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**ESCUELA DE INGENIERÍAS  
INDUSTRIALES**

**UNIVERSIDAD DE VALLADOLID**

**ESCUELA DE INGENIERIAS INDUSTRIALES**

**Grado en Ingeniería Electrónica Industrial y Automática**

**Sistema de visión para una maquina CNC**

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TÍTULO: **Vision system for CNC machine**  
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### **Abstract:**

Se trata de una instalación de un sistema de visión artificial para una maquina CNC. El sistema permite tener una realimentación visual de los agujeros que la maquina realiza en una plancha, generalmente de madera. El sistema, después de que la maquina termine de realizar los agujeros los revisa. Se obtiene el contorno del agujero creado y se calcula su tamaño en milímetros, tras realizar una calibración y un correspondiente paso de la medida en pixeles a milímetros. Al tener esta medida, se compara el diámetro del agujero creado con el tamaño de la herramienta.

Si el tamaño es exactamente el mismo, se continúa comprobando los agujeros restantes, si dista de la medida de la herramienta, pero el error está dentro de una diferencia especifica, se revisa por si el error es diferencial. Si el error es mayor que la diferencia, se para la producción para arreglar desperfectos.

It is an installation of an artificial vision system for a CNC machine. The system allows to have visual feedback of the holes that the machine makes in a plate, generally of wood. The system, after the machine finishes making the holes, checks them. The contour of the created hole is obtained and its size in millimeters is calculated, after performing a calibration and a corresponding measurement calibration in pixels to millimeters. Having this measurement compares the diameter of the hole created with the size of the tool.

If the size is the same, continue checking the remaining holes, if it is far from the tool size, but the error is within a specified difference, check if the error is differential. If the error is greater than the difference, production is stopped to fix defects.

**Keywords:**

Visión, CNC, Python, Camara, Agujeros / Vision, CNC, Python, Camera, holes.



VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

FACULTY OF MECHANICS

DEPARTMENT OF MECHATRONICS, ROBOTICS AND DIGITAL MANUFACTURING

Pablo Ricardo Dueñas Fernández

**Vision system for CNC machine**

Final Bachelor's Project

Study programme MECHATRONICS AND ROBOTICS,

Code 612H73002

Vilnius, 2022

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Pablo Ricardo Dueñas Fernández

**Vision system for CNC machine**

Final Bachelor's Project

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# DECLARATION OF AUTHORSHIP IN THE FINAL BACHELOR'S PROJECT

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I confirm that my course project (work, integrated project), which topic is Vision system for CNC machine, is written independently. The material presented in this project (work, integrated project) is not plagiarized. Quotations from other sources used directly or indirectly are indicated in the literature references.

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# TASK TO PREPARE FINAL BACHELOR'S PROJECT

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

Production and Manufacturing engineering study field  
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## TASK FOR BACHELOR THESIS

16 May 2022 No. 1  
Vilnius

For student Pablo Ricardo, Dueñas Fernández.

Bachelor Thesis title: Vision system for CNC machine.

Approved on 25 November, 2019 by Dean's decree No 226me.

The Final work has to be completed by 15 May, 2020.

### TASK FOR FINAL THESIS:

#### Initial data:

In the initial system, a CNC cutting machine must be upgraded with a camera vision system. The CNC machine has a LD52GF-400W rotove motor for the cutting part. The Vision system is mainly represented by a Digital 1600X 8LED 2MP usb microscopic camera. The vision system must be able to detect the made holes by the CNC machine and to calculate the error of the made hole. This will help in deciding if the manufactured piece is good enough or not.

#### Explanatory part:

Introduction: Investigation problem. Object of Project. The aims and purposes of the project

1. Overview of analogic constructions. 1.1 – 1.5 different market solutions. 1.6 Substantiation of the decision.
2. Overview of specific nodes. Final solution for vision system. Hardware and software analysis.
3. Calculations of the project. Frequency study. Force study. Displacement study.
4. Description of the construction and operational principle. Electric-block scheme. Algorithm of management of device or node.
5. Determination of the requirements for safe working and environmental protection taking in account the design of sorting cell.
6. Evaluation of economic indicators of the designed or upgraded device. Business plan. Component list.
7. Final conclusions and recommendations.
8. Literature reference list.

#### Drawings:

1. General drawing of the device (1 sheet A1);
2. Assembly drawing of the device (node) (1 sheet A1);
3. Control algorithm (1 sheet A1);
4. The structural holder of the device (0.25 sheet A1);
5. The electrical scheme (0.25 sheet A1);
6. Economic indicators (0.5 sheet A1).

Supervisor .....

(Signature)

Doc. dr. Andrius Dzedzickis  
(Academic Title, Name, Surname)

Task accepted



.....  
(Student's signature)

Pablo Ricardo, Dueñas Fernández  
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## ANNOTATION

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Title: **Vision system for CNC machine.**

Author **Pablo Ricardo Dueñas Fernández** Academic supervisor **Andrius Dzedzickis**

Thesis language

Lithuanian

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**Annotation** The CNC (Computerized Numerical Control) machine sometimes works in different conditions, sometimes delicate ones that make the work even more difficult than it is supposed. In order to maintain the quality of the cutting process for a CNC machine, a vision system is developed. The system must work to increase the accuracy and reduce the cost of losing a bad-developed plate.

This vision system for the CNC machine looks for the made holes, once they are already made, examine them and search for discrepancies in between the supposed size of the theoretical hole and the actual manufactured one.

The dimension of the holes is calculated using python and a microscopic camera. The python program creates a contour around the made hole and designs a square that circumscribes the circle.

Once the circle is measured, a calibration takes place. After that, the program starts to measure the holes in millimeters and to compare the sizes. If the made hole is bad developed, the system asks for a correction on the machinery or the manufactured plate.

Structure: introduction, overview of analogic constructions, overview of specific nodes, calculations of the project, description of the construction and operational principle, worksafety, economic calculations, conclusions and suggestions, list of literature.

Thesis consist of: 55 text without appendixes, 36 pictures, 8 tables, 24 bibliographical entries.

Appendixes included.

**Keywords:** CNC, vision system, holes, python, dimension, camera, calibration.



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# INTRODUCTION

## **Investigation problem:**

One of the main problems of the CNC (Computerized Numerical Control) machinery is that they are blind in comparison to new kind of machinery. The advancements that need to be made are on terms of computer vision. Providing valid image data to the cutting procedure is one of the keys.

The CNC machines are probably one of the most common machineries in the field of machining, but they sometimes do not provide the accuracy needed. By introducing systems such as artificial vision you provide additional feedback to the process. This brings a big improvement. Been able to locate a problem that may cause even the destruction of the object is important in one of the most important terms in actual machinery: reducing costs.

Also, with this analysis, you can know if you need to change parameters, the path of the machine or even the tool used for the process.

In these days, there are a couple of programs of CNC machine control that provide open-source software to use or develop new control programs, you may even need two different computers, one for the machine and one for the vision system. Even though this, it is still worth to implement this new technology or even look for a way to create the software to cross the two applications in one unique PC.

The basic vision system installed in actual CNC machines are to improve the results over the final manufactured product, but not only to improve the product itself, but to take the machines into the best condition to make the best product possible. If there are no errors, or the errors can be solved, the cost reduces hugely. By these, the machine will not be “blind” to face the errors.

## **Object of Project.**

In order to make some upgrades to the CNC machine, the project implements an artificial vision system that will be attached to the front of the CNC machine to make a recognition of the different holes or forms.

## **The aims and purposes of the project.**

The main purpose is to build a suitable artificial vision system that improves the actual CNC machine.

The exact mechanism that is going to be implemented is a camera that enables to have vision feedback of the exact situation that is happening in the working place.

To be able to do that we need to have a proper structure that will be installed on the CNC machine itself to anchor the different parts to the structure, and a camera.

### Advantages and disadvantages:

#### Advantages:

- You will get feedback of the things that are happening in the cutting process. Knowing this, you will be able to correct the parameters, change the different components or material or even stop the process if needed.
- The balance between the money invested in the artificial vision structure and the money you save because you do not lose material, time of work, electricity and maybe even a salary for a maintenance technician.

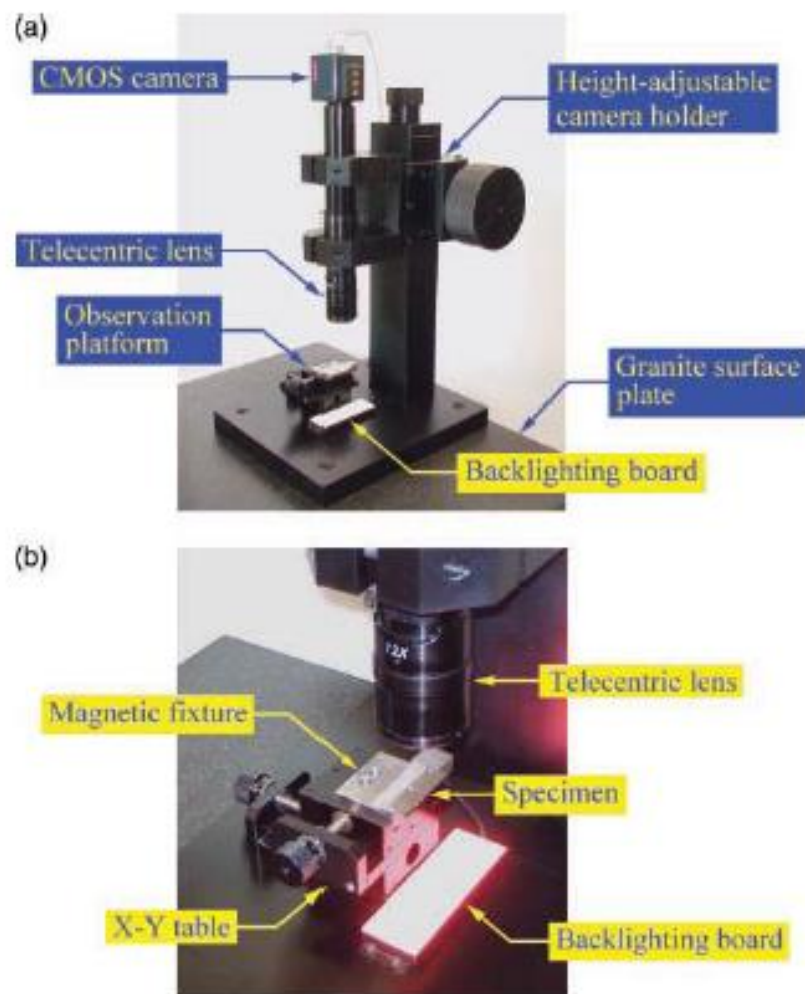
#### Disadvantages:

- You have a decrease on the production speed. This may be suitable for a small factory or workshop, but it is not realistic to stop a whole production chain just to make sure that one object is correctly done. If that is the case the project may be suitable just at the end of the production chain, when a check in the manufactured pieces is done.
- The different vibrations may cause a slight mismatch between the reference stayed for the camera and the new situation. This ruins all the calculations for the distances and even for the camera focus.

# 1. OVERVIEW OF ANALOGIC CONSTRUCTIONS

## 1.1. Microdrill fluting by an image-based contour matching method

The grinding wheels of the cutting machine must be trued and dressed regularly to maintain the quality in the process. To achieve this, the group of the department of Mechanical Engineering of the university of Taipei, Taiwan has developed a vision system that is capable of locate this grinding wheels, examine them and determine if it is necessary to change the complete wheel. The method they use is border detection with a contour matching to calculate the deviations between the theoretical and real borders.



**Fig. 1.1.** The built inspection system: a) set-up of the system; b) system working (T-H Chen, W-T Chang\*, P-H Shen DOI: 10.1243/09544054JEM1749. 28 July 2009.)

The image processing and contour matching method is made on different steps.

First, you calibrate the pixel to millimetre parameter by a calibration template with a standard circular hole which diameter is exactly 0.701 mm.

The system captures the image. The same circular hole is measured by the program, resulting in 927.52 pixels, and with a simple conversion factor, the relation is obtained:

$$T_c = \frac{D_s}{D_d} = \frac{0.701}{927.53} \sim 0.000756 \frac{mm}{pixel} = 0.756 \frac{\mu m}{pixel} \quad (1)$$

Where  $D_s$  is the diameter in mm, and  $D_d$  is the diameter in pixels.

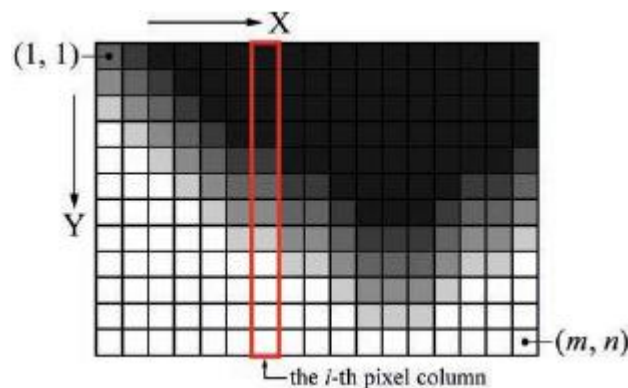
The result of this part is the relation mm/pixels for any object catch by the image processing. For the edge detection, there is a backlight process where the piece is projected and the telecentric lens takes the image.

The edges in this case are identified by locating significant discontinuities in pixel intensity. These discontinuities may characterize the boundaries of and object.

The intensity is measured in greyscale from 0 to 255 and the location of each pixel is represented on an array of (m x n).

- (1) (Weng, J., Cohen, P., and Herniou, M. Camera calibration with distortion models and accuracy evaluation. IEEE Trans. Pattern Anal. Mach. Intell., 1992, 14(10), 965–980.)

The edge of the line can be found where the peak of the first-order derivative occurs.



**Fig. 1.2.** Pixel distribution, intensity, and location.

(T-H Chen, W-T Chang, P-H Shen DOI: 10.1243/09544054JEM1749. 28 July 2009.)

Every time the pixel is lower than a threshold calculated by the mean of intensity of the other pixels, the edge will be marked.

By having the exact theoretical contour of the wheel and the contour of the real one, the comparison between them must be really accurate to continue using the actual wheel of the machine.

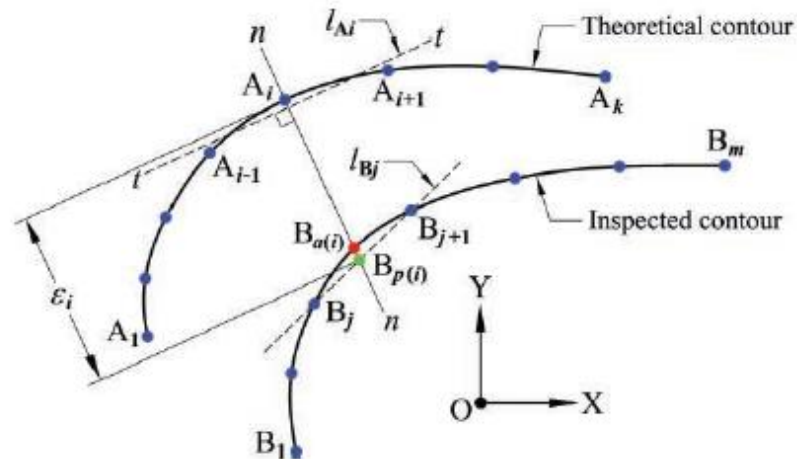
The calculations done to matching the contours of the path is done by normal deviation of both contours, the theoretical one and the inspected one.



