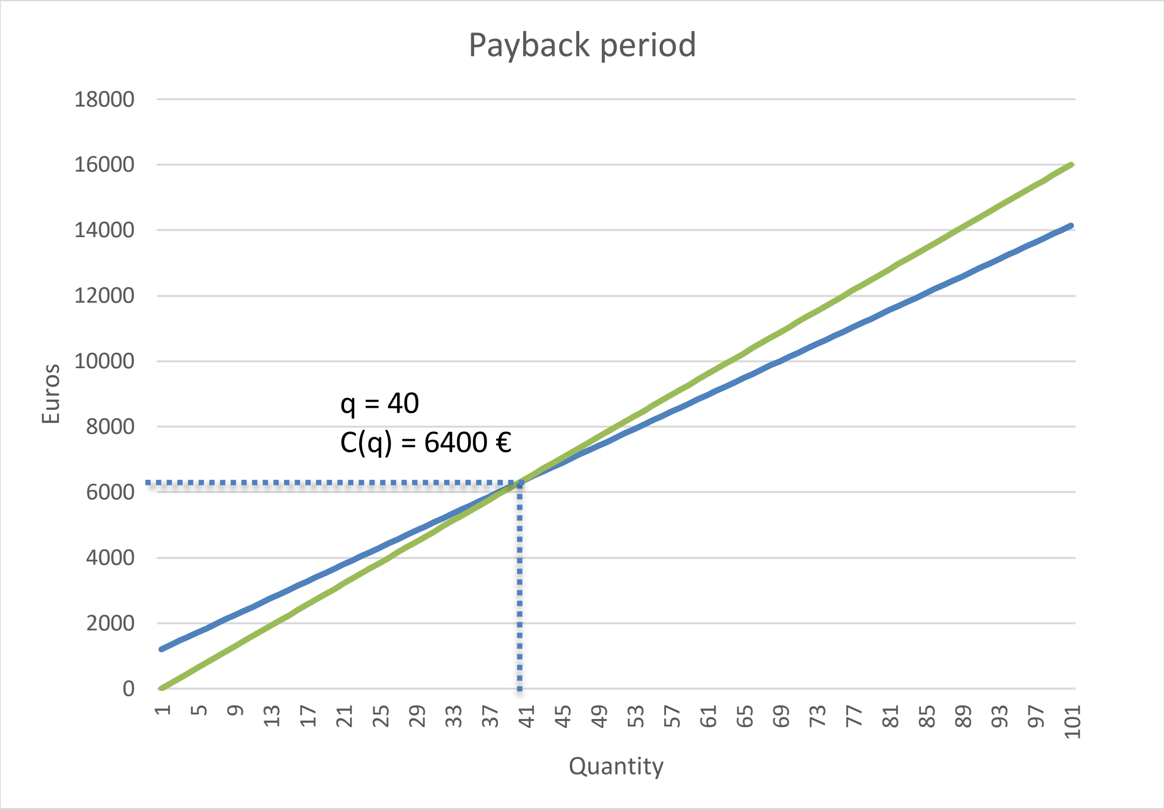


Fig. 34. Payback period

This device has many advantages but in particular the price would be one of them. It is made by low cost electronic devices, but well quality design, what makes it a reliable tool for trajectory and point coordinates definition. It is made for a educational purpose, but in fact it could operate in an industrial environment, facilitating the maintenance process and also the robot programming tasks.

Another feature to keep in mind is the durability of the gadget and the long time performance, specifically for long daily work routines. Due to its battery connection is easy to replace it in seconds to perform task for long periods of time without disruptions.

CONCLUSIONS

1. Currently, there is a wide range of systems for trajectory capture and definition in industrial environments, including camera-based solutions, UWB systems and inertial sensors combined with laser sensors (ToF). After a thorough analysis of the advantages and disadvantages of these options, it was determined that the combination of an inertial measurement unit (IMU) with a ToF sensor offers the best accuracy-to-cost ratio, being ideal for industrial applications where high accuracy and robustness against adverse environmental conditions are required.
2. A comprehensive study has been carried out on the accuracy and resolution of the sensors used. The MPU6050 IMU demonstrated sufficient accuracy at low ranges of acceleration and angular velocities, thereby meeting the project's requirements. Conversely, Waveshare's ToF laser sensor yielded consistent measurements with an accuracy of within 2 centimetres at ranges extending up to 2 metres, thereby substantiating the system's feasibility for industrial applications, such as the precise delineation of weld seams.
3. The prototype's electrical system is based on an ESP32 microcontroller, which efficiently manages data acquisition from both sensors using independent I2C protocols, facilitating precise synchronisation and low latency in trajectory capture. In addition, an effective method of wireless transmission via Wi-Fi has been implemented, enabling fast and convenient transfer of the acquired data for further processing.
4. The developed prototype has been designed with an ergonomic and compact configuration, thereby ensuring that it can be utilised for extended periods without resulting in operator fatigue. The device's low weight, in conjunction with features such as accessible buttons and a removable battery via magnetic connectors, has been shown to enhance its usability and maintenance. Furthermore, a structural analysis in SolidWorks has been conducted to validate the design, thereby confirming its resistance to both the forces applied during normal use and accidental drops.
5. Clear and specific procedures have been detailed to ensure both user safety and system integrity, highlighting aspects such as the proper use of the positioning laser, safe battery handling, and electrical precautions associated with the use of the ESP32 microcontroller. These procedures are essential to prevent accidents and ensure the correct and safe operation of the device in industrial environments.
6. A thorough economic study was carried out which determined a total production cost per unit of approximately €129.4, establishing a competitive selling price of €160, which generates a profit of 20%. This analysis also determined a short payback period, with only 40 units needed.

LIST OF LITERATURE

(In this section is written in alphabetical order all used literature)

1. Benbasat, A. Y., Paradiso, J. A. 2002. An Inertial Measurement Framework for Gesture Recognition and Applications. In: *Revised Papers from the International Gesture Workshop on Gesture and Sign Languages in Human-Computer Interaction, GW'01*, pp. 9–20. London: Springer-Verlag.
2. Cutti, A. G., Giovanardi, A., Rocchi, L., Davalli, A. 2006. A simple test to assess the static and dynamic accuracy of an inertial sensors system for human movement analysis. In: *Proceedings of the 28th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBS'06)*, pp. 5912–5915.
3. ESP32 Datasheet [interaktyvus]. 2024. [žiūrėta 2025 03 28]. Prieiga per internetą: https://www.espressif.com/sites/default/files/documentation/esp32_datasheet_en.pdf
4. what is an Inertial Measurement Unit [interaktyvus]. 2024. [žiūrėta 2025 03 28]. Prieiga per internetą: https://www.jouav.com/blog/inertial-measurement-unit.html
5. Kumar, P., Verma, J., Prasad, S. 2012. Hand Data Glove: A Wearable Real-Time Device for Human-Computer Interaction. *Hand*, 43 p.
6. Motion capture introduction [interaktyvus]. 2020. [žiūrėta 2025 03 28]. Prieiga per internetą: https://pmc.ncbi.nlm.nih.gov/articles/PMC7583783/
7. Minimum distance calculation using laser scanner and IMUs for safe human-robot interaction [interaktyvus]. 2018. [žiūrėta 2025 03 28]. Prieiga per internetą: https://www.sciencedirect.com/science/article/pii/S0736584518301200?via%3Dihub
8. Neto, P., Mendes, N. 2013. Direct off-line robot programming via a common CAD package. *Robotics and Autonomous Systems*, 61(8):896–910.
9. Neto, P., Mendes, N., Araujo, R., Pires, J. N., Moreira, A. P. 2012. High level robot programming based on CAD: Dealing with unpredictable environments. *Industrial Robot*, 39(3):294–303.
10. Pires, N., Godinho, T., Ferreira, P. 2004. CAD interface for automatic robot welding programming. *Industrial Robot: An International Journal*, 31(1):71–76.
11. Waveshare TOF Laser Range Sensor – Product Page [interaktyvus]. 2024. [žiūrėta 2025 03 28]. Prieiga per internetą: https://www.waveshare.com/tof-laser-range-sensor-b.htm