By adding  $k$  points on the contour, the approximated tangent line is calculated between the  $A_{i-1}$  point of the contour and the  $A_{i+1}$ . The same is done for the inspected contour, naming the points as  $B$ . Then a normal line is calculated between  $A_i$  and  $B_i$ .

The Euclidean distance between points  $A$  and  $B$  is calculated and the average error is based on the normal deviation if the whole contour.

- (2) (Faires, J. D. and Burden, R. Numerical methods, 3<sup>rd</sup> edition, 2003, pp. 340–348 (Thomson Learning, Pacific Grove, California).)



**Fig. 1.3.** Normal Deviation between theoretical and inspected contours

(T-H Chen, W-T Chang, P-H Shen DOI: 10.1243/09544054JEM1749. 28 July 2009.)

In conclusion, the results are showed for two different uncertainty tests, the static and the dynamic, done by ten different samples and examining their mean, standard deviation, and uncertainty.

Table 1.1. test for verification of the error

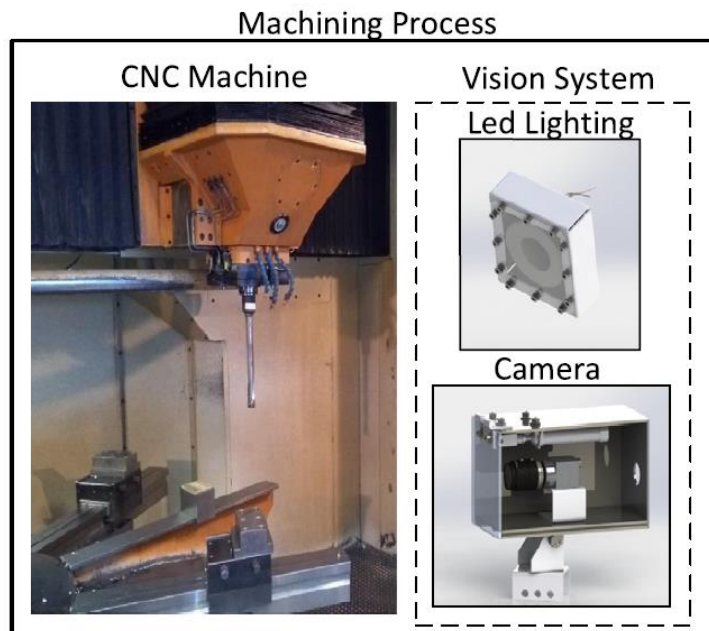
	Static (Eavg)	Dynamic (Eavg)
Test 1	0.5621	0.5650
Test 2	0.5647	0.5628
Test 3	0.5625	0.5653
Test 4	0.5633	0.5656
Test 5	0.5638	0.5670
Test 6	0.5619	0.5667
Test 7	0.5634	0.5660
Test 8	0.5643	0.5647
Test 9	0.5627	0.5659
Test 10	0.5627	0.5673
Mean	0.5631	0.5656
Standard Deviation	0.0009	0.0013
Uncertainty	0.0028	0.0039

So, the test present decent results with almost a 0.2  $\mu\text{m}$ . repeatability resulting in a good way to measure the accuracy and wear of a grinding wheel.

## 1.2. In-process machine vision monitoring of tool wear for Cyber – Physical Production Systems.

This machine vision system was developed by Federal University of ABC, Brazil.

It is another type of machine vision system developed to control the tool wear on the machining process. This is crucial, as it was for the first one, to predict the lifespan and to be able to replace the tool in time, before some accident happens.



**Fig. 1.4.** CNC Machine and Vision system.

(Romulo Gonçalves Lins,a, Paulo Ricardo Marques de Araujo, Marcio Corazzimb (2020))

This project integrates machine vision monitoring into a production system based on CPS (Cyber-Physical Systems) approach.

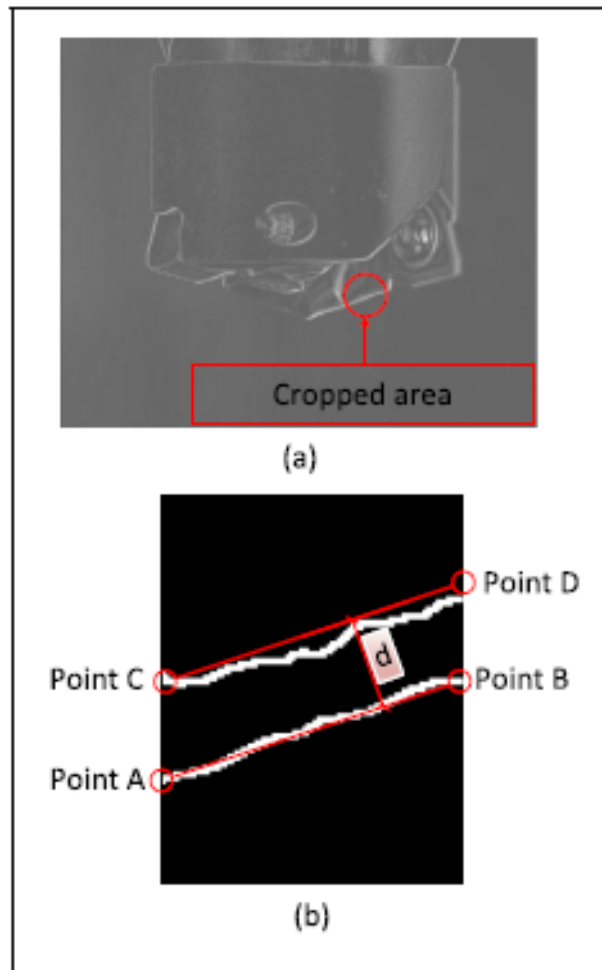
For this computer vision system, the goal is to detect mistakes during the assembling service for preventing crucial damages that may give rise to high repair costs and discontinuance of production.

This needs to be done with a low computational cost for processing, so an optimized approach for measuring is introduced.

As a CPS is used, the machine vision system must be responsible for the three first tasks shown on it; acquisition, signal processing and measurement.

- (3) P. Leitao, S. Karnouskos, L. Ribeiro, J. Lee, T. Strasser, A.W. Colombo, Smart agents in industrial cyber–physical systems, Proc. IEEE 104 (5) (2016) 1086–1101.

The next photo shows not the theoretical line should be, but because of the cropped area of the machine, the actual line looks like the one in white:



**Fig. 1.5.** Isolation of the tool wear and schematic to calculate the wear.

(Romulo Gonçalves Lins,a, Paulo Ricardo Marques de Araujoa, Marcio Corazzimb (2020))

An algorithm based on the Structural Similarity Index will carry out the images to output the best of them for posterior measurement. The last routine receives the best images, and it estimates the flank wear through a sequence of image processing instructions.

The algorithm is written in C++ using Roborealms as the software and the program will all be in a single computer, which makes its architecture more decentralized.

When the best acquired image is selected, the image processing part begins. The first task is to apply a Population threshold and a Sobel filter to detect the wear region and the edge of the wear zone. Then, a Blob detection filter is applied to detect the exact coordinates of the wear in pixels, to be able to calculate the wear of each part. If the final wear is more than a specific threshold, then the tool needs to be changed.

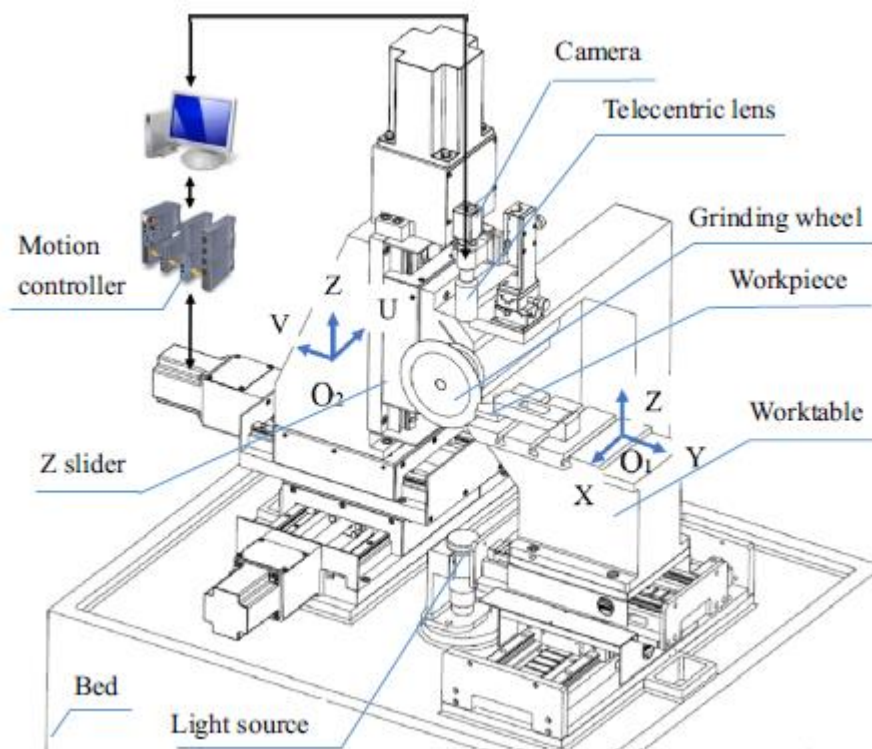
### 1.3. Vision-oriented open CNC (Computerized Numerical Control) system for profile grinding

In this study, a new vision system open CNC system used for profile grinding machines for precise machining of parts with contour surfaces. With this method an error can, be visually detected and compensated during the machining process.

An ethernet-based hardware was proposed and constructed for the CNC system. The software includes, besides the CNC system, a new type of multi-thread software architecture. The integration of an interface with image processing and virtual online error compensation.

It also has a time-consumption analysis of the measurement and control in the vision-oriented CNC system, verifying the effectiveness of the developed vision-oriented CNC system.

- (4) Jurkovic J, Korosec M, Kopac J New approach in tool wear measuring technique using CCD vision system. *Int J Mach Tool Manu* 45(9):1023–1030



**Fig. 1.6.** Profile grinding based on the vision-oriented open CNC.

(L. M. Xu & F. Fan & Z. Zhang & Y. Chen & D. J. Hu & L. Shi. 3 October 2018.)

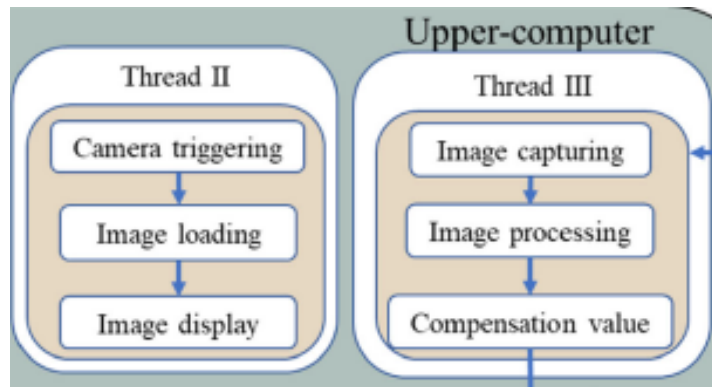
The execution module const of servo drivers and motors. The digital drivers have an Ethernet interface. The image-collecting module comprises the vision system and the image acquisition process can be internally triggered, the data after that is transmitted due to and Ethernet bus. This brings more reliably and efficient in the moment of data transmission.

In terms of the multi-thread software, it is form mainly of 4 threads:

- Thread 1 is the thread used for human-machine interface operation and it also takes the G-code, the check for the actual condition and the set of parameters.
- Thread 2 is for the live image load and image display.
- Thread 3 takes the error signal and finish the image capturing part.
- The last thread, thread 4, guides all the communication part of the process.

(5) Liu J, Fu Y, Han Z, Fu H (2015) Design of an industrial Ethernet based embedded open architecture CNC system. International Conference on Estimation, Detection and Information Fusion IEEE: 413–417

For the camera vision system, the real important ones are the second and third threads, because they carry all the camera and image work that needs to be done for the image treatment:



**Fig. 1.7.** Threads 1 and 2 main functions.

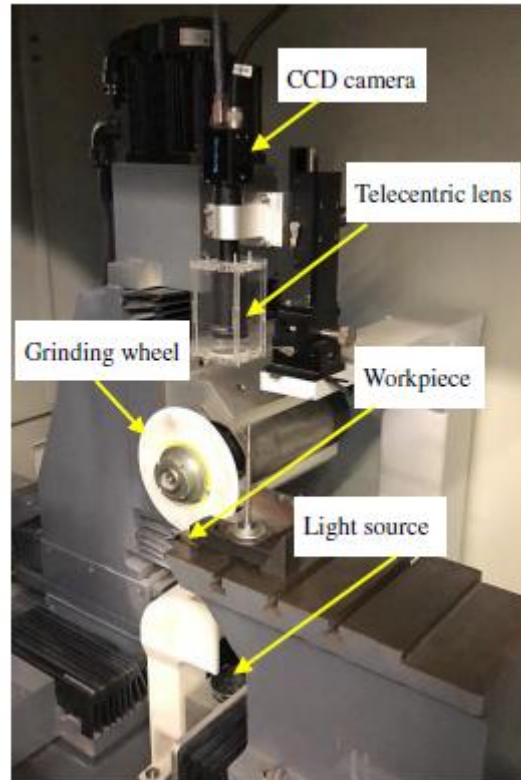
(L. M. Xu & F. Fan & Z. Zhang & Y. Chen & D. J. Hu & L. Shi. 3 October 2018.)

The image processing algorithm gets the contours of the object and compares it to the theoretical expected one. If needed, the new compensation for the direction and the dimension of it is calculated.

The lower computer is the one that must deal with the memory problems related with space, the memory is limited by two main factors, the computing capacity and the data storage. These two main factors are the cause of the increase on the time consumption that is tried to be solved with the multi-thread structure.

There is a need to calibrate the system before it starts working, to do that, it is used a calibration template with the resolution 1 micrometer resulting on a conversion factor of  $T_c = 6.982$  micrometer per pixel.

(6) NI vision concepts manual, 2005, pp. 48 and 216 (National Instrument Corp., Austin, Texas)



**Fig. 1.8.** CNC structure with vision system applied

(L. M. Xu & F. Fan & Z. Zhang & Y. Chen & D. J. Hu & L. Shi. 3 October 2018.)

If we talk about the time-consumption part, there are a couple of factors included on the investigation such as time for working with the image, capturing it, processing and error calculations and compensation for the control.

One thing to highlight, once the time-consumption part is measured is the time taken for the image capturing and processing part, that takes more than a 90% of the total time of the process.

The contour image is taken with the vision camera. There are two parts considering, the first measures taken with compensation and without it. This will mark the error as the distance in between points of the two different measures.

Taking all this factors into account, the next table is erected:

Table 1.2. Time consumed during vision system action.

Measure	Time consumed (ms)	%
Image capture	101.013	74,7
Image processing	22.284	16.5
Time for error measure	11.617	8.6
Compensation	0.25	0.2
Total time consumed	135.164	100

- (7) Chen TH, Chang WT, Shen PH, Tarn YS (2010) Examining the profile accuracy of grinding wheels used for microdrill fluting by an image-based contour matching method. Proc Inst Mech Eng B J Eng Manuf 224(6):899–911

In conclusion, the results seem to be efficient enough to be worth to do, because the time-consumption is such a low value in comparison to the effective result you get at the end.

#### **1.4. Design of an algorithm for automatic correction of position in the PCB(printed circuit boards)-drilled process using computer vision techniques.**

This artificial vision system has been developed by Jeison A.Cardenas and Flavio Augusto Prieto-Ortiz.

The main goal is to create and algorithm capable to control the position of the perforation process in a low-cost CNC machine. This perforation is thought to be done for PCB boards, so the precision needs to be constantly corrected.

The algorithm brings a realimentation of the process to be able to make a careful look at the detection and error correction in the tool position before and during the action.

The results show that the accuracy is  $0.4853 \pm 0.202$  mm, making the result valid to applicate and fulfil the industry needs.

The hardware consists of three different parts:

- i) The software installed on the control station that contains the algorithm.
- ii) Serial-parallel communication interface that allows the connection between the main software and the control box, from where the motors of the machines receive the necessary instructions to operate.

iii) The control box belonging to the machine which connects directly to the motors, through the respective controller cards.

The CNC machines usually use the communication ports of the computer they are attached to, but there are a couple of new ports that can be used, such as USB or serial port.

This specific machine uses a simplified version of a parallel port, but it can be substituted for an USB port. To be able to pass through this problem it is needed a specific chip to interpret the message and complete the communication.

For the algorithm part, we must divide text into 3 different parts:

#### 1.4.1. Calibration Process.

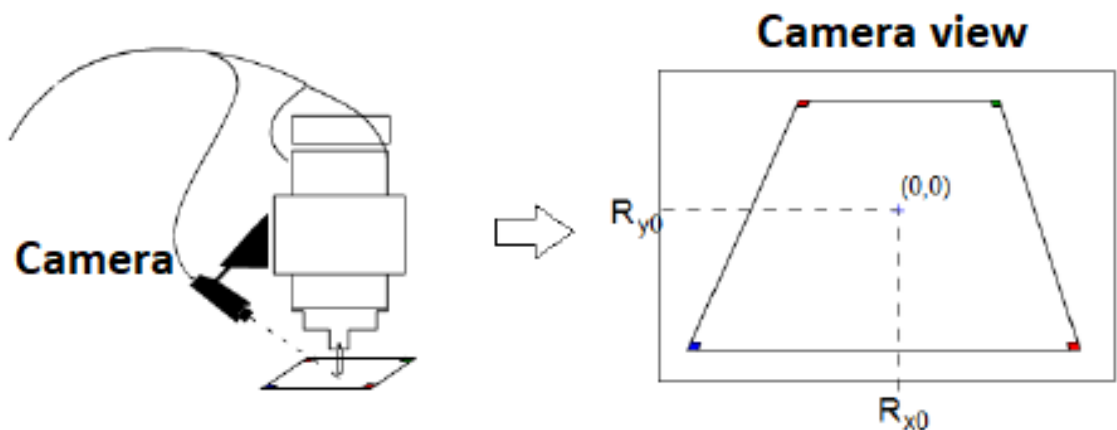
To do a correct calculation of the calibration we have to do some certain steps.

(8) Bayram et al., 2007

First, we have to define the zero coordinate of the working area and definite the 4 perspective markers, applying the perspective correction based on them. It is needed to determine the relation between the pixel number and the real displacement in millimetres in the XY plane.

Finally, before making a return of the tool to the zero coordinate, we have to make a read of the displacement through the 4 anchor points skew correction.

The first measure needs to take in account the perspective distortion as is shown in the next image:



**Fig. 1.9.** Vision distortion and perspective.

(Cárdenas, J., & Prieto-Ortiz, F. A. (2015). Diseño de un algoritmo de corrección automática de posición para el proceso de perforado PCB, empleando técnicas de visión artificial.

Rev.investig.desarro.innov, 5(2), 107-118.)

To surpass this obstacle, there is a need to correct the perspective with a specific matrix and applying calculations relating the origin(dst) and destiny(src) of the image.

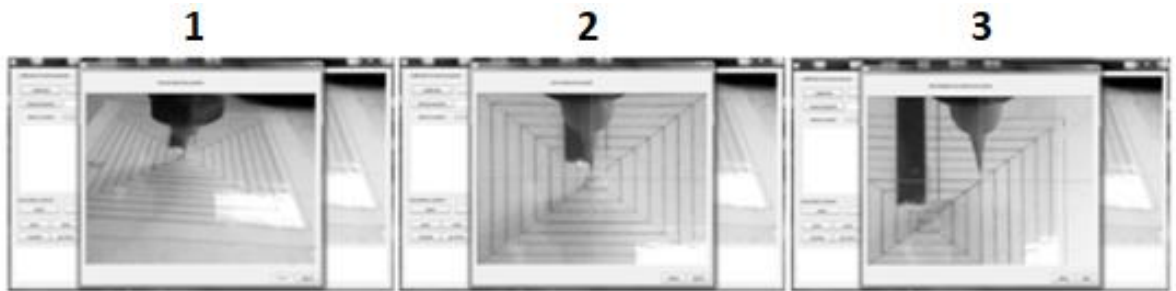


The equation that does this process is the following one:

$$dst(x, y) = src\left(\frac{M_{11}x + M_{12}y + M_{13}}{M_{31}x + M_{32}y + M_{33}}, \frac{M_{21}x + M_{22}y + M_{23}}{M_{31}x + M_{32}y + M_{33}}\right) \quad (1.2)$$

Where  $dst$  is the distance,  $M_{ab}$  is related to the position in the matrix of the perspective and  $x, y$  is the location of the point.

When taking the right adjustments, we can see the machine working in a real process. In the next image, a calibration process is being taking part:



**Fig. 1.10.** 1) Perspective points. 2) Zero coordinate. 3) Pixel/millimeter relation.

(Cárdenas, J., & Prieto-Ortiz, F. A. (2015). Diseño de un algoritmo de corrección automática de posición para el proceso de perforado PCB, empleando técnicas de visión artificial.

Rev.investig.desarro.innov, 5(2), 107-118.)

#### 1.4.2. Detection of the perforated area.

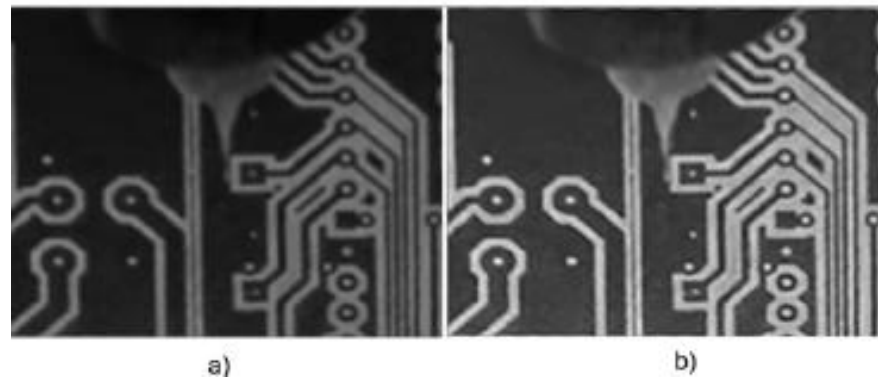
This part is done by a simple process of visual recognition, that is based in treatment, one segmentation and location awareness of the drilling area, based on contours.

(9) Zuwairie et al., 2013; De luca Penaccia & de la Fraga, 2009.

The pre-treatment of the captured image is performed through an image filter, whose responsibility consists of applying four adjustments namely: a brightness adjustment, an increase scene contrast, noise reduction and finally an improvement in the definition of the edges of the elements present in the scene.

One of the biggest conditions to the best performance of this part is the to apply a proper illumination to avoid reflexion and shadow forms that may affect the recognition of the contour. To mitigate the impact of inadequate lighting, backlighting was applied high intensity white lightning.

Also, to make the system even better, there is a variation applied in the brightness, luminance, and saturation. With all these applied, the result is as follows:



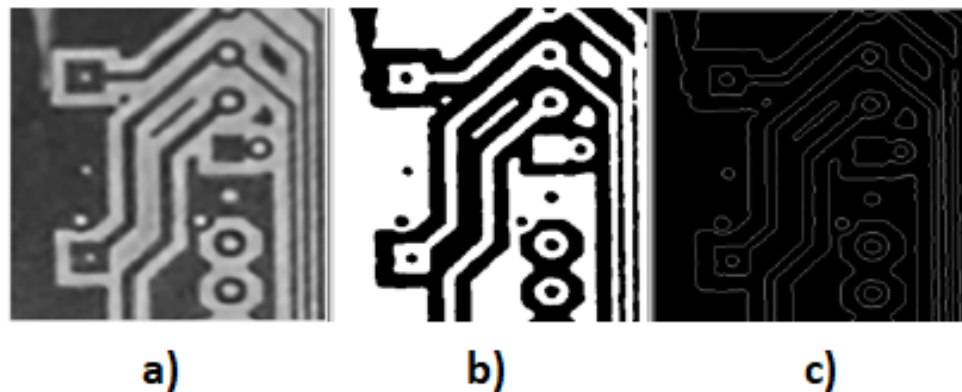
**Fig. 1.11.** a) original image. b) Image with different filters.

(Cárdenas, J., & Prieto-Ortiz, F. A. (2015). Diseño de un algoritmo de corrección automática de posición para el proceso de perforado PCB, empleando técnicas de visión artificial.

Rev.investig.desarro.innov, 5(2), 107-118.)

Once the image is processed, we can apply the canny filter from OpenCV library to extract the contours. It is a derivative process that iterates every pixel of the image.

Subsequently, obtaining the contours is completed by creating a data structure in form of a linked list, which contains the information associated with the contours found with Canny detector. The result of Canny is showed on the next image:



**Fig. 1.12.** a) original image. b) Image with external contours. c) image with internal contours.

(Cárdenas, J., & Prieto-Ortiz, F. A. (2015). Diseño de un algoritmo de corrección automática de posición para el proceso de perforado PCB, empleando técnicas de visión artificial.

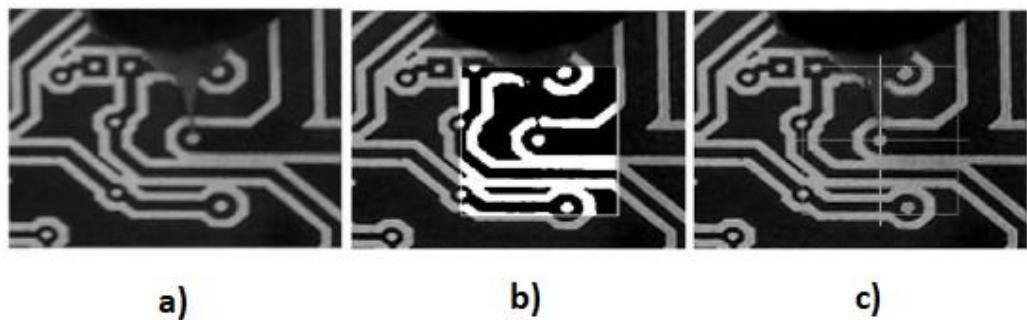
Rev.investig.desarro.innov, 5(2), 107-118.)

The canny filter is used to get the contours more clearly, but also to be able to apply new different filters to the image.

### 1.4.3. Position autocorrection.

The position self-correction phase consists in applying the corrections found during the detection phase; this application can be in real time, while the program is running. work, or through a simulation of the displacement, where the corrections are kept in memory and apply to the work program once simulation is finished.

The automatic correction is done by applying a reverse process like that described in calibration section, where a method is shown to determine the position, in real measurements, of an element seen from the measured camera in pixels, which can be directly sent to the machine to physically position the tool drilling as determined by the detection program. In the next image you can observe the application of the automatic correction of the position of the drilling tool after piercing point detection more appropriate.



**Fig.1.13.** location of the correct perforation point. a) approximate to the point. b) set the working zone. c) locate the exact point.

(Cárdenas, J., & Prieto-Ortiz, F. A. (2015). Diseño de un algoritmo de corrección automática de posición para el proceso de perforado PCB, empleando técnicas de visión artificial.

Rev.investig.desarro.innov, 5(2), 107-118.)

As you can see, there is a cross-piece in the c) image that refers to the exact point the work needs to be done.

## **1.5. Automatic inspection system for PCBs by means of artificial vision.**

This work has been developed by Wilson Rene Ayo Masabanda and Hilda Marizol Moreno Andrade. The work is based on an Artificial Vision system that facilitates, simplifies and avoids fatigue problems related with PCB inspection.

Hardware is implemented as an optic sensor, and the digital processing image is done through a computer. Inside a metal cage there is a light system that increases the light around the PCB. The PCB goes inside the structure with help of a couple of motors controlled by Arduino.

(10) Viera-Maza, G. (marzo de 2017).

Software is implemented in programming language such as Python, with OpenCV and PyQt5. This is needed to detect the defects comparing the developed PCB board and the digital image of the PCB. These errors can be visualized through a graphic interface.

In the next section we will talk a bit about the image treatment of this device and about the automatic detection of the errors.

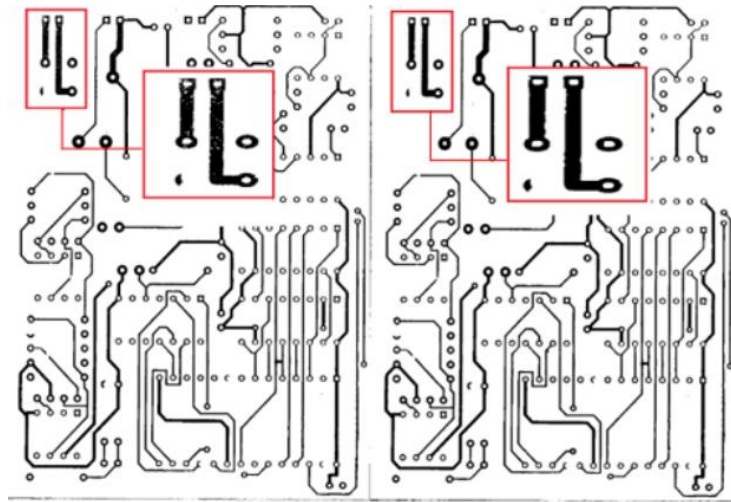
**Image filtering:** The noise can affect significantly to the information of the image characteristics. The filters to make the image more usable are implemented in the pixels to make them better. The filter may want to highlight a specific part of the image or achieve a special effect inside an image.

The main filter actions are the following ones:

- **Smoothing of the image:** it consists in reducing the intensity variations between neighbouring pixels.
- **Edge Enhancement:** This is to accentuate the edges in an image.
- **Noise removal:** consists of removing pixels whose intensity level is very different from its neighbours, typically the noise is generated in the image acquisition or transmission process.

An example is shown on the following image, the transformation may be not so notorious, but it can be crucial in terms of failure detection.

The pixels are corrected, avoiding any problem once the next operations with the XOR gate are done.



**Fig. 1.14.** filtering of the noisy pixels.

(Wilson Rene Ayo Masabanda. Hilda Marizol Moreno Andrade. March 2021.)

There is another type of filtering methods, such as filtering in the frequency domain with low pass filters, high pass filters or filtering in the space domain with the Laplacian technique.

For this study we are searching for different errors that appears in during the fabrication of the copper lines in the PCB, such as open circuit, copper losses, short circuits, spurious and pad damaging.