12. Waveshare TOF Laser Range Sensor – Wiki [interaktyvus]. 2024. [žiūrėta 2025 03 28]. Prieiga per internetą: https://www.waveshare.com/wiki/TOF_Laser_Range_Sensor_(B)#Specification

THE ANNEXES

ANNEX 1: Code of algorithm

```
/*******************************/
/***    MARIO LAIZ ZAMORA    ***/
/***      VILNIUS TECH       ***/
/***        06/05/2025       ***/
/*******************************/

#include <WiFi.h>
#include <SPIFFS.h>
#include <WebServer.h>
#include <Wire.h>
#include <Adafruit_MPU6050.h>
#include <Adafruit_Sensor.h>

#define REF_BUTTON_PIN  12
#define TRAJ_BUTTON_PIN 13

// Credenciales WiFi
const char* ssid = "Tu_SSID";
const char* password = "Tu_PASSWORD";

// Instancias
WebServer server(80);
TwoWire I2C_MPU = TwoWire(0);
TwoWire I2C_Laser = TwoWire(1);
Adafruit_MPU6050 mpu;

// Variables
bool is_reference_set = false;
bool is_acquiring_data = false;

#define MPU_SDA_PIN   21
#define MPU_SCL_PIN   22
#define LASER_SDA_PIN 19
#define LASER_SCL_PIN 18
#define I2C_ADDRESS   0x08

uint32_t distance = 0;
uint16_t disStatus = 0;

void setup() {
  Serial.begin(115200);

  pinMode(REF_BUTTON_PIN, INPUT_PULLUP);
  pinMode(TRAJ_BUTTON_PIN, INPUT_PULLUP);

  // Inicialización SPIFFS
  if (!SPIFFS.begin(true)) {
    Serial.println("SPIFFS falló al iniciar");
    return;
```

```
  }

  // Inicialización WiFi
  WiFi.mode(WIFI_STA);
  WiFi.begin(ssid, password);
  Serial.println("Conectando a WiFi...");
  while (WiFi.status() != WL_CONNECTED) {
    delay(500);
    Serial.print(".");
  }
  Serial.println("\nWiFi conectado");

  // Inicialización servidor HTTP
  server.on("/download", HTTP_GET, handleFileDownload);
  server.begin();
  Serial.println("Servidor HTTP iniciado");

  // Inicialización I2C
  I2C_MPU.begin(MPU_SDA_PIN, MPU_SCL_PIN);
  I2C_Laser.begin(LASER_SDA_PIN, LASER_SCL_PIN);

  // MPU6050
  if (!mpu.begin(0x68, &I2C_MPU)) {
    Serial.println("MPU6050 no detectado");
    while (1);
  }
  mpu.setAccelerometerRange(MPU6050_RANGE_8_G);
  mpu.setGyroRange(MPU6050_RANGE_500_DEG);
  mpu.setFilterBandwidth(MPU6050_BAND_21_HZ);
  Serial.println("MPU6050 inicializado");
}

void loop() {
  server.handleClient();

  if (digitalRead(REF_BUTTON_PIN) == LOW && !is_reference_set) {
    guardarPuntoReferencia();
    is_reference_set = true;
  }

  if (digitalRead(TRAJ_BUTTON_PIN) == LOW && is_reference_set &&
!is_acquiring_data) {
    is_acquiring_data = true;
  }

  if (digitalRead(TRAJ_BUTTON_PIN) == HIGH && is_acquiring_data) {
    is_acquiring_data = false;
  }

  if (is_acquiring_data) {
    adquirirDatos();
```

```
  }

  delay(100);
}

void guardarPuntoReferencia() {
  File refFile = SPIFFS.open("/referencia.txt", FILE_WRITE);
  if (refFile) {
    refFile.println("Punto de referencia guardado");
    refFile.close();
    Serial.println("Referencia guardada");
  } else {
    Serial.println("Error guardando referencia");
  }
}

void adquirirDatos() {
  File dataFile = SPIFFS.open("/datos.txt", FILE_APPEND);
  if (dataFile) {
    unsigned long timestamp = millis();
    readLaserDistance();

    sensors_event_t a, g, temp;
    mpu.getEvent(&a, &g, &temp);

    dataFile.printf("%lu,%.2f,%.2f,%.2f,%.2f,%.2f,%.2f,%lu\n", timestamp,
                    a.acceleration.x, a.acceleration.y, a.acceleration.z,
                    g.gyro.x, g.gyro.y, g.gyro.z, distance);
    dataFile.close();
    Serial.println("Datos guardados");
  }
}

void readLaserDistance() {
  I2C_Laser.beginTransmission(I2C_ADDRESS);
  I2C_Laser.write(0x24);
  I2C_Laser.endTransmission();
  I2C_Laser.requestFrom(I2C_ADDRESS, 2);
  if (I2C_Laser.available() == 2) {
    distance = I2C_Laser.read() | (I2C_Laser.read() << 8);
  } else distance = 0;
}

void handleFileDownload() {
  String filePath = server.arg("file");
  if (SPIFFS.exists(filePath)) {
    File downloadFile = SPIFFS.open(filePath, FILE_READ);
    server.streamFile(downloadFile, "text/plain");
    downloadFile.close();
  } else server.send(404, "text/plain", "Archivo no encontrado");
}
```

ANNEX 2: Bill of Materials

Format	Zone	Item nº	Tag	Title	Qty.	Remarks
				<u>Documents</u>		
A1			MERS BM 25 ML 01 00 00 00 GV	General View	1	
				<u>Subassemblies</u>		
A1		1	MERS BM 25 ML 01 01 00 00 AD	ORPU device	1	
		2	MERS BM 25 ML 01 02 00 00 AD	Industrial table	1	
		3	MERS BM 25 ML 01 03 00 00 AD	welding personal	1	
		4	MERS BM 25 ML 01 04 00 00 AD	Welding piece	1	
		5	MERS BM 25 ML 01 05 00 00 AD	base for ORPU device	1	