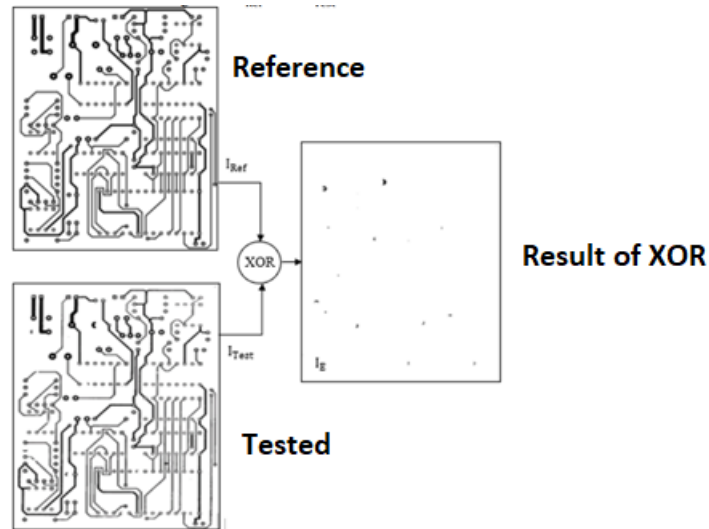
(11) Ashish Singh, M. G. (noviembre de 2014).

The automatic inspection must detect these defects to be able to discard the unusable boards. This will save money and time and making sure the user of the PCB board gets the work it is required.

Once we have the PCB board and the image of it, we proceed with the software work, which implies a conversion into grey scale, binarization of the image and noise attenuation. After that, a resize of the image is needed and the comparison takes place.

The comparison is done by applying a XOR between the desired image, taken from the PCB design program and the actual image that it has being taken, of the real PCB board.

By applying this XOR we get the points that are missing on the real PCB board, and we can rate if the accuracy of it is a problem, or we can dismiss the errors. On the next image, we can appreciate the errors and the process made:



**Fig. 1.15.** Error localization on PCB board.

(Wilson Rene Ayo Masabanda. Hilda Marizol Moreno Andrade. March 2021.)

The system also makes a recognition about the different errors that appears after the XOR application. The main ones are drill lose, pad damage, copper excess (copper in not desired areas), open circuit and short circuit.

## 1.6. Substantiation of the decision

After analysing the market designs and the huge number of different solutions for the same type of vision approaching, I have finally decided to fulfil my model as follows. Dividing the explanation on two parts, hardware and software, the best solution to my problem is defined.

### 1.6.1. Hardware part of the project

The main part of the project is the one related with the vision system, so in order to achieve the best results possible we search on the market for the best camera that fulfils our needs. The cameras shown on the previous compared models are more related with a bigger industrial field of manufacture. Also, most of the solutions need to have different light system or specific cages to make sure the contour problem is not the cause of the errors.

So, we need to search for a small solution, that enters in the required space. Also we need to include a light system within that space, and it may have to be small or to be installed in a different part of the CNC (with the consequent loss of light).

We may need to check for a protective frame that covers the camera, such as the ones mentioned before, but with the same problem in the table, the space required.

To be able to hold that camera into the CNC machine, it is mandatory to build a specific structure for this camera. This product needs to be strong enough, but the CNC cutting motor is not that strong so, ruling out the need for metal, we can work with a 3D printer and PLA.

#### 1.6.2. Software part of the project

It is no realistic to have a computer on every CNC machine in a industrial factory, but this distribution is perfect for small CNC stores or workers.

So the main goal is to work with the same computer that has the CNC machine software. To do this, in the case of our CNC machine, we need to work with LinuxCNC program, with works with a difficult G-code programming. The other solutions explored involve programming in a different software. The best one located is one that is used in both cases of PCB treatment, OpenCV and in our case Python as the programming language.

This gives us versatility for choosing different options for both sectors, hardware, and software.

The most suitable option to calculate the calibration part is one that appears at 1.1, to calculate the measure in pixels, and make a conversion factor, knowing the exact dimension of the object in mm.

The market of the different vision systems is quite large, so to be able to innovate, the system must wear or do some new component or way to approach the problem. With this, the product will be easier to sell while the market remains almost the same.

## 2. OVERVIEW OF SPECIFIC NODES

### 2.1. Final solution for vision system

After analysing the market designs and the huge number of different solutions for the same type of vision approaching, I have finally decided to fulfil my model as follows. Dividing the explanation on two parts, hardware and software, the best solution to my problem is defined.

#### 2.1.1. Hardware part of the project

The main part of the project is the one related with the vision system, so to achieve the best results possible we search on the market for the best camera that fulfils our needs. The cameras shown on the previous compared models are more related with a bigger industrial field of manufacture. Also, most of the solutions need to have different light system or specific cages to make sure the contour problem is not the cause of the errors.

Taking all these in account, the possible market reduces on two different cameras brought by the university:



**Fig. 2.1.** Camera solution: a) microscopic camera. b) Raspberry camera.

<https://www.amazon.com/-/es/1600X-Microscopio-Digital-C%C3%A1mara-Endoscopio/dp/B07KYP3R4P>

<https://www.amazon.com/Raspberry-Pi-Camera-Module-Megapixel/dp/B01ER2SKFS>

The figure 2.1. a) show a digital microscope 1600X 8 LED 2MP USB. This model possesses an augment valid for 1600X and possess 8 LED's that covers the vision and illumination part. Depending on the distance from the camera to the specific object to be measured we will need to amplify this illumination part to be sure there is no problem on the image catching part. The LED's bring white intense light and the camera is enough to even catch the porosity of the different wood tables.

The figure 2.1. b) show a Raspberry Pi camera module V2. This camera also fulfils the needs, even though the resolution is quite less, the camera supports 1080p30 or 720p60, that should be



more than enough to complete the project. The main problems come with the lightning part and the connection to the computer.

The USB camera brings its own light system, so it should only be needed a support light if necessary. This camera, for my own experience, and to be able to read the contours for the image properly enough, needs not only good illumination system but a box to make the place darker.

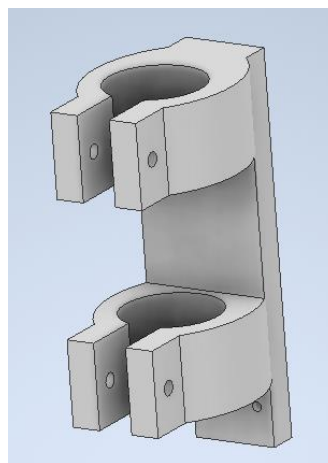
This comes with a problem of the space to allocate such illumination system.

The second problem to be resolved is that to use that camera, a Raspberry Pi is needed, this will make another problem in terms of interchanging the information from the camera to the computer. The raspberry needs to get the information from the camera, that it will be processed and passed to the main computer, the one that has the CNC software. To avoid making intermediary problems, we work with a USB directly that is connected to the main computer, that will solve the algorithm and code problems.

Also, with the USB connection we assure a better and reliable connection than the model that communicates via Ethernet, which is the best option in an industrial environment, but not for just one CNC machine.

To be able to hold that camera into the CNC machine, it is mandatory to build a specific structure for this camera. The holder will be made from 3D printer and made of PPS (a chemical and corrosion resistant plastic material) which is used for high temperatures and corrosive exposure.

Then the camera holder will be attached to a metal plate where the CNC motor is also screwed. The camera holder is designed on Autodesk Inventor Professional, whereas the different tests applied on the holder are done on SOLIDWORKS. The result of the holder is the following:



**Fig. 2.2.** Camera holder.

The holder is simple but effective enough, it is made thinking on saving money on PLA plastic without losing any properties for the holder apart.

### 2.1.2. Software part of the project

For the software part of the project, the selected programming language is Python with OpenCV. It is going to be implemented with Spyder as an IDE. The USB connection gives the freedom to be able to use the program in the same computer that has the CNC machine software, so the communication is a little bit faster than the models showed previously.

It is no realistic to have a computer on every CNC machine in an industrial factory, but this distribution is perfect for small CNC stores or workers.

Entering on the specific part of the code and the main goal, we are going to distribute this explanation such as the model showed on the device number 1 of the fourth compared option:

- Calibration process: The calibration was planned with two alternatives, both treated on the compared projects. The first one, and the discarded one, is the one that calculates the conversion factor taking in count the squared manufacturer area. The process is the same in the first and the second case, but for our camera settings, it will mean a recalculation and recalibration of the camera every time the project and the CNC machine is turned on.

Also, the microscope is not able to measure such distances as a paper or a workbench. So, for the project, we will be using a small object or image to measure its distance in pixels. Knowing its distance in millimetres, we can apply a conversion factor for every distance measured:

$$T_c = \frac{D_s}{D_d} = \frac{mm}{pixel} \quad (3)$$

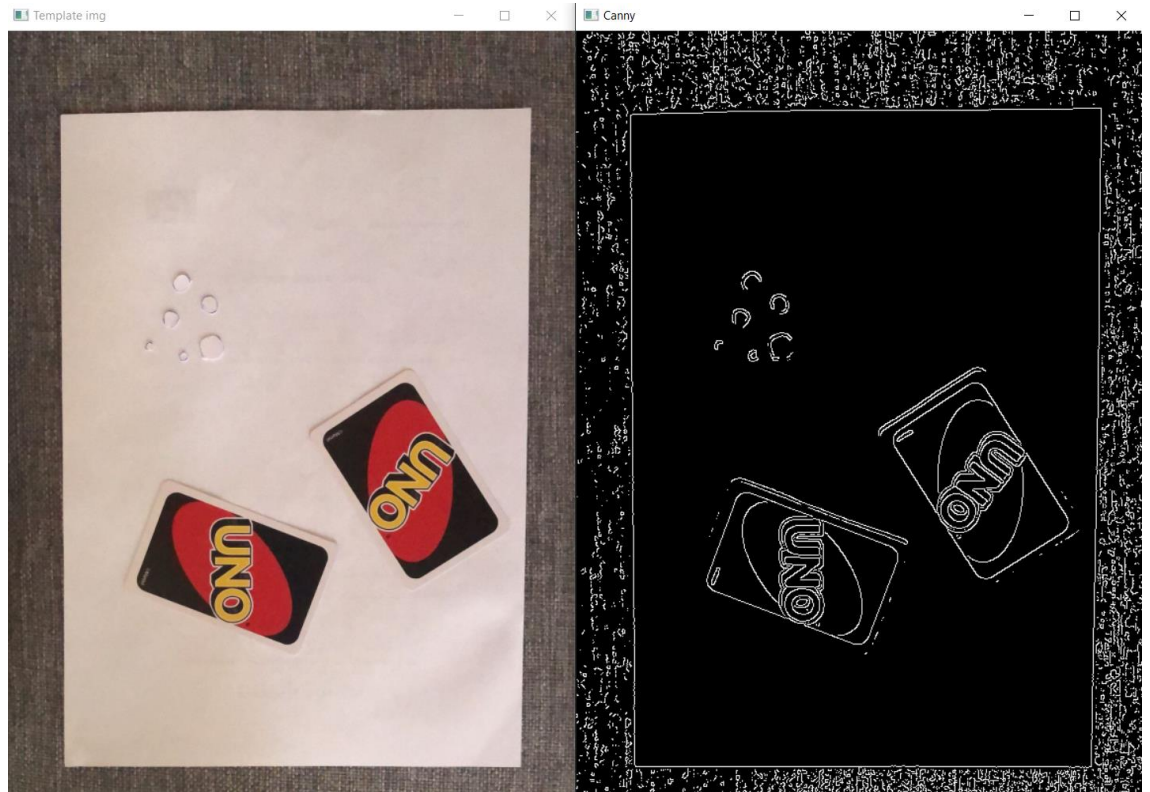
$D_s$  the diameter in mm,  $D_d$  the diameter in pixels and  $T_c$  the conversion factor.

- Image processing: we will be measuring holes in such different materials. The worst-case scenario for the camera is porous materials such as wood or ocumen. The camera catches all the imperfections on the material, so we must make a good filter application on our code to be able to take the desired hole.

To get the best working image we apply the following techniques:

Brightness adjustment, an increase scene contrast, noise reduction and finally an improvement in the definition of the edges of the elements present in the scene.

After improving the image, we apply the canny filter on the OpenCV library, with a scale of grey colours. To show how the filters work we apply the changes to a specific image taken with the mobile phone camera:



**Fig. 2.3.** Template image and image with canny filter.

This is an example of some of the filters applied. To be more specific with the project, the zone that is going to be detected are mainly holes, so to reduce the level of noise in the environment, we choose to use a mask filter, which gives us an action zone of 215 pixels. To give some approximation, the conversion factor is calculated considering 21,25 mm as the diameter in millimeters, which is exactly the diameter of a 5-cent coin.

The result of executing this part is showed in the next image:



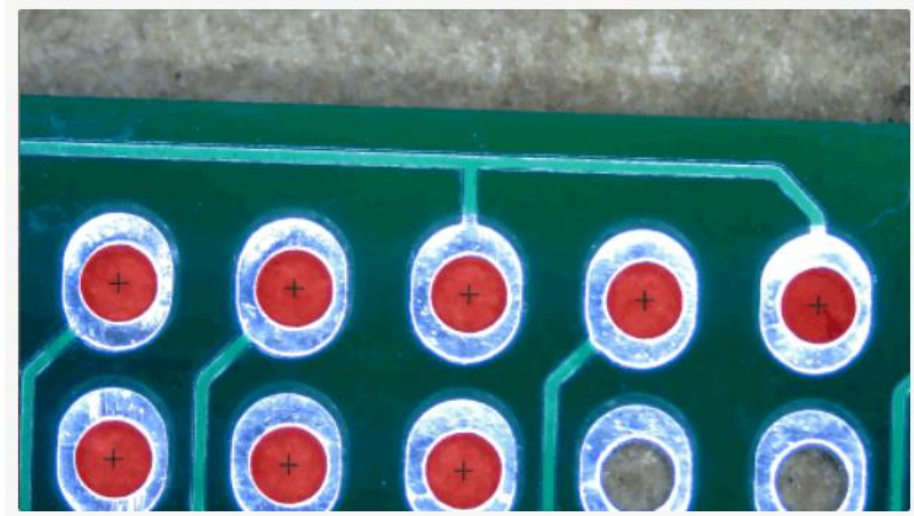
**Fig. 2.4.** 5-cent paper coin and edge detection

As you can see, the image represents a 5-cent coin and a border in its limits. This border is not closed in all the part but is more than enough to make the measures we want to make.

To do the measures, we make a square to circumscribe the circle into it. Then the side of the square is taken as the diameter of the circle. We divide the diameter by 2, to work with the radius, which is more accurate for the calculations and the approximations for the tool size and the error committed.

- Hole detecting and correction of the errors: Once we get and treat the image, the final goal is to compare the holes made by the CNC machine with the theoretical ones. The study is directly on the manufactured part not on the machinery or the tool of the CNC machine. This is an advancement in comparison to the previous vision system models. The reason is because this system can locate if something is wrong, then you can search for the reason of the failure. If the holes are done bad is because something wrong is working. The other systems only locate the tool, so if the reason of the failure is the vibration of the machine, you do not detect the failure until the tool is worn out.

- To be able to allocate the holes, our vision system develops code that makes it easy to find the different circle holes, the next image shows an idea of how it could be done:



**Fig. 2.5.** Searching for holes in a PCB board.

<https://www.kurokesu.com/main/2016/07/25/advanced-opencv-3-python-hole-detection/>

- The calculations are made as said in previous chapters, but once the calculations are made, the size in mm of the radius is shown in the program, letting the user see if there are some problems with the measurement:

```
163.29 280.87
140.435
10.65154638255345
Conversion factor is: 0.07584680729557054
```

**Fig. 2.6.** Results of the hole management.

The first two values are the square sides, it may seem like a big difference between the two sides, but the measure is in pixels which is not that far in terms of mm.

The third value is the radius measure in pixels, the fourth one is the measure in mm after the conversion factor is applied and the last one is the value of the conversion factor.

- How the squares and the calculations are made are more visual in the next figure. The square around a rectangle is easier to be defined, and the measure should be more accurate:



**Fig. 2.7.** Measuring distances with a camera vision system.

[https://www.youtube.com/watch?v=tk9war7\\_y0Q&ab\\_channel=Murtaza%27sWorkshop-RoboticsandAI](https://www.youtube.com/watch?v=tk9war7_y0Q&ab_channel=Murtaza%27sWorkshop-RoboticsandAI)

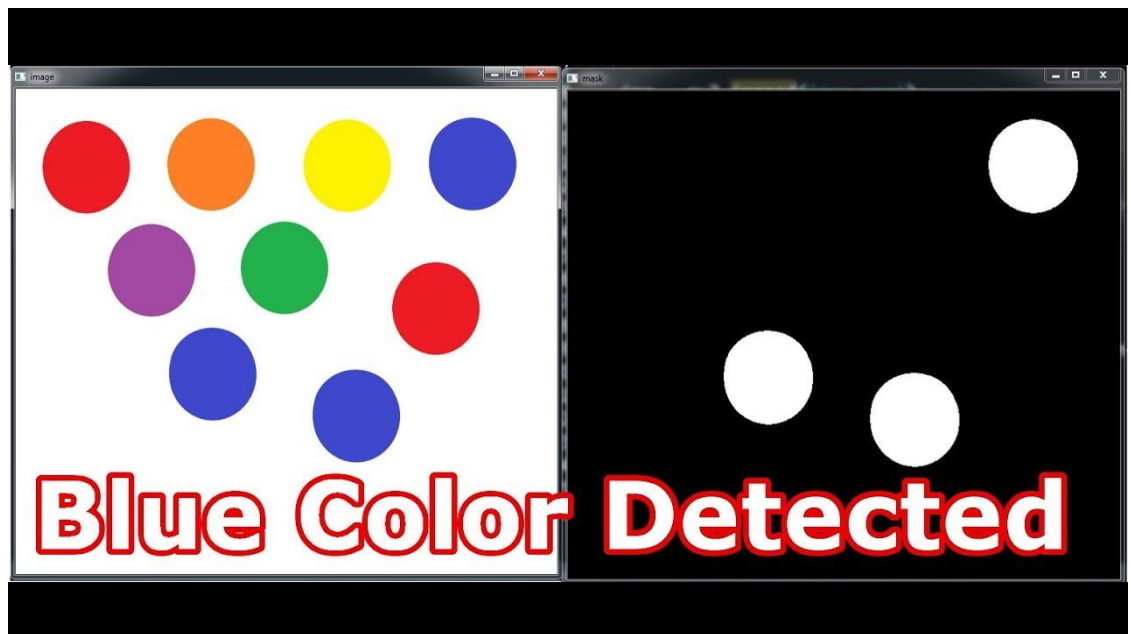
The measures here differ some cm, so we may have to be more accurate. The system we are treating must work with differences in millimeters, so we must make a more exhaustive analysis of the photos and the apply more filters and blurs to make the image more accurate on the exact object.

To make a more exhaustive filtering part, we fix the area searched for the holes as a high area at first, to allocate the dimension of the object for the calibration, and we reduce that area to search for the smaller holes made in the manufacturing process.

The second action is to apply a more exhaustive filter for the image, changing it from gaussianBlur, to medianBlur, which is almost the same technique, but instead of work with the gaussian calculations for the pixels, it works with the median.

One other solution can be to treat only with dark images, as it is going to be a hole, the quantity of light in it will be less than in the surface. After locating the hole, we can make a blur of the image, this will lead to a better object detection. These filters can be done before the different canny and black and white filters.

The next image show how the color detection is done, the desire holes may be enough dark to look for them as RGB (red,green,blue) = (0,0,0)



**Fig. 2.8.** Detect forms in images due to its color.

Our design almost covers all the needs while being able to have a different approach. The small size and the cheap price will for sure fulfil the markets requirements. Also, the way to solute the problems of the hole measuring give more wide sight about a possible error on the CNC machine, without discarding any kind of possible issue.



### 3. CALCULATION OF PROJECT

#### 3.1. Frequency Study

To know the capability of the designed structure, a frequency test is done.

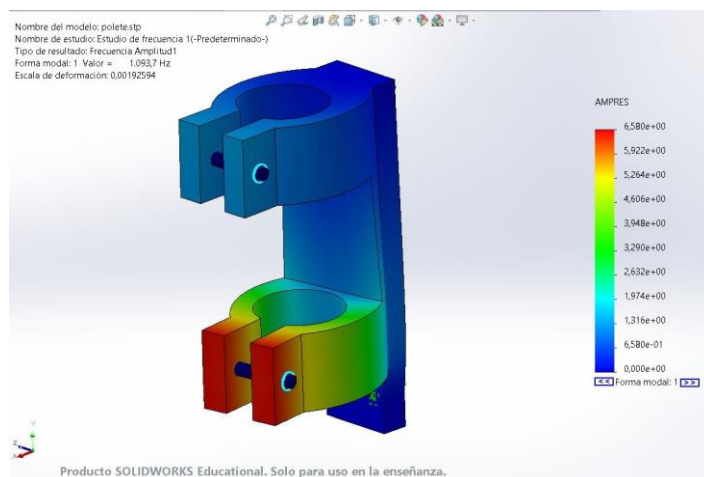
A solid whose rest position has been changed tends to vibrate at resonant frequencies. For each resonant frequency, the solid takes on a shape called the mode shape. Frequency analysis calculates the resonant frequencies and the mode shapes.

A solid is assumed to have infinite mode shapes. In FEA, there are as many modalities as (GDL).

Resonance describes the phenomenon of increasing amplitude that occurs when the frequency of a periodic force is equal to or close to a resonant frequency of the system.

When an oscillatory force is applied at a resonant frequency of a dynamic system, the system oscillates at a higher amplitude than when the same force is applied at another non-resonant frequency. Frequency analysis helps you avoid resonance by calculating resonant frequencies.

I developed a frequency test through SolidWorks, with the results being as follows:



**Fig. 3.1.** Frequency analysis for the structure.

The supports applied are 4 permanent attachments on the screws placed on the metal plate of the CNC machine, and two screws that makes subjection of the camera more reliable.

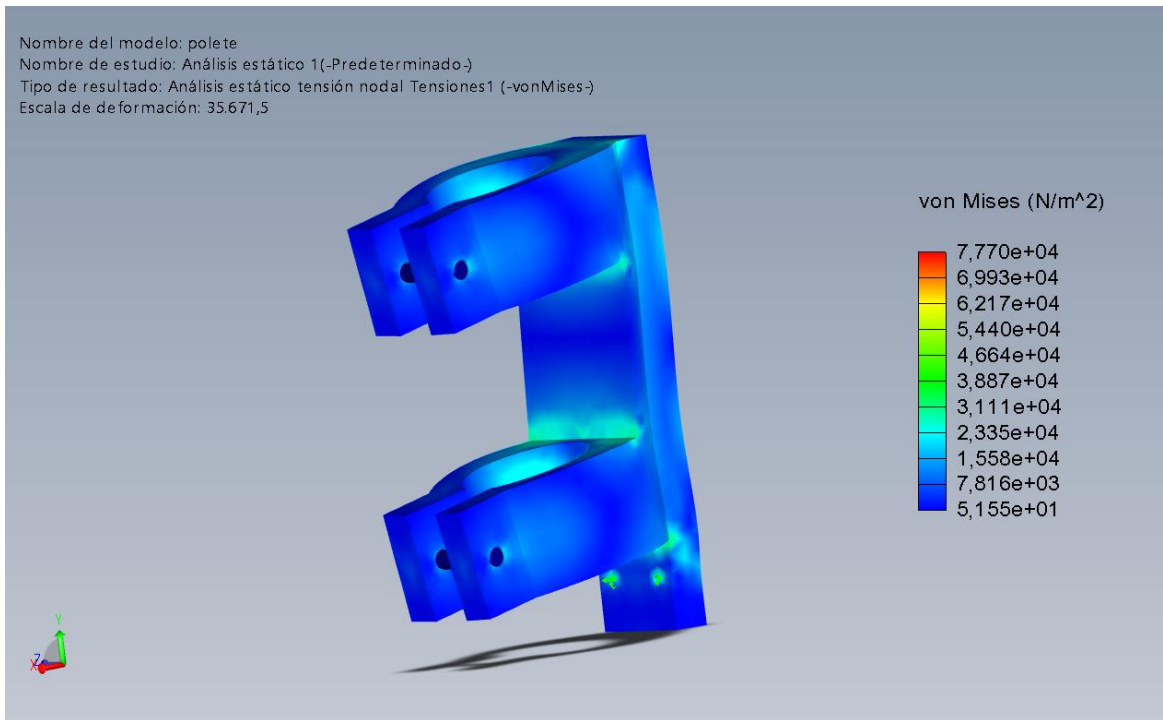
Executing the test result in an expected alteration on the second hole for the camera. This is mainly because the union between that part and the rest of the structure is not as hard as the first one. Even though this happens, the frequency level is high enough to endure any problem of happening on work time. Having more than 100 Hz on the test is a good result, and it happens to have more than a thousand Hz. The deformation scale is also low, resulting on a good 0,00192594 mm.



### 3.2. Force Study

To know the capability of the designed structure, a VonMises study is developed.

This study refers to the maximum distortion criterion and states that a ductile material begins to yield once the second invariant of the stress of deviation reaches a critical value. It is applied the most to ductile materials, but it is also key to search for the response in plastic material.

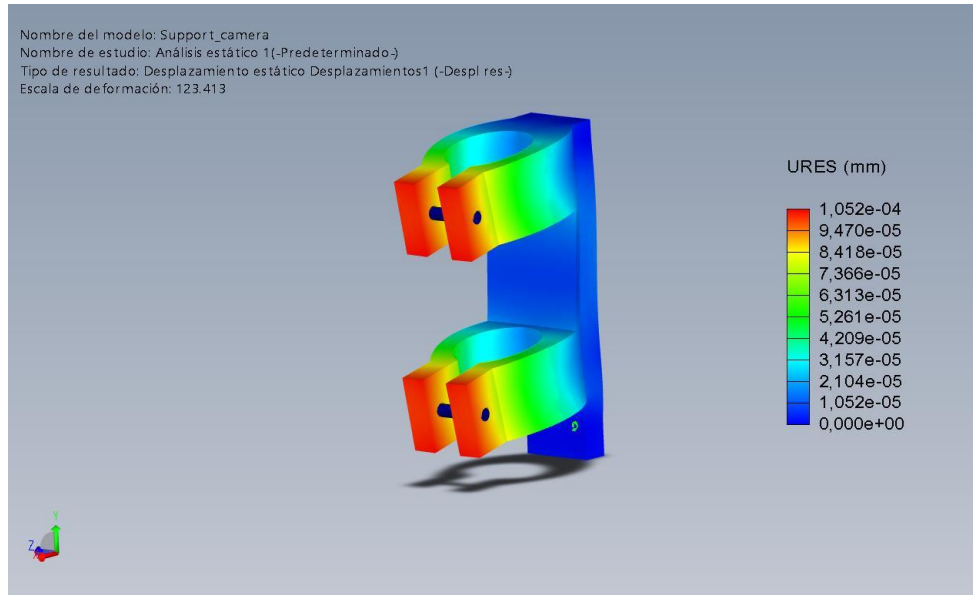


**Fig. 3.2.** Force study for the structure.

As it is shown, the actual performance is quite well developed. The VonMises show a deformation scale of 35.671,5 N/m<sup>2</sup>, which is, with difference, way more than it is expected to endure.

### 3.3. Displacement study

The displacement study is made to simulate the possible movements that the structure may experience during the holding action. To try to simulate the action presented, we develop this study in SolidWorks:



**Fig. 3.3.** Displacement study for the structure.

As expected, the displacement is more likely to happen on the parts situated more at the end of the structure, whether the actual situation of the part of the holder fixed to the CNC is unlikely to move.

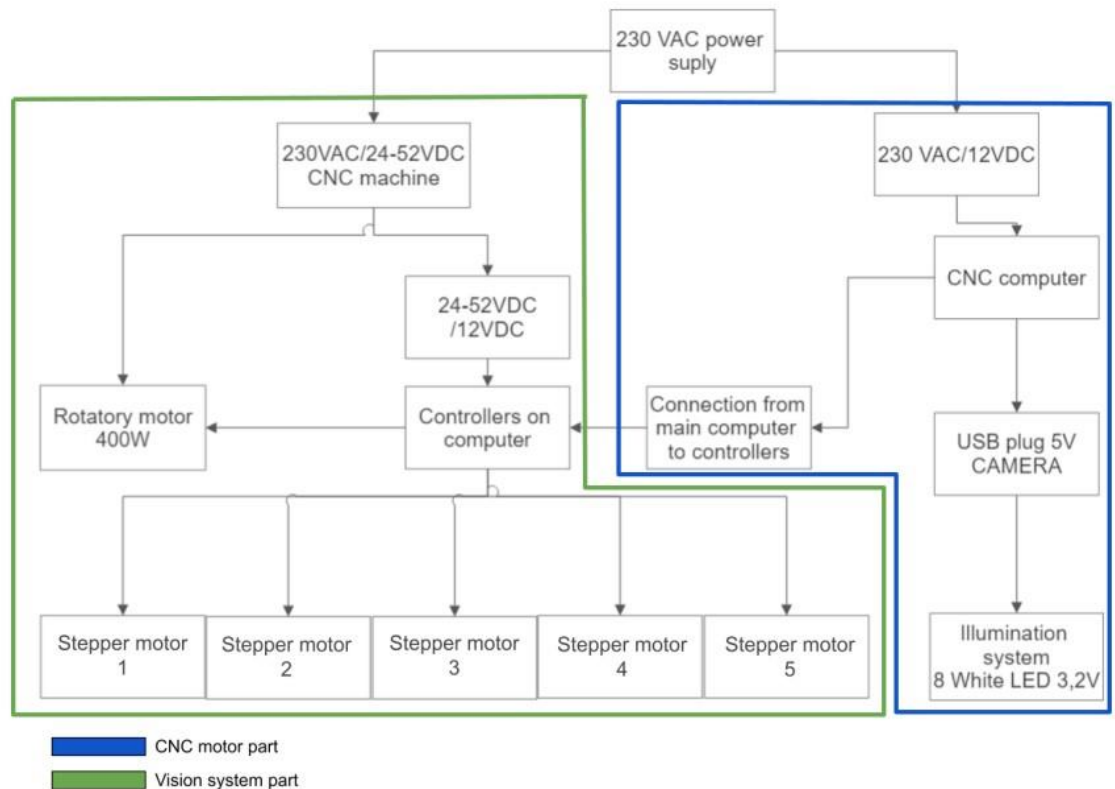
The critical part of the structure has only about  $1.052 \times 10^{-4}$  mm of displacement, it is a low value to be considered as a problem, knowing the actual work our holder will be developing.

All the different studies made are remarking the good condition of the holder. The holder fulfils the needs of the camera, and it is reliable enough to work correctly.