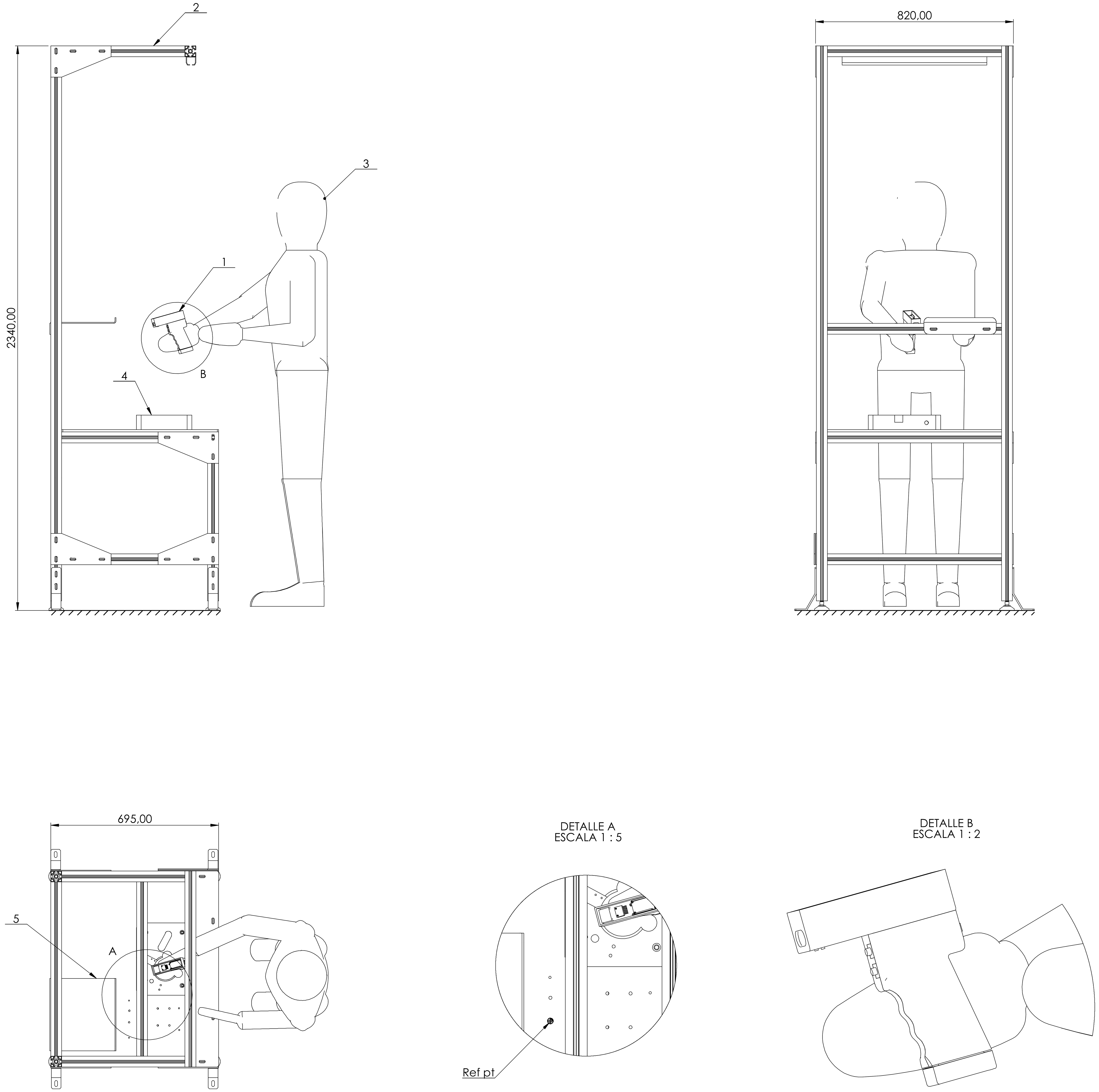
Respon.depart. Dep. of mech., rob, and dig. man.	Adviser	Document type: Specification	Status of the document: Educational
Owner: Vilnius Tech	Prepared by: M. Laiz Zamora Approved by: V. Bučinskas	Title: Specification table	Tag: MERS BM 25 ML 01 00 00 00 GV Issue: A · Date: 17/05/2025 · Lang.: En · Page: 1/2

Format	Zone	Item nº	Tag	Title	Qty.	Remarks
				Documents		
A1			MERS BM 25 ML 01 01 00 00 AD	Assembly View	1	
				Parts		
A3		1	MERS BM 25 ML 01 01 01 00	Charger	1	
A3		2	MERS BM 25 ML 01 01 02 00	left handle	1	
A3		3	MERS BM 25 ML 01 01 03 00	Electronic case	1	
		4	MERS BM 25 ML 01 01 04 00	right handle	1	
				Electronic components		
		5	MERS BM 25 ML 01 01 05 00	Esp 32	1	
		6	MERS BM 25 ML 01 01 06 00	MPU6050	1	
		7	MERS BM 25 ML 01 01 07 00	ToF Sensor	1	
		8	MERS BM 25 ML 01 01 08 00	Pushbutton	2	
		9	MERS BM 25 ML 01 01 09 00	Switch	1	
		10	MERS BM 25 ML 01 01 10 00	Male magnetic connector	1	
		11	MERS BM 25 ML 01 01 11 00	Female magnetic connector	1	
				Standard components		
		12	MERS BM 25 ML 01 01 12 00	socket head cup (ISO 4762) M2,5 x 16	4	
		13	MERS BM 25 ML 01 01 13 00	socket head cup (ISO 4762) M3 x 10	4	
		14	MERS BM 25 ML 01 01 14 00	socket head cup (ISO 4762) M1,6 x 4	2	
		15	MERS BM 25 ML 01 01 15 00	socket head cup (ISO 4762) M1,6 x 8	2	
		16	MERS BM 25 ML 01 01 16 00	socket head cup (ISO 4762) M1,6 x 6	2	

Respon.depart.	Adviser	Document type	Status of the document
Dep. of mech., rob, and dig. man.		Specification	Educational

Owner	Prepared by	Title	Tag			
Vilnius Tech	M. Laiz Zamora	Specification table	MERS BM 25 ML 01 01 00 00 AD			
	Approved by		Issue	Date	Lang.	Page
	V. Bučinskas		A	17/05/2025	En	2/2

ANNEX 3: Drawings



Range of measuring: 20mm to 2000mm with 5mm accuracy

Device controlled by Microcontroller Esp 32.
Voltage 5V DC
Data Transmission: via Wifi

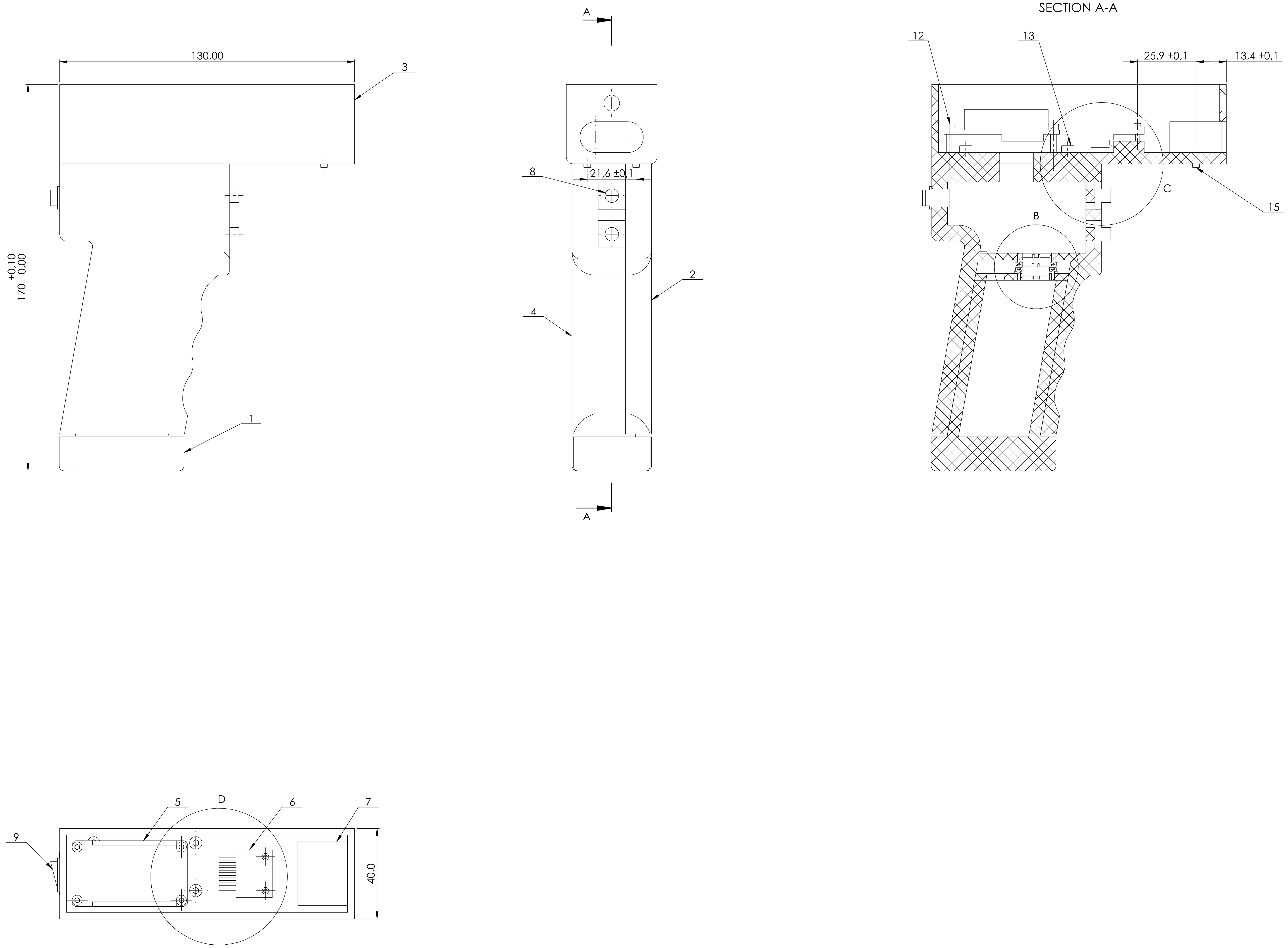
Inertial measurement unit: MPU6050
Working voltage: 3~5V.
Protocol comunication: I2C

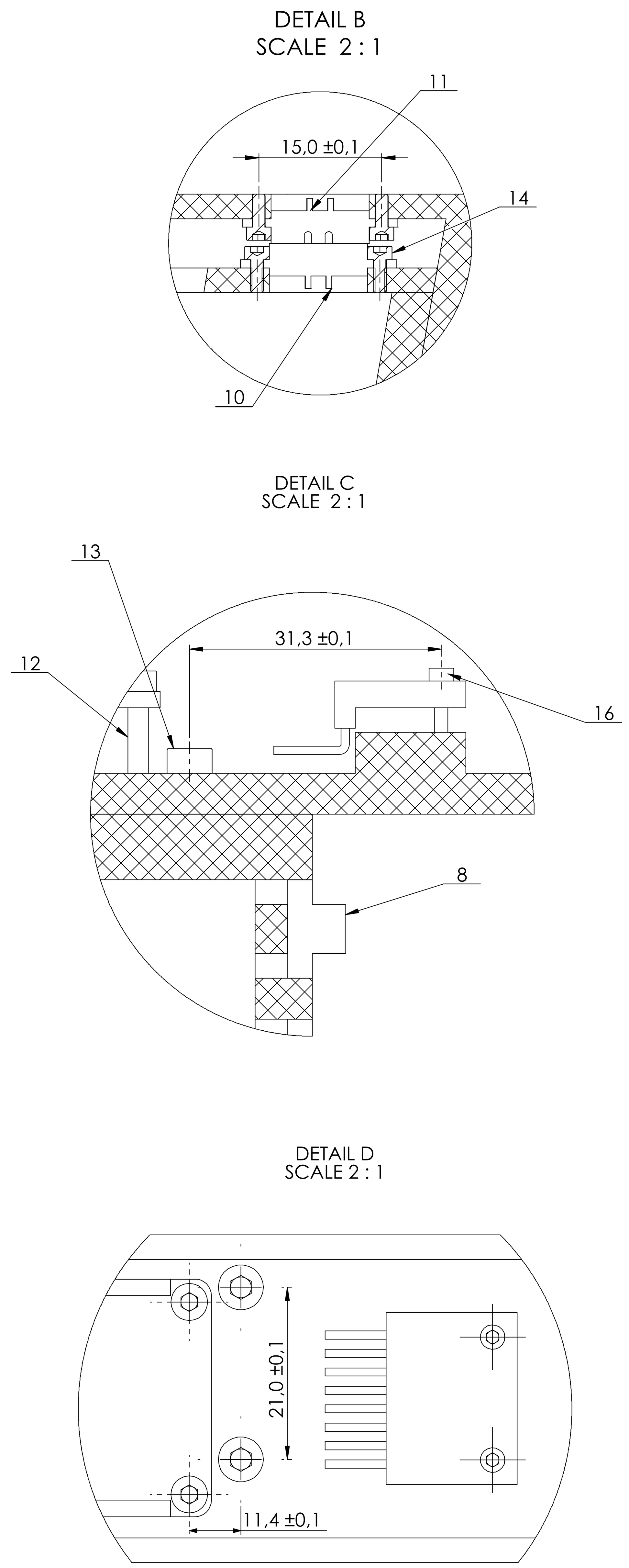
Distance Sensor: ToF Sensor by Waveshare
Working Voltage: 5V
Protocol comunication: I2C
Accuracy: 5 mm~2cm at 2 meter

Laser: positional red laser
Working voltage: 3 ~ 5V.
Working temperature: + 10 ~ + 40C

File No.	Aditional information	Material		Scale 1:10
Respon. depart. Dep. of mech., rob, and dig. man.	Adviser	Document type		Status of the document
Owner	Prepared by M. Laiz Zamora	Title	MERS BM 25 ML 01 00 00 00 GV	
Vilnius Tech	Approved by V. Bučinskas	General View	Issue 1 / Date 22/05/2025 / Lang. Eng.	Page 1/8