## 4. DESCRIPTION OF THE CONSTRUCTION AND OPERATIONAL PRINCIPLE

### 4.1. Electric-block scheme

The following electrical scheme show how the different connections are applied, and the different voltage changes that happens during the electricity flow through the machinery:



**Fig. 4.1.** Electrical scheme.

As it can be seen in Fig 4.1. we first have the connection to the national electrical net, then the system is distributed in two different sectors:

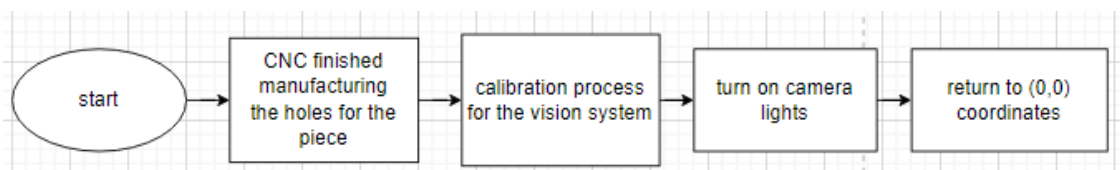
- CNC machine: This sector is mainly made up of the different voltage converters and the motors that conform the movement of the system. There is a first motor that correspond to the rotatory motor used for the cutting part of the CNC machine. This motor is supplied with 24-52 V and gives 400W of rotatory power.  
The other motors are for the machine movement. This PAP motors need 12 V to function and are simple PAP motors.
- Vision system: the second sector consist of another converter, in this case, one to get 12 V and to make the computer work. With this supply, we can connect the camera for the vision system, via USB of 5V. The camera has white, bright LEDs of 3,2 V.

The last block to be commented is the one that reaches both sectors. It is the connection port for transferring the data from the computer to the machine.

## 4.2. Algorithm of management of device or node

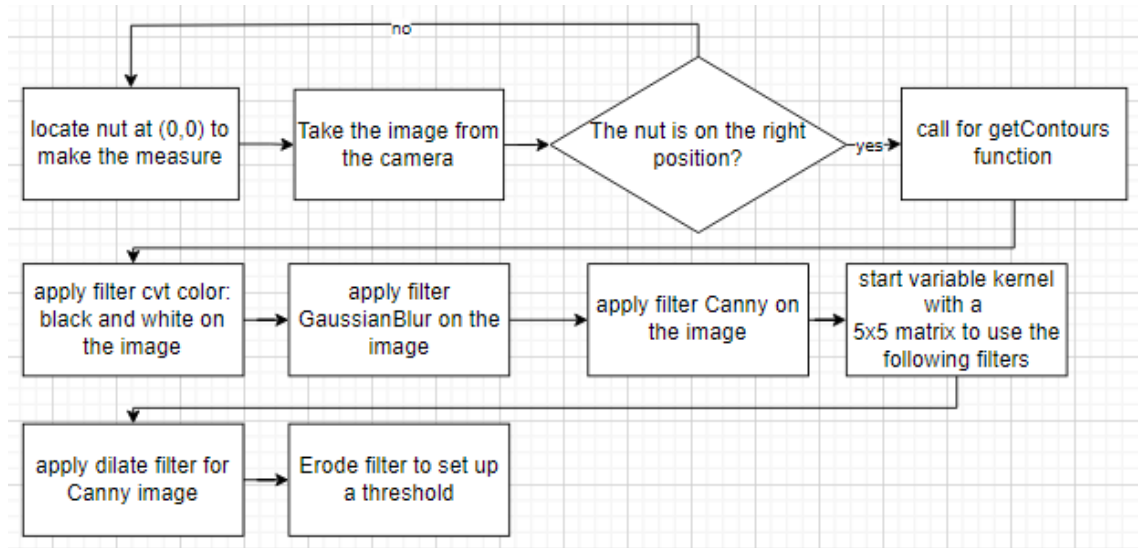
The flow chart of the algorithm is an A1 format, so I am going to comment the exact parts in here, with the equivalent description for each part and place the drawing at the end of the document as an annex. This chart describes the functioning part of the Vision System placed on the CNC.

First of all, we have to wait until the CNC machine has finished cutting the corresponding holes on the material. Then the operator has to clean the zone and lubricate the indicated parts to assure the machine will work as expected on the next occasion, but that is a man labour, so we do not include this part into the flowchart. After that the calibration process begins. With the start of the python program and turning on the camera lights. The machine goes to the (0,0) point of the CNC machine and there will be a nut at that point.



**Fig. 4.2.** Starting part of the flow chart.

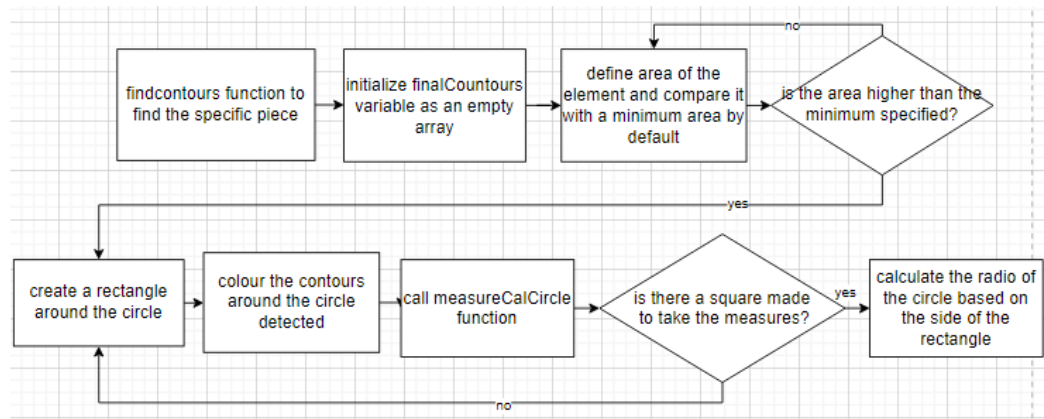
Then the camera will start taking image of the zone. There is a call for the getContours function, which applies different filters, such as cvt color, gaussian blur, canny, dilate and erode of the image between other filters on applied con the image.



**Fig. 4.3.** Second part of the flow chart.

After applying the filters, we need to find the exact contours of the image and then begin the measure of the object. The area of each element detected is compared with a minimum area defined, to be able to delete some possible noise introduced in the image.

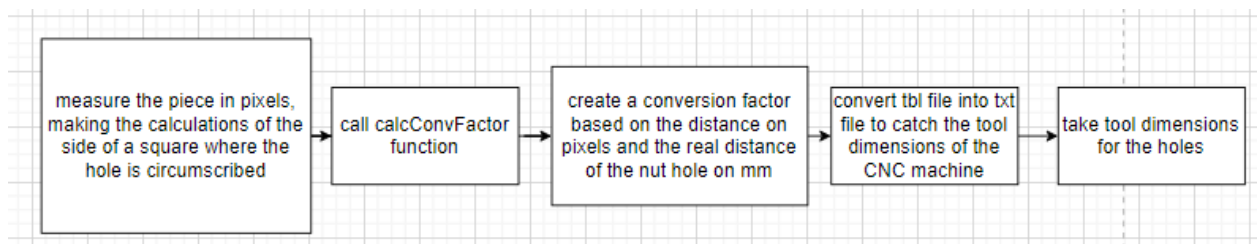
Then a rectangle is created around the hole and there are some calculations to get the radius of the object.



**Fig. 4.4.** Third part of the flow chart.

After being able to get the radius, and to make sure everything is going well, we colour the contours around the figure to check the contour is good enough to make the measure reliable. Then the measure is taken in pixels, so we get the side of the squared made and divide it by 2, that gives the radius of the circumscribed circle. Then the conversion factor is created, based on the distance on pixels measured and the real distance on mm of the object.

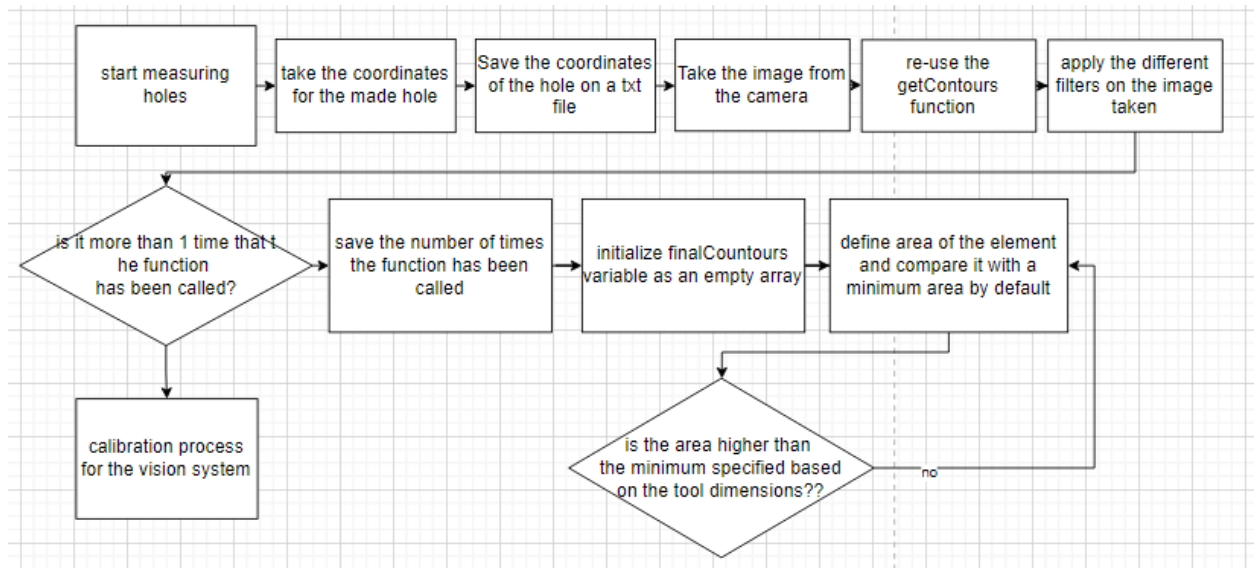
When we have this conversion factor, we must look for the tool dimension, this gives the possibility to compare the expected real measure with the measure taken by the program. To do this, there is a need to convert the file where the datatool is saved (.tbl) to a text file. Then, the measure of the tool is taken from that file.



**Fig. 4.5.** Forth part of the flow chart.

The measuring begins with the same process of the calibration one, the coordinates of the hole are taken, and the different filters and contours are applied and calculated. If the function has been called more than one time, the process continues with the finalcontour function and the definition of the area. This area gets compared with a different amount of minimum area value, because it is supposed that the made holes are going to be smaller than the actual figure of the calibration process.

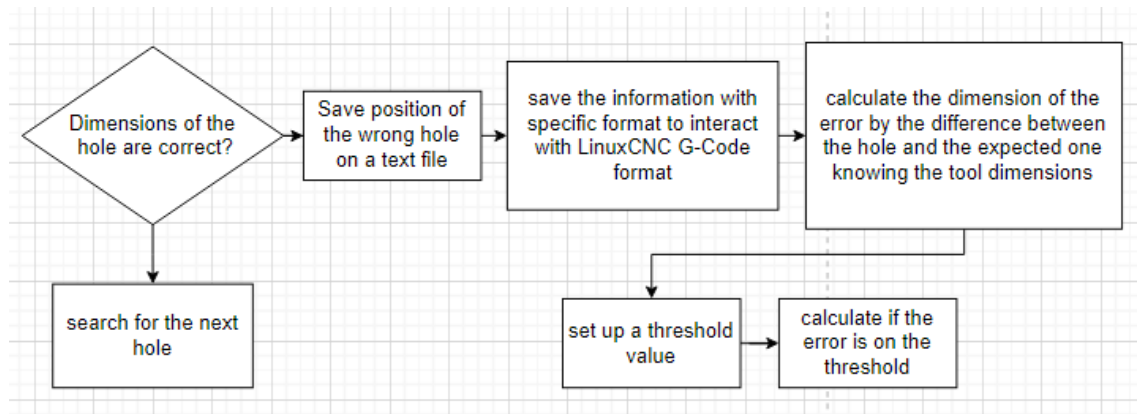
If the counter for the calibration process is set as one, the calibration process restarts.



**Fig. 4.6.** Fifth part of the flow chart.

Once the measure has been done, the comparison with the tool dimensions takes place, if the measure is correct, the system looks for another hole.

If it is incorrect, the position of the holes is saved in a txt file. After calculating the dimension of the error, the system checks if the error is on a specific error threshold, or it is out of it.

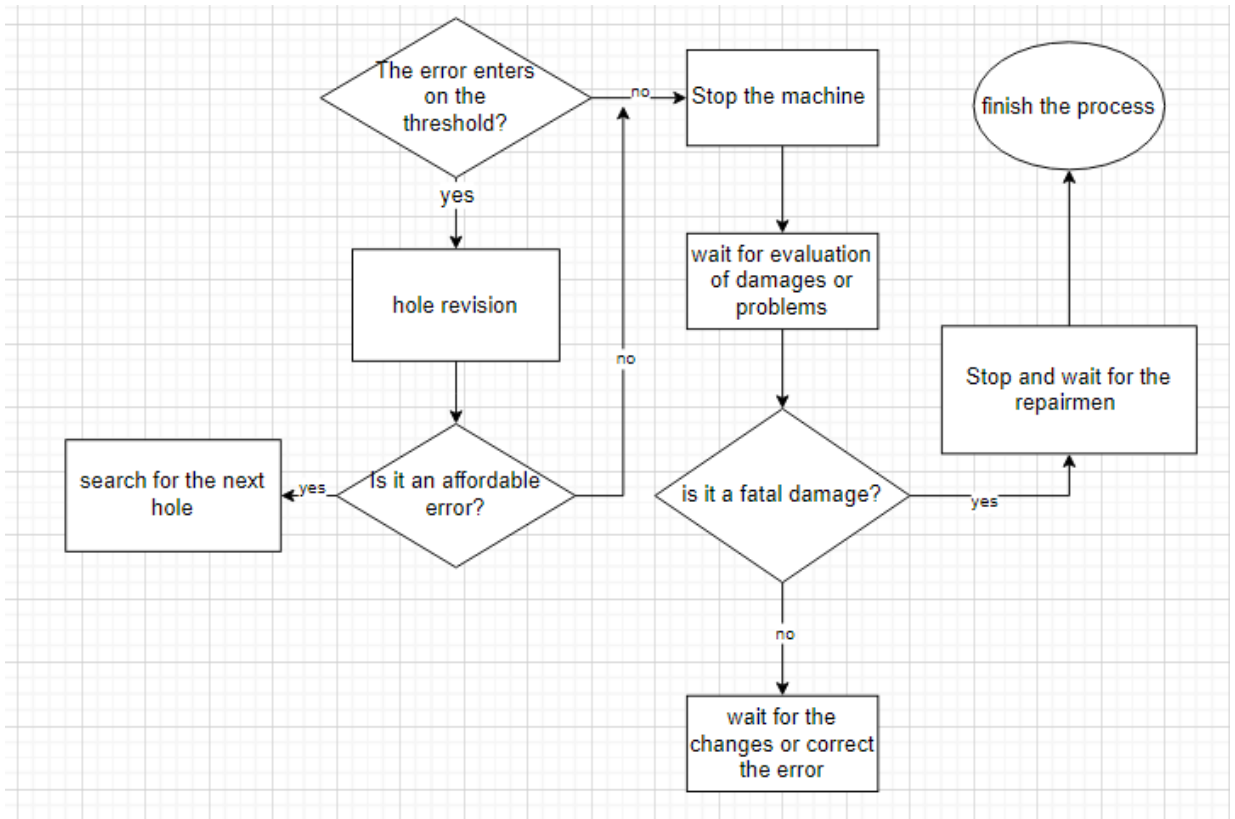


**Fig. 4.7.** Sixth part of the flow chart.

If the error is in the threshold, the hole is revised to check if it is all correct, if it is, it starts searching the next hole, if not the worst-case scenario is supposed. The control for errors is calculated as different patron for checking if a certain key from the keyboard is pressed for right or wrong decision. This part of the process is repetitive and tedious, so the next images does not show that part of the chart.

If the worst-case scenario is applied or the error is out of the threshold, the machine is stopped to look for the cause of the problem.