MERS BM 25 ML 01 01 00 00 AD

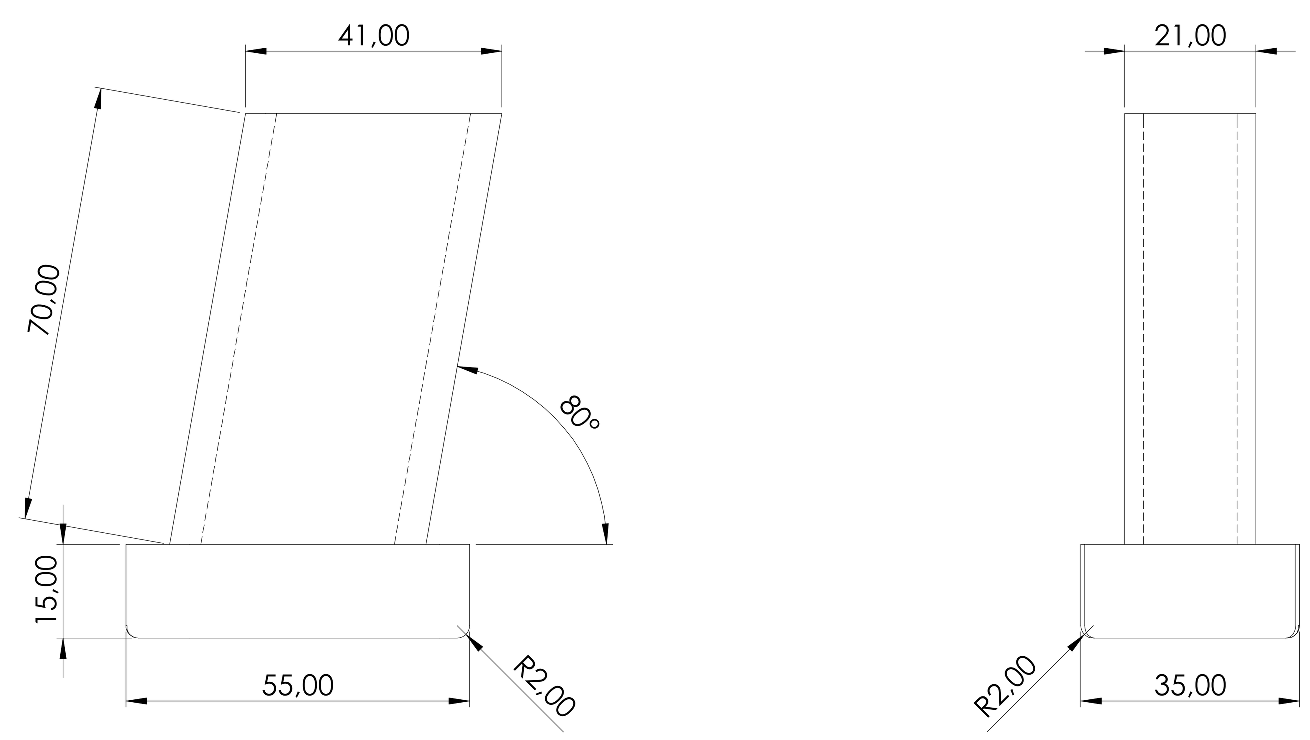


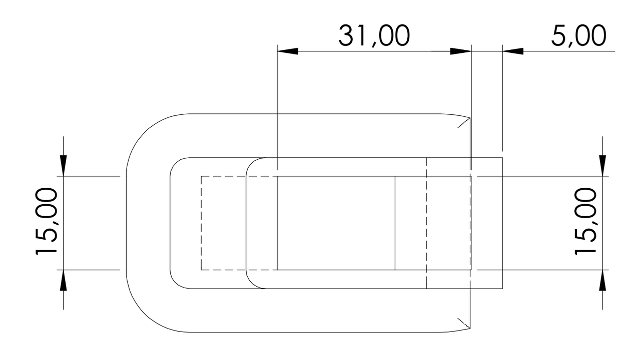


Notes:

1. The battery should be installed in a manner analogous to the insertion of a magazine into a pistol. The magnetic connections will fix the charger to the handle.
2. Magnetic Conection are fixed with M1,6x4
3. The assembly of the handle shall be done by pressing one part into the other and applying glue.
4. the electronic box is fixed to the handle with 4 M3x10
5. Esp32 is fixed to electronic box with 2-4 M2,5x16
6. Tof Sensor is fixed to electronic box with 2 M1,6x6
7. Inertial Unit is fixed to electronic box with 2 M1,6x8

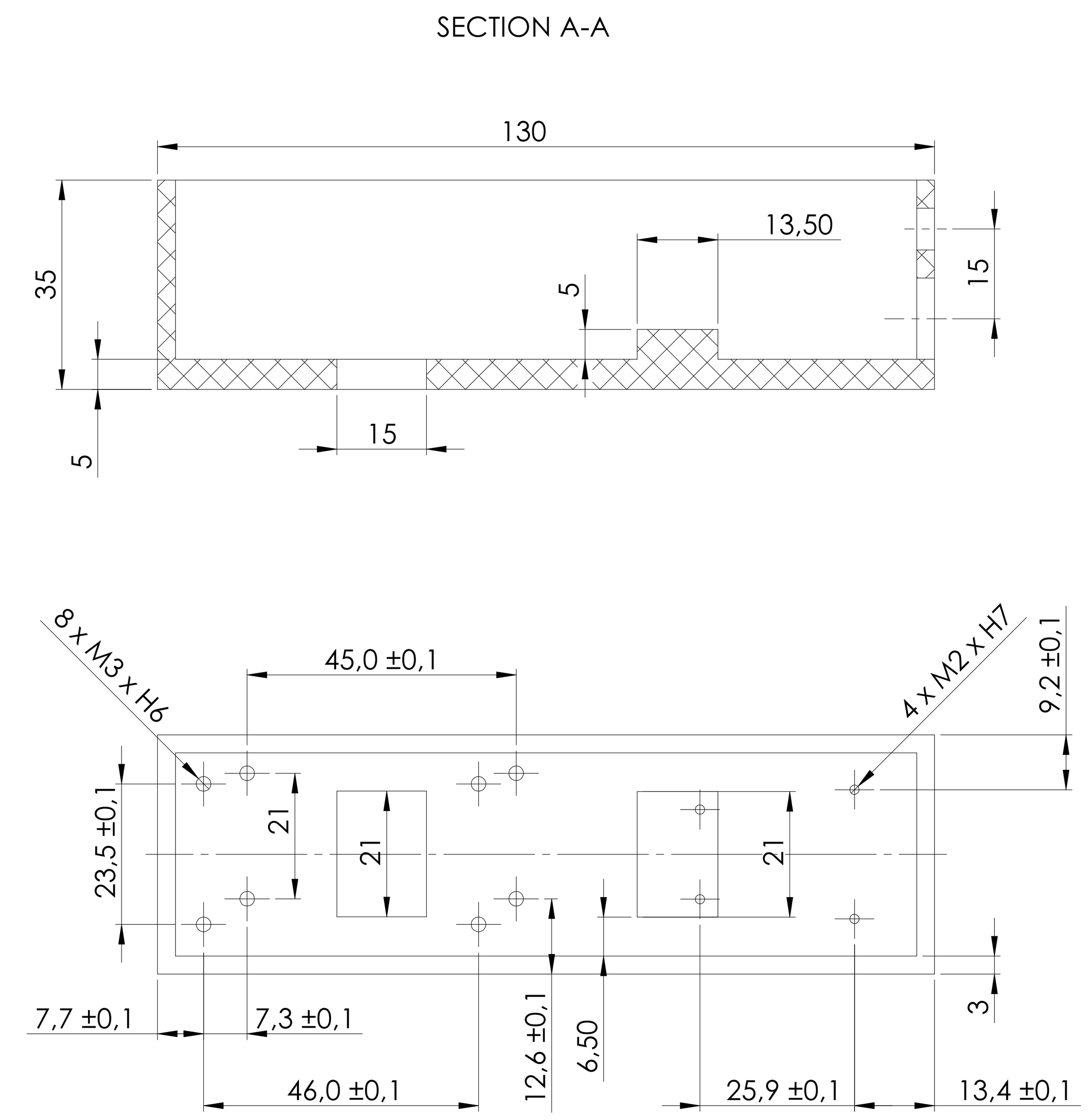
File No.		Aditional information	Material	Scale 1:1
Respon. depart. Dep. of mech., rob. and dig. man.	Adviser	Document type		Status of the document
Owner Vilnius Tech	Prepared by M. Laiz Zamora	Title Assembly		MERS BM 25 ML 01 01 00 00 AD
	Approved by V. Bučinskas			Issue 1 / Date 22/05/2025 / Lang. Eng. / Page 2/8





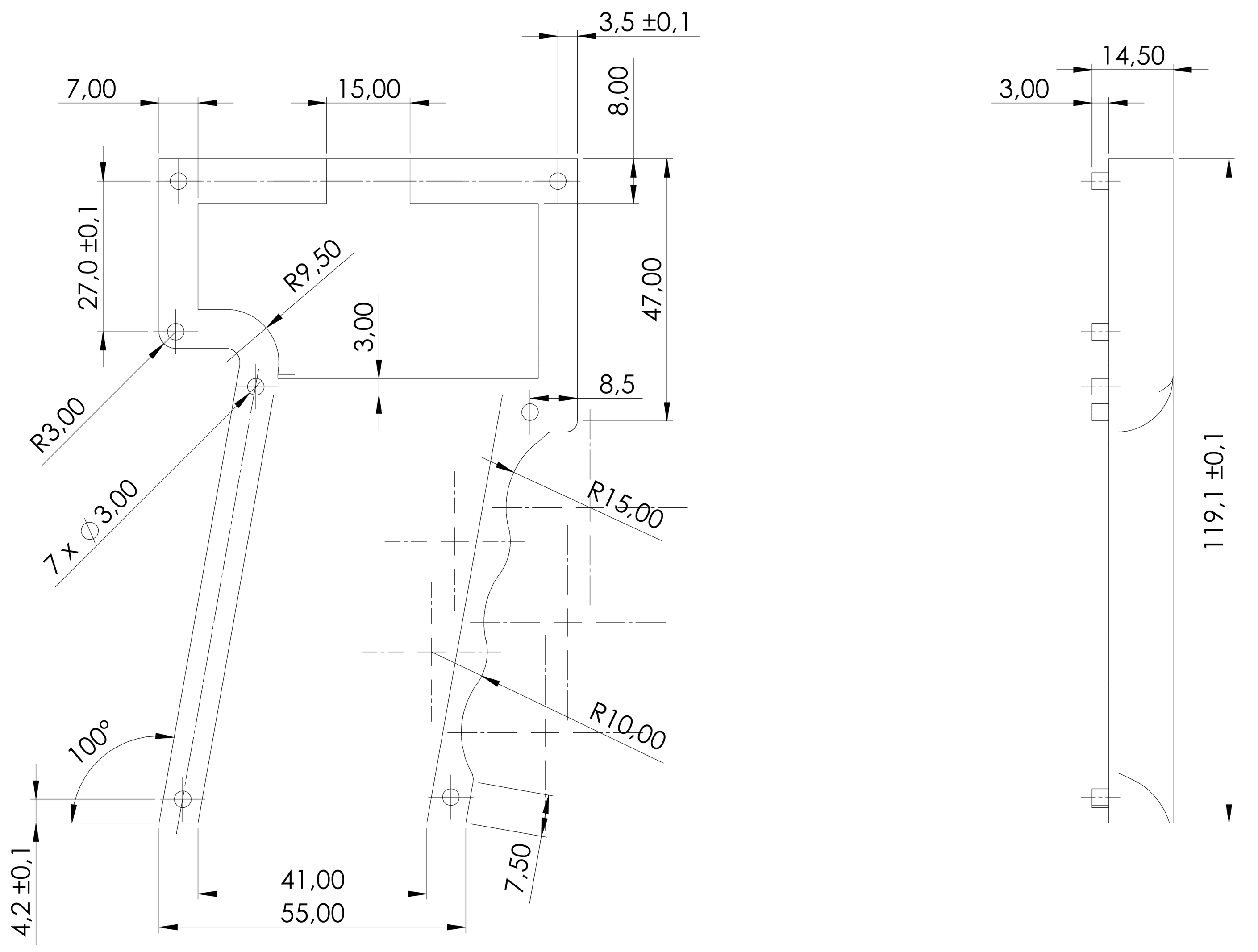
Notes:
General tolerances according to ISO-2768-m
Remove sharp edges before assembly

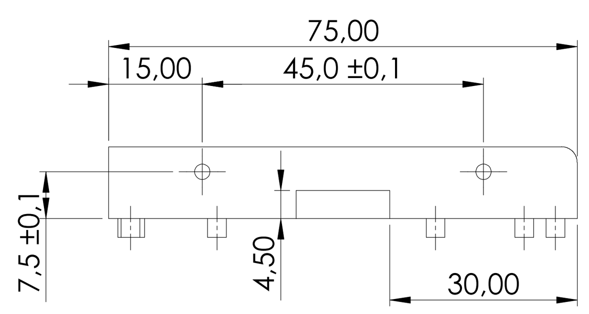
File No.	Additional information	Material	Acrylonitrile Butadiene Styrene - Polycarbonate (ABS-PC)	Scale 1:1
Respon. depart Dep. of mech., rob, and dig. man.	Advisor	Document type: Work drawing	Status of the document: Educational drawing	
Owner: VILNIUS TECH	Prepared by: M. Laiz Zamora; Approved by: V. Bučinskas	Title: Detail View Charger	MERS BM 25 ML 01 01 01 00	Issue A; Date 22/05/2025; Lang. Eng.; Page 3/8



Note:
Remove sharp edges before assembly
General tolerances according to ISO-2768-m

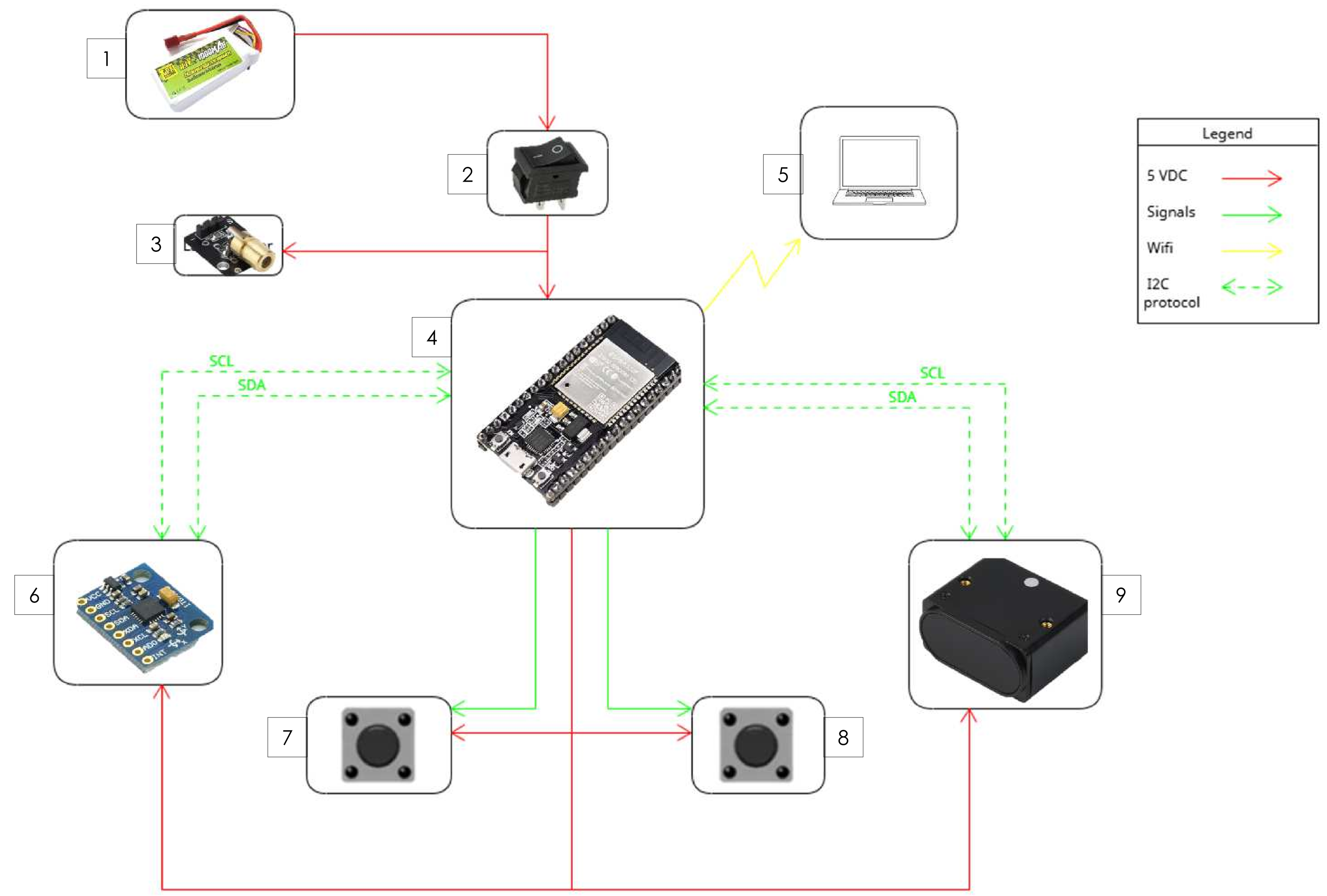
File No.	Additional information	Material	Acrylonitrile Butadiene Styrene - Polycarbonate (ABS-PC)	Scale 1:1
Respon. depart Dep. of mech., rob, and dig. man.	Advisor	Document type: Work drawing	Status of the document: Educational drawing	
Owner: VILNIUS TECH	Prepared by: M. Laiz Zamora; Approved by: V. Bučinskas	Title: Detail View Electronic case	MERS BM 25 ML 01 01 03 00	Issue A; Date 22/05/2025; Lang. Eng.; Page 4/8