If the system has a fatal damage, the machine is stopped until the repairmen get it ready. If the error can be solute, it is corrected and checked before trying to get the machine to work again.



**Fig. 4.8.** Final part of the flow chart.

If we finish with the holes in a plate, we search for another plate to be manufactured. If the next plate is ready, the process restarts, but if there are no more plates, the system is turned off.

## **5. WORK SAFETY**

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

#### 5.1.1. General provisions and requirements for safe working

First, we are working with a CNC machine, so I must introduce some basic rules to make sure the user stays safe:

- Do not use the CNC machine table as a workbench.
- Do a dry run to make sure everything works as expected.
- The machine must be turned down while we develop the cleaning work.
- Do not leave the clamping chuck key in.
- Do not take measurements while the machine is turned on.
- When finishing working, make a check for any damaged parts to be replaced.
- If you must change a tool, make sure the machine is not turned on.
- Check that the tools are in good condition of usage and set correctly.
- Check that the tool is in the CNC program.
- Make sure the tool works as expected by doing a check.
- Make sure the surface and tools are cleaned to be used.
- Use the specific tools available for your CNC machine.
- Do not use broken tools.

This was developed for a good usage of the machinery, but to be able to protect yourself, there are also a couple of requirements needed:

- Protect your eyes from possible chips or dust with one of the followings, if not more than one: Safety glasses, safety goggles or face methacrylate mask.
- Noise protection: if the CNC machine is not provided with an enclosure, the worker must wear hearing protection such as ear plugs or noise cancelling earmuffs.
- Wear a closed shoe or safety boots.
- Avoid wearing jewellery, especially in hands and wrists.
- Long hair must be covered to avoid drags from the rotating parts of the CNC machine.
- Do not get too close to the machinery when it is working.
- Do not wear gloves.
- Do not get your hands close to the cutting parts.



In order to be able to localize, assess and minimise de risk you must be aware of any kind of strange behaviour of the machinery, strange sound or smell. You must be safe, as well as your partners, so make sure to fix the error, if possible, if not make sure to get rid of the machinery or substitute it for a new one.

#### 5.1.2. General Environmental protection

The different moving parts of the CNC machine should have lubricants, this kind of lubricants must be made for metal.

The different chips that appear during the machining process must be saved for later re-utilization, taking in account that this material may have lubricant within them. This material must pass the specific test. The machinery also has to pass the corresponding test.

Lubricants must be specially treated, so the lubricant itself, the lubricant mixed with chips or dust, or other material must be taken into an special recipient to collect it.

Provides general provisions and requirements for the safe operation and protection of working with similar devices and equipment.

## **5.2. Work safety and environmental requirements of camera vision system**

### 5.2.1. Specific provisions and requirements for safe working

The added part is not that complicated to be used in a safety way:

- Make sure the connections are properly linked.
- Make sure the cables do not interfere in the path of the CNC machine.
- Make the proper camera adjust assuring the CNC machine is turned off.
- The camera may accumulate dust or chips, make sure to keep the camera clean enough so these particles do not interfere in the vision or even the function of the camera.
- Assure that the camera is well adjusted to the support, if not, the camera may fall in the field of work of the CNC machine.

### 5.2.2. General Environmental protection

The environmental problem the new adding's may have been mainly two:

- In relation with the camera, make sure to switch off the light of the camera and the computer itself, if not the camera may keep turned on with the consequent light consume.
- In relation with the holder, which is made of PLA, make sure to recycle in a proper way the different supports needed to do the print at a more accurate way.

## **5.3. Safety installation of the system**

The installation needs to be done with the machine non-functioning. There system comes with 6 screws, 4 screws to attach the holder to the CNC machine and 2 for adjusting the camera.

The 4 different screws are M3 screws with a length of 20 mm. You just need to attach the 4 screws until is possible and making sure the plastic holder does not suffer any damage.

To be able to adjust the camera, first you need to put the camera through the holder. This is already tight enough to adjust the camera. If you need more reliable adjustment, you have the other 2 screws that are M5 and 35 mm that make the camera union with the holder tighter.

## 6. ECONOMIC CALCULATION

For this section, an economic calculation is done taking in account different processes. The main are the electricity, material, and workforce costs, but there is a need in doing calculations between them.

First, we need to talk about the variable costs per manufactured product:

Table 6.1. Variable costs per unit

Variable costs x unit	
Description	Costs €
3D printing	0,2175
PLA	1,0626
Camera	42
workforce	0,35664683

The 3D printing cost is result of the following calculations:

Table 6.2. 3D printer costs.

3D printer	Costs €
€/KWh =	0,087
e consumption =	0,5
working hours =	5

The €/KWh price has been taken in relation to the Lithuanian standard about the electricity price in 2022 year, without taking in account the actual changes about the source material prices.

e consumption is about the electricity consumption in KW for the 3D printer resulting in 0,5 KW, and he working hours is the total amount of hours per product that the printer is working which is 4h59min with taking almost a minute of taking the object out of the printer as time that the printer is working.

Returning to the main table, we have PLA, which is the material we are using for the 3D printer. Taking the €/kg of PLA and the actual PLA used we have the following table and results:

Table 6.3. PLA costs.

PLA	Cost €
€/kg PLA =	16,1
g PLA used =	66

Searching for the actual price of a PLA roll it results that is rounding between 14 and 22 € per roll. The actual quantity of PLA used is 66g, resulting on the price we have on table 1.

The third value is about the Camera price. The exact model is quite difficult to find, depending on the camera version we are taking, but it oscillates between 16 and 45 €. The exact model is 42€ on Amazon, but its cost will reduce surely by taking more quantity.

Workforce is calculated with the minimum salary established by the Lithuanian government, which is 730 €. Calculating the minutes, the worker needs to spend since the last piece is developed, for a quick check of the product and the time invested in selecting the next printing, we calculate the total invest for each product.

Table 6.4. Workforce cost.

<b>Workforce</b>	<b>Cost €</b>
lithuanian workforce x month	730
minutes invested on printing	5

The last value considered is the screws and nuts, that represent a low-cost, but they have to be taken into account:

Table 6.5. Screws cost

<b>Screws</b>	<b>cost</b>
m3-20mm	0,032
M5-35mm	0,02

And the nuts table:

Table 6.6. Nuts cost

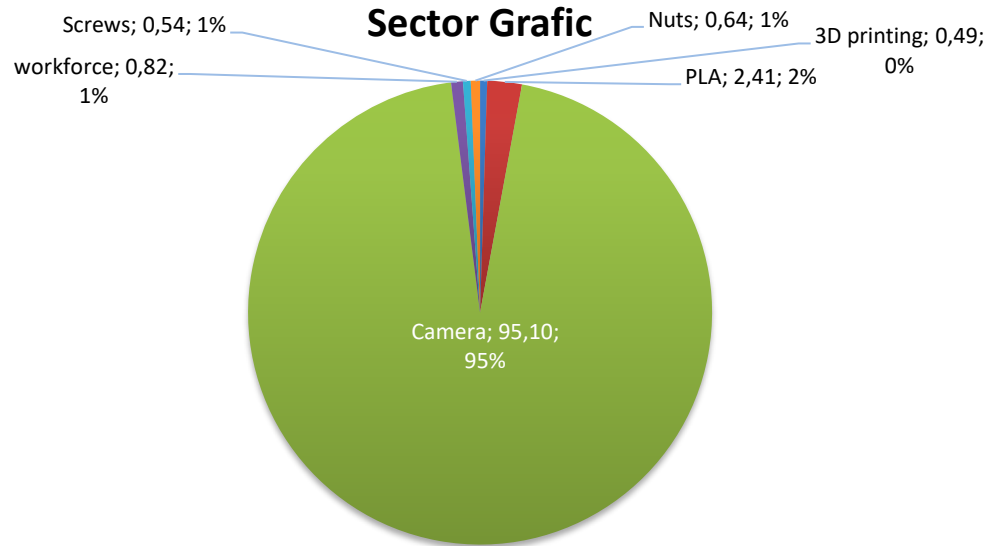
<b>nuts</b>	<b>Cost €</b>
m3 nuts	0,1
m5 nuts	0,041

The total manufacturing cost of the product is 44,16 €, so the actual market price needs to be at least high than that price. The final price set is 49,99 €, following the market selling tricks.

To make the results more showable, two different graphics are developed, the circular sector graphic and the dispersion one, where the key point is the equilibrium point. The first one is to make the different cost more visual; this makes it easier to allocate the highest raw material needed.

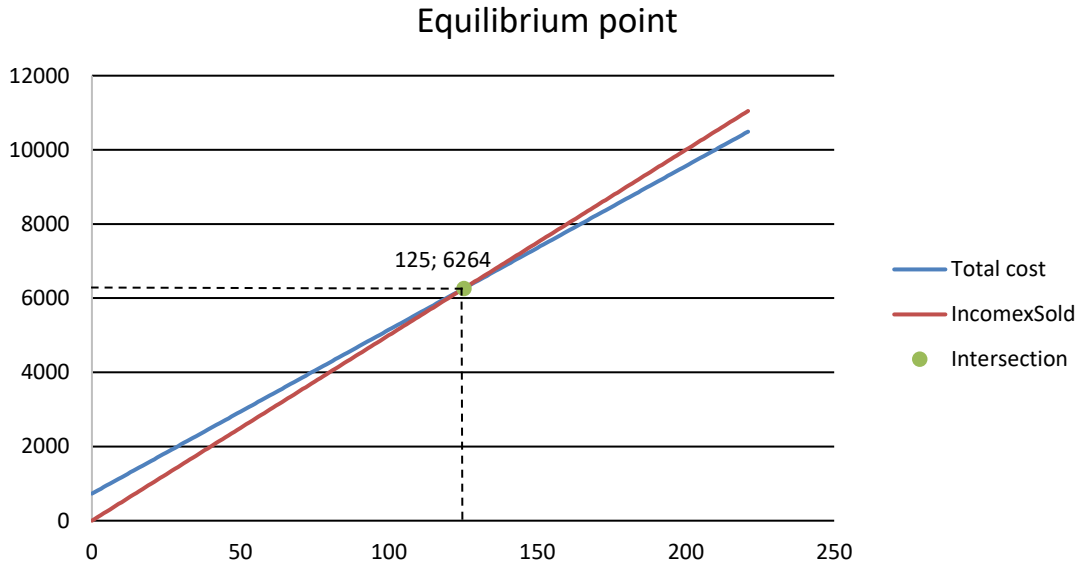
The second one shows the balance between the total cost and the income per sold. When the income per sold is higher than the total cost line, we start to get benefits from the product.

The next two images show both graphics:



**Fig. 6.1.** Circular Sector graphic.

The percentages in some cases do not reach even a 1% in comparison to the camera price.



**Fig. 6.2.** Equilibrium point graphic.

The first image shows the circular sector of the products and the different cost of them. As we can see, there is a big difference between the cost of the main product, the microscopic camera, and the rest of the products.

The raw materials for the process represent a 98,69% of the final costs, per unit. The other expenses are the ones related to the manufacturing process itself, representing the remaining 1,31%.

The second graphic show the equilibrium point, and as said before, the equilibrium point indicates the moment till we start to get benefits from the products.

## 6.1. Business plan

The product is perfectly designed for small factories, where you can install the vision system at any part of the main metal plate of a CNC machine. If you can set up the system next to the cutting motor it is the perfect situation, so you do not have to modify the main code.

You must place the system as the safety plan explained before. It is not difficult to install, there is no special need to do the installation, you just need to add 4 screws to attach the holder to the CNC place selected, and another 2 screws to place the camera in the exact position.

The vision system is easy to deliver and to transport, so the pack will be deployed in a small packaging just to cover all the product, the exact screws, camera, and camera holder will only occupy 13 x 5,5 x 8 cm. If there is special protection needed, you need to confirm the protector in advance. The final product is small, efficient, and cheap in comparison with the other products in the market.

## 6.2. Components list

The component list is finally as follows:

Table 6.7. Component list

ELEMENT	QUANTITY	NAME	DESCRIPTION
1	1	chapa	metal plate that supports the motor
2	1	Support_camera	Support_camera that supports the motor
3	1	camara	Camera for the vision system
4	2	Nut_m03	M3 nut for the M3 screw
5	2	M5x35	M5 screw of 35 mm
6	4	M3x20	M3 screw of 20 mm
7	2	Nut_m05	M5 nut for the M5 screw

The cost of producing the camera is low enough to make a competitive product on the market and an attractive way to install a CNC vision system on the small factories.

## 7. CONCLUSIONS

1. The solutions in the market fulfil different tasks compared to what we are looking for, the models differ mainly in the industrial needs, being more focused on big fabrics rather than small factories. The main goal is to translate the big vision systems showed into a smaller system.
2. The main conclusion involves the number of elements worked with and the type of products available. The camera used is way more efficient in image taking than needed. A microscopic camera takes more information than needed and a solution must be taken to reduce the noise.  
Solution: we may want to have two different cameras. The microscopic one to search for the errors in the holes, and another one, with less resolutions but bigger amplitude, to search and locate the camera in the exact manufactured point.  
The lights can be also a problem, a solution can be to put some led strips into the metal plate next to the manufactured piece.
3. The calculations made for the chapter are more than enough to fulfil the needs of the project. The frequency, force and displacement studies show coherent and resistant coefficients. The failure values are high enough (6000 Hz in the frequency study, order of  $10^4$  N/m<sup>2</sup> in force study and displacement of  $10^{-4}$  mm in case of the last study) to fulfil the needs.
4. The electrical scheme is simple because the actual alimentation is only needed for a couple of elements in the system, once these elements receive electricity, the distribution is done correctly between the vision system, which is only for the camera and the previous computer, and for the CNC machine, that involves more drivers and motors to be fed with electricity.
5. The work safety part is more focused on the CNC machine part, which can bring more problems to the actual system. The vision system we are working with is quite simple because the main problem can be caused from the camera movement and there are no difficult specifications in its working process, the main one should be to switch off the led lights of the camera to maintain the light durability.

6. The last chapter considers the main products we need to buy. Considering the price for manufacturing the system, we can give a higher price on the final product, but if we want it to be competitive, the price is good enough. The equilibrium point confirms our proposed price, being able to take benefits after 4 months from the market release. Before being established as a big company in the vision system market, we have to sell in a competitive price, once we get the confidence of our clients (if we give a good service) we should be able to lower the manufacturing price and to increase the selling value.



## 8. LIST OF LITERATURE

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

1. Examining the profile accuracy of grinding wheels used for microdrill fluting by an image-based contour matching method. T-H Chen, W-T Chang\*, P-H Shen, and Y-S Tarnng  
DOI: 10.1243/09544054JEM1749. 28 July 2009.
2. In-process machine vision monitoring of tool wear for cyber-physical Production Systems. Romulo Gonçalves Lins,a, Paulo Ricardo Marques de Araujoa, Marcio Corazzimb (2020)
3. Methodology and implementation of a vision-oriented open CNC system for profile grinding. L. M. Xu & F. Fan & Z. Zhang & Y. Chen & D. J. Hu & L. Shi. 3 October 2018.
4. Cárdenas, J., & Prieto-Ortiz, F. A. (2015). Diseño de un algoritmo de corrección automática de posición para el proceso de perforado PCB, empleando técnicas de visión artificial. Rev.investig.desarro.innov, 5(2), 107-118.
5. Desarrollo de un sistema de inspección automático de PCB's mediante visión artificial. Wilson Rene Ayo Masabanda. Hilda Marizol Moreno Andrade. March 2021.
6. The main information sources for the comparison of products were stracted from google scholar: <https://scholar.google.com/>
7. Python, OpenCV tutorial:  
[https://www.youtube.com/watch?v=oXlwWbU8l2o&ab\\_channel=freeCodeCamp.org](https://www.youtube.com/watch?v=oXlwWbU8l2o&ab_channel=freeCodeCamp.org)
8. Machining and measuring techniques: [https://www.youtube.com/watch?v=tk9war7\\_y0Q](https://www.youtube.com/watch?v=tk9war7_y0Q)
9. Lens distorsion: <https://www.youtube.com/watch?v=lbgl2u6KrDU>
10. Auto-measuring coins: <https://www.youtube.com/watch?v=1CVmjTcSpIw>
11. How to read and write at csv and excel: <https://onestopdataanalysis.com/read-csv/>
12. Led power: <https://acortar.link/PkmcB4>
13. PLA aliexpress product: <https://acortar.link/V9nb7X>
14. Microscopic camera on Amazon: <https://www.amazon.com/-/es/1600X-Microscopio-Digital-C%C3%A1mara-Endoscopio/dp/B07KYP3R4P>
15. Convert .tbl files into .txt: <https://www.file-extensions.org/convert-tbl-to-txt>
16. LinuxCNC webpage to get to know the CNC software: <http://linuxcnc.org/>
17. Webpage to develop the flow chart: <https://app.diagrams.net/>
18. Different python functions: <https://www.geeksforgeeks.org/python-opencv/>
19. How to use len function: <https://acortar.link/BTXUu6>
20. The different screws and bolts were taken from grabcad: <https://grabcad.com/library>
21. How to graphic the equilibrium points in excel:  
<https://www.youtube.com/watch?v=w3MYphvLtWU>

22. CNC tips for a safety workplace: <https://www.mscdirect.com/betterMRO/4-essential-workplace-safety-tips-cnc-machinists>
23. CNC tips for a safety workplace: <https://www.multicam.com/6-unbreakable-safety-rules-for-cnc-machinery-safety/>
24. Camera tips for a safety workplace: <https://digital-photography-school.com/5-tips-for-keeping-your-camera-safe-and-working/>

## **THE ANNEXES**

## Annex 1: Code of the system

```
# -*- coding: utf-8 -*-
"""
Created on Mon Apr 18 13:33:49 2022

@author: polet
"""

import cv2
import numpy as np
import time

def getContours(img,cThr=[100,100],showCanny=False,minArea=1000,filter=0,draw
=False):
    imgGray = cv2.cvtColor(img,cv2.COLOR_BGR2GRAY)
    imgBlur = cv2.medianBlur(imgGray,7)
    imgCanny = cv2.Canny(imgBlur,cThr[0],cThr[1])
    kernel = np.ones((5,5))
    imgDial = cv2.dilate(imgCanny,kernel,iterations=2)
    imgThre = cv2.erode(imgDial,kernel,iterations=1)
    blank = np.zeros(img.shape[:2], dtype='uint8')
    circle = cv2.circle(blank, (imgThre.shape[1]//2, imgThre.shape[0]//2), 230,
255, -1)
    masked = cv2.bitwise_and(imgThre, imgThre, mask=circle)
    contours,hierarchy =
cv2.findContours(masked,cv2.RETR_EXTERNAL,cv2.CHAIN_APPROX_SIMPLE)
    finalCountours = []
    for i in contours:
        area = cv2.contourArea(i)
        if area > minArea:
            peri = cv2.arcLength(i,True)
            approx = cv2.approxPolyDP(i,0.02*peri,True)
            bbox = cv2.boundingRect(approx)
            finalCountours.append([len(approx),area,approx,bbox,i])
    finalCountours = sorted(finalCountours,key = lambda x:x[1] ,reverse= True)
    for con in finalCountours:
        cv2.drawContours(img,con[4],-1,(0,255,0),3)
```

```

return img, finalCountours

def findDis(point1,point2):
    return ((point2[0]-point1[0])**2 + (point2[1]-point1[1])**2)**0.5

def measureCalCircle(contours2):
    if len(contours2) != 0:
        for obj in contours2:
            numP = obj[2]
            nWid = round((findDis(numP[0][0],numP[1][0])),2)
            nHei = round((findDis(numP[0][0],numP[2][0])),2)
            nRad = nHei/2
            print(nWid,nHei)
            print(nRad)
            return nRad

def calcConvFactor(radius):
    diameter = 2.*radius
    origDia = 21.25
    convFact = origDia/diameter
    return convFact

def dataInmm(dataR, convFact):
    data = dataR*convFact
    return data

capt = cv2.VideoCapture(0)
capt.set(cv2.CAP_PROP_FRAME_WIDTH,1280)
capt.set(cv2.CAP_PROP_FRAME_HEIGHT,720)
counter = 0;

while True:
    correct, img = capt.read()

```

```

if counter == 0:
    imgCanny, finalCont = getContours(img, showCanny = True, minArea =
10000)
    dataR = measureCalCircle(finalCont)
    conversion = calcConvFactor(dataR)
    cv2.imshow("Live Geometric Figures", imgCanny)
    counter = counter + 1
    time.sleep(1)
else:
    imgCanny, finalCont = getContours(img, showCanny = True, minArea = 300)
    dataR = measureCalCircle(finalCont)
    cv2.imshow("Live Geometric Figures", imgCanny)
    datamm = dataInmm(dataR, conversion)
    print(datamm)
    time.sleep(1)
    if cv2.waitKey(1) & 0xFF == ord('q'):
        break
if cv2.waitKey(1) & 0xFF == ord('q'):
    break

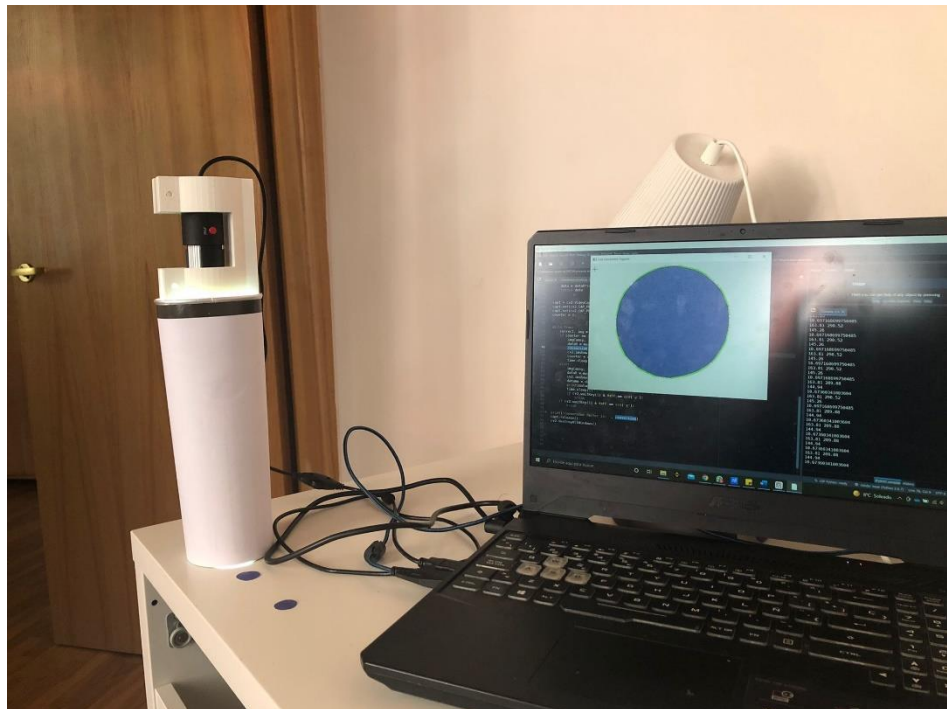
print('Conversion factor is: ', conversion)
capt.release()
cv2.destroyAllWindows()

```

## Annex 2: Photos of the prototype



Prototype with the paper coins.



Prototype working and screen results.

## **Annex 3: Bill of materials**

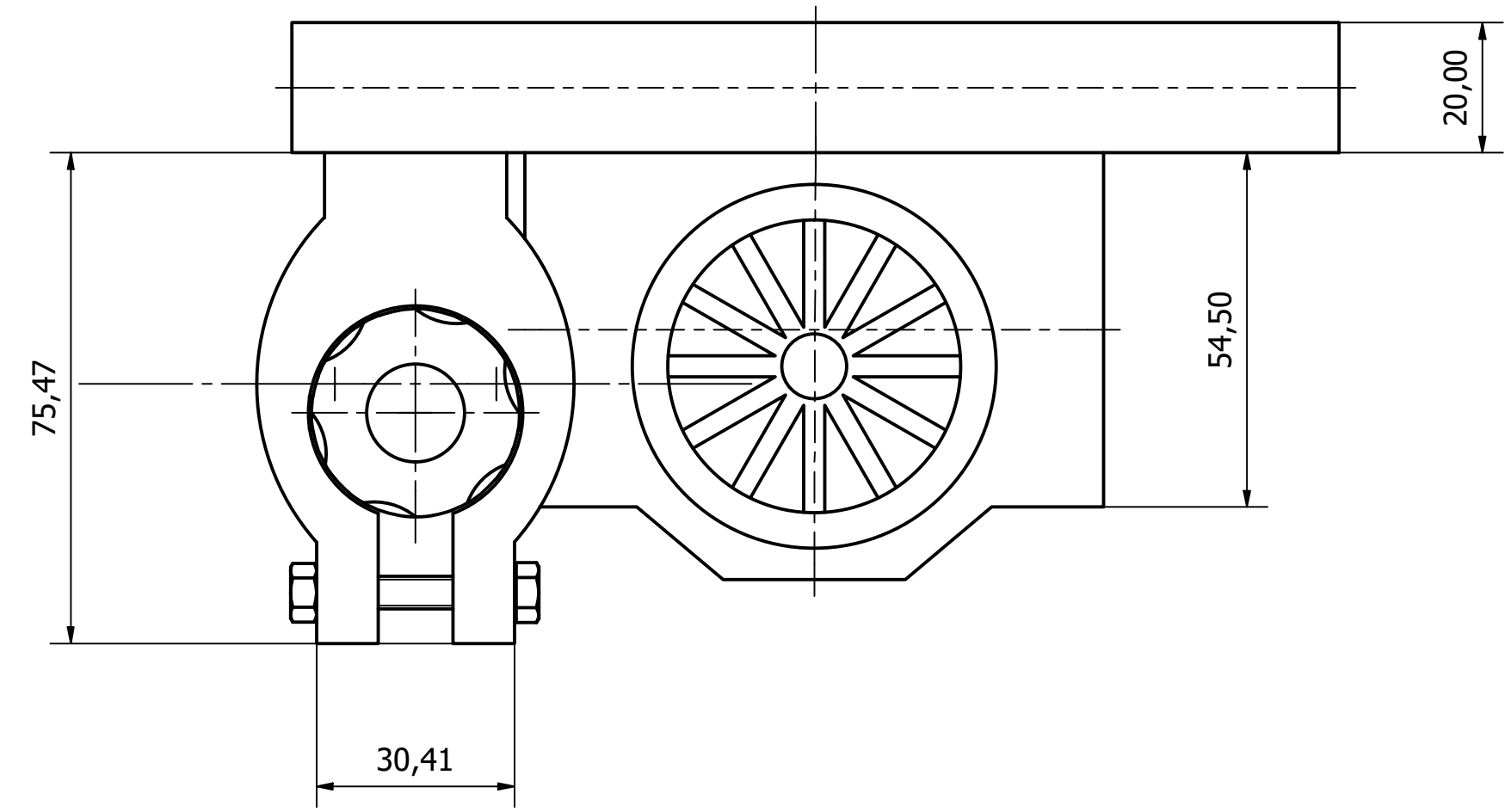
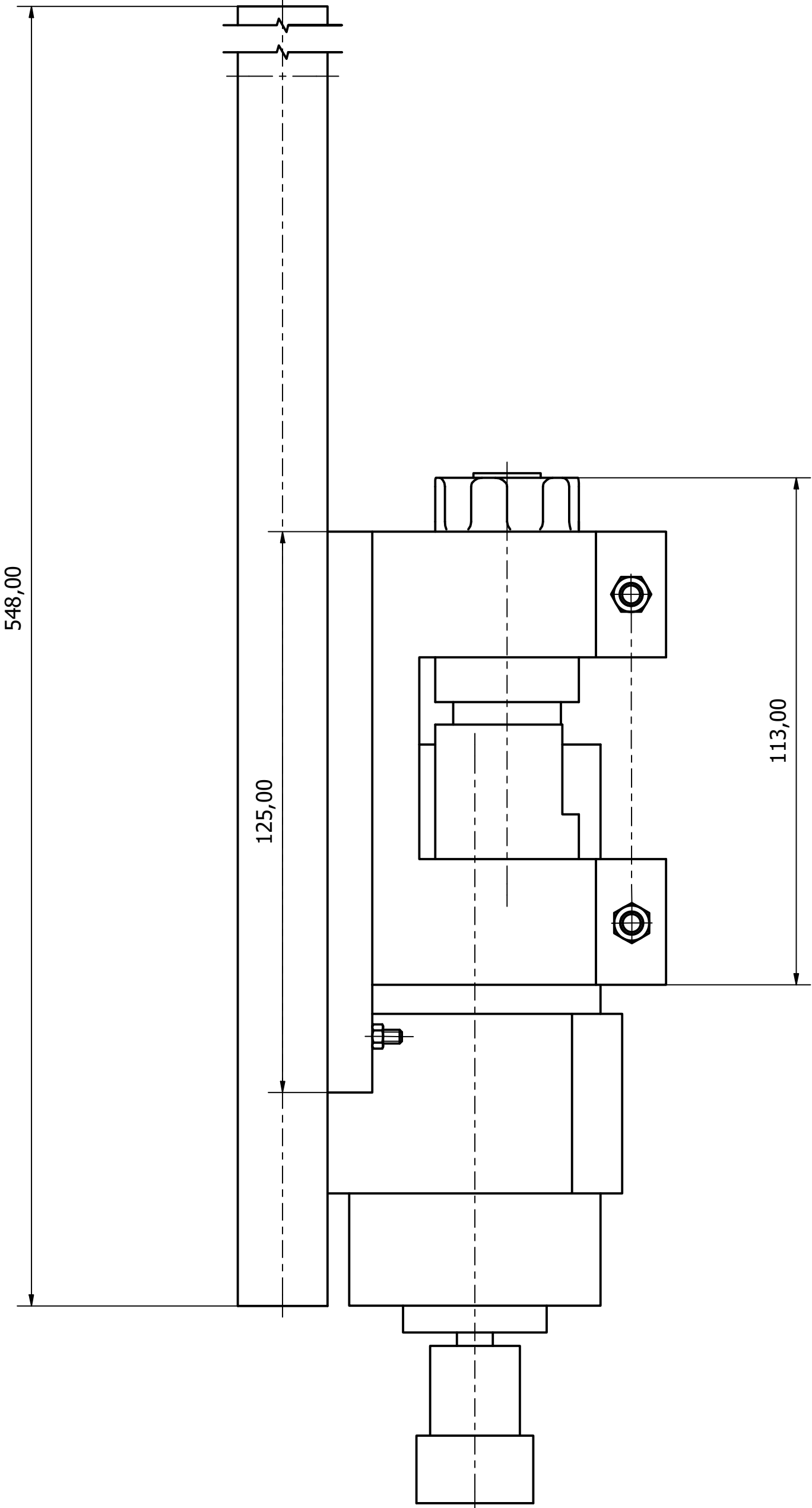