Note:
Remove sharp edges before assembly
General tolerances according to ISO-2768-m

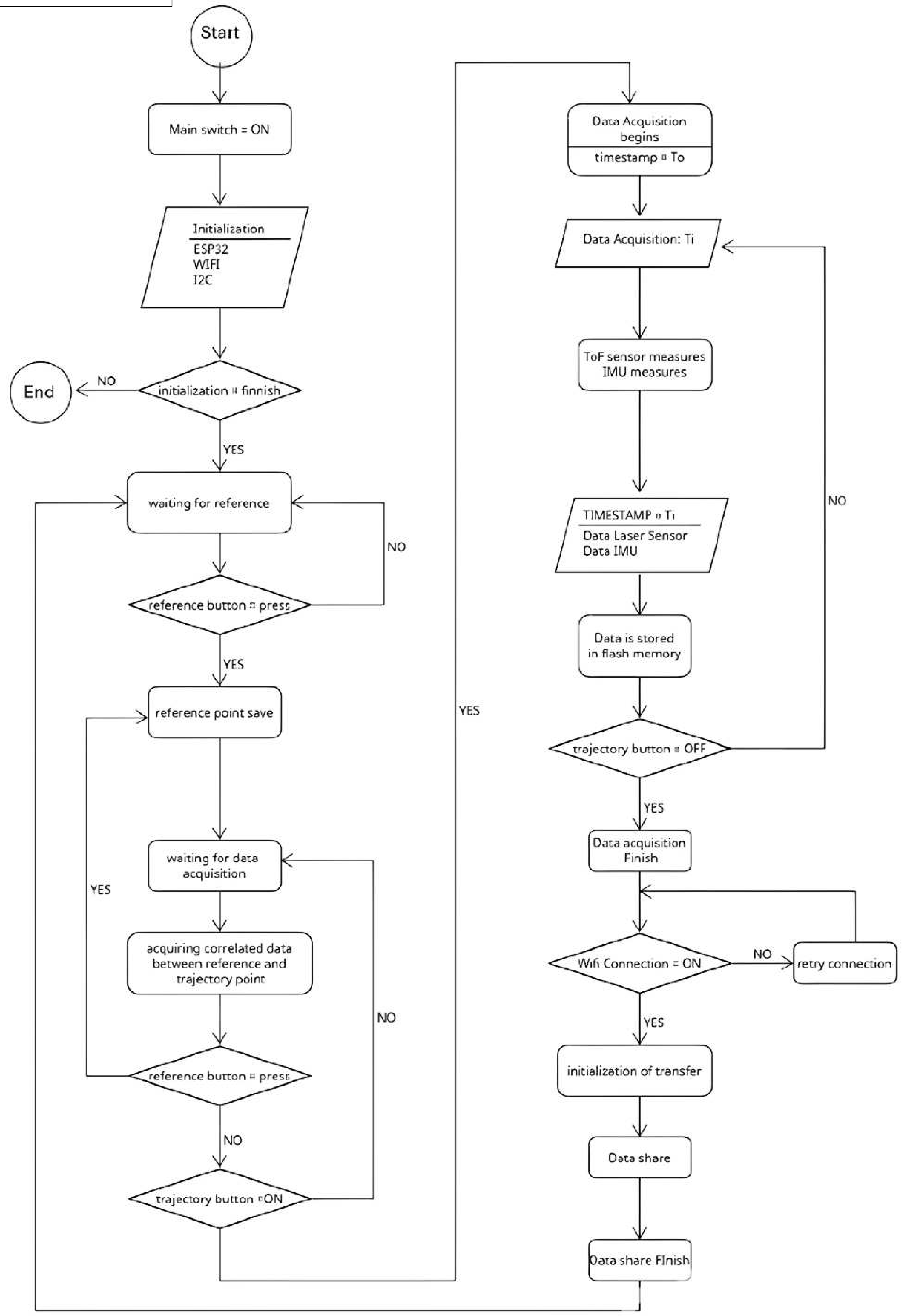
File No.	Additional information	Material	Acrylonitrile Butadiene Styrene - Polycarbonate (ABS-PC)	Scale 1:1
Respon. depart Dep. of mech., rob, and dig. man.	Advisor	Document type: Work drawing	Status of the document: Educational drawing	
Owner: VILNIUS TECH	Prepared by: M. Laiz Zamora; Approved by: V. Bučinskas	Title: Detail view Handle	MERS BM 25 ML 01 01 02 00	Issue A; Date 22/05/2025; Lang. Eng.; Page 5/8



Number	Component
1	Battery 5 volts
2	Main switch
3	Laser pointer
4	Esp 32
5	Computer
6	Inertial unit (IMU)
7	Trajectory button
8	Reference button
9	Tof sensor

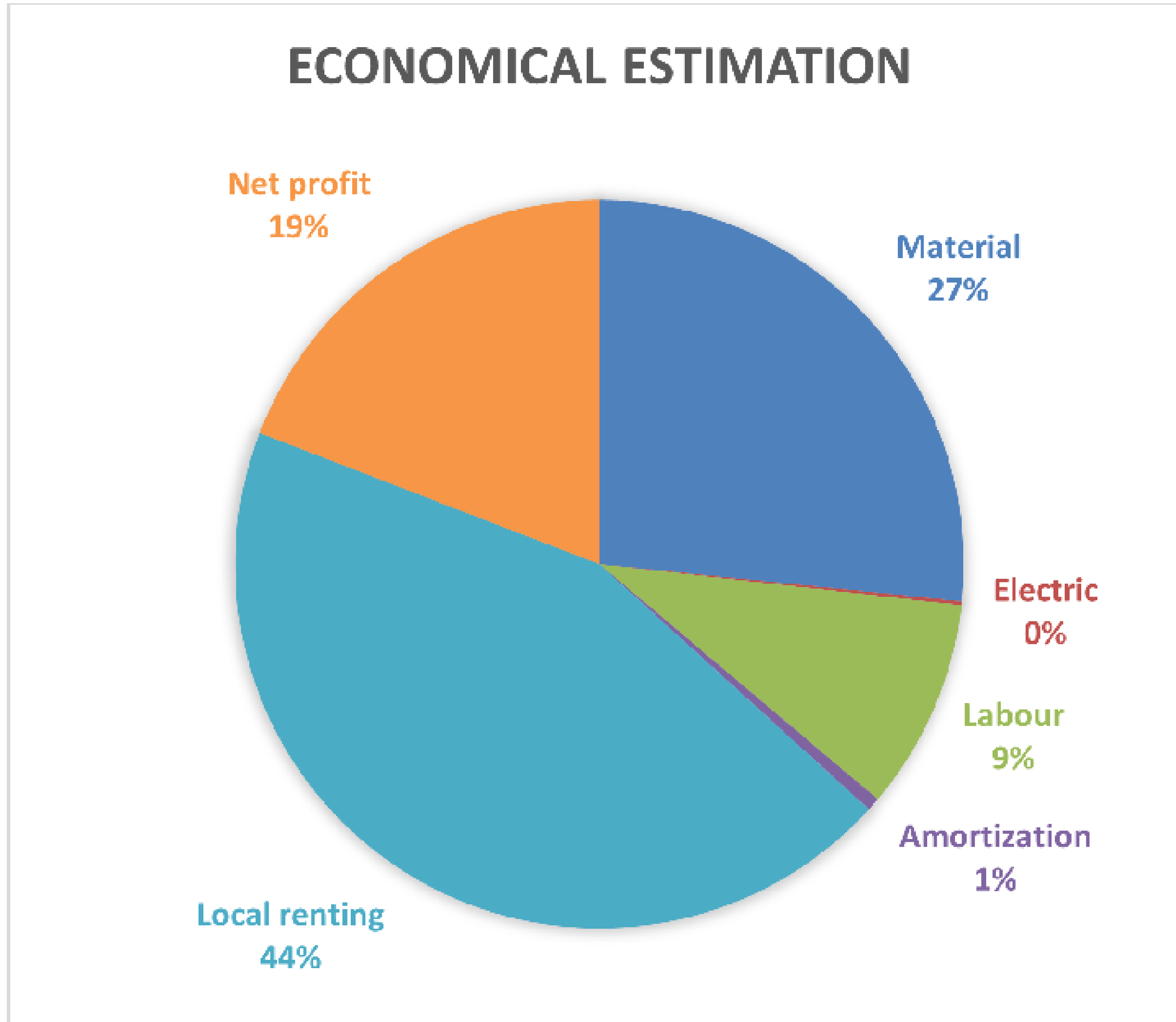
File No.	Additional information	Material	
Respon. depart Dep. of mech., rob, and dig. man.	Advisor	Document type: Electronic Block Scheme	Status of the document: Educational drawing
Owner: VILNIUS TECH	Prepared by: M. Laiz Zamora; Approved by: V. Bučinskas	Title: Development of offline robot programming unit for tool position control	MERS BM 25 ML 01 00 00 00 ES; Issue A; Date 22/05/2025; Lang. Eng.; Page 6/8

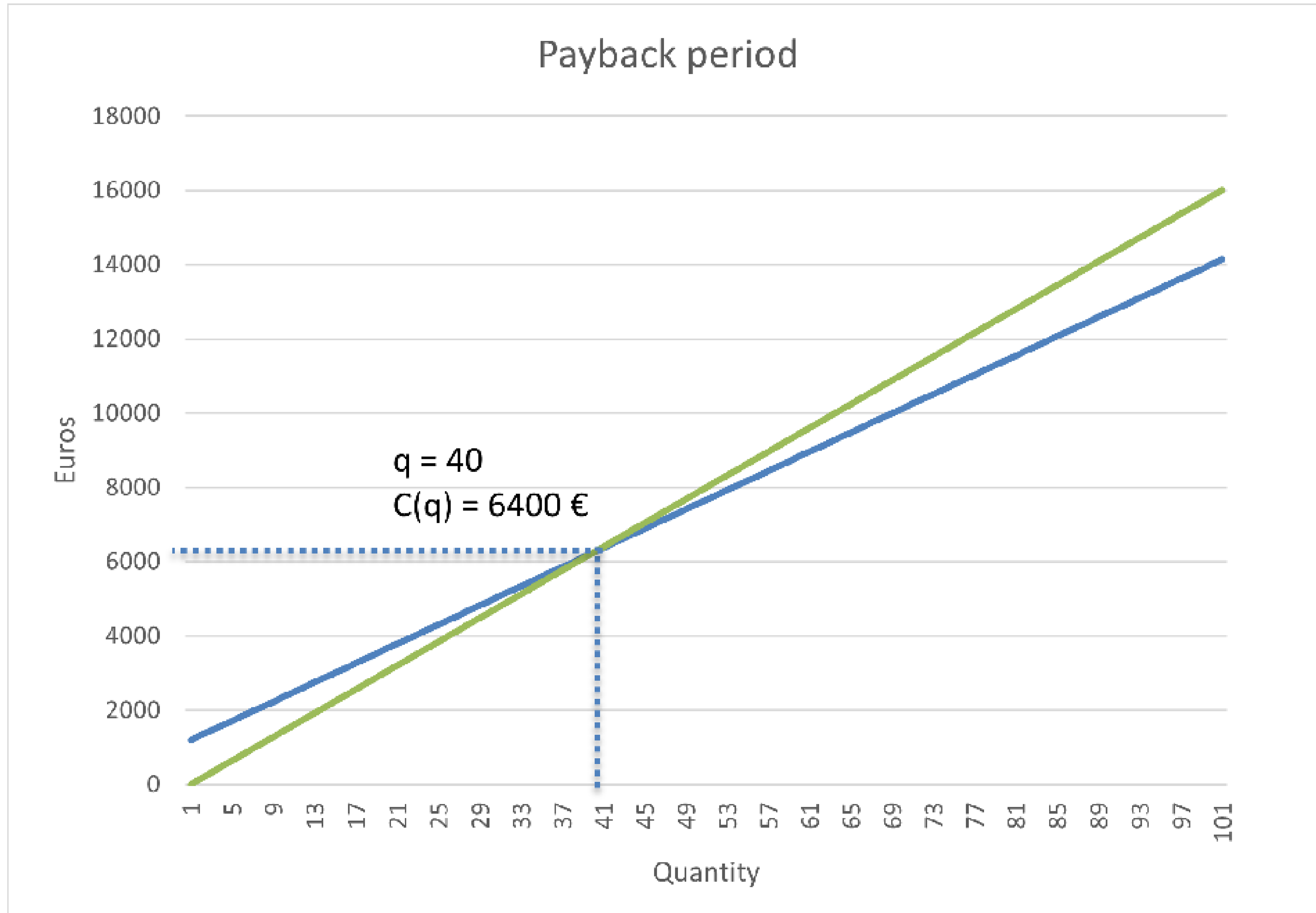
MERS BM 25 ML 01 00 00 00 CA



	File No.	Additional information	Material	
Respon. depart Dep. of mech., rob, and dig. man.	Advisor	Document type Algorithm of management of device	Status of the document Educational drawing	
Owner VILNIUS TECH	Prepared by M. Laiz Zamora	Title Development of offline robot programming unit for tool position control	MERS BM 25 ML 01 00 00 00 CA	
	Approved by V. Bučinskas		Issue A	Date 20/05/2025	Lang. Eng.	Page 7/8

MERS BM 25 ML 01 00 00 00 EM





	File No.	Additional information	Material	
Respon. depart Dep. of mech., rob, and dig. man.	Advisor	Document type Economic Calculation	Status of the document Educational drawing	
Owner VILNIUS TECH	Prepared by M. Laiz Zamora	Title Development of offline robot programming unit for tool position control	MERS BM 25 ML 01 00 00 00 EM	
	Approved by V. Bučinskas		Issue A	Date 20/05/2025	Lang. Eng.	Page 8/8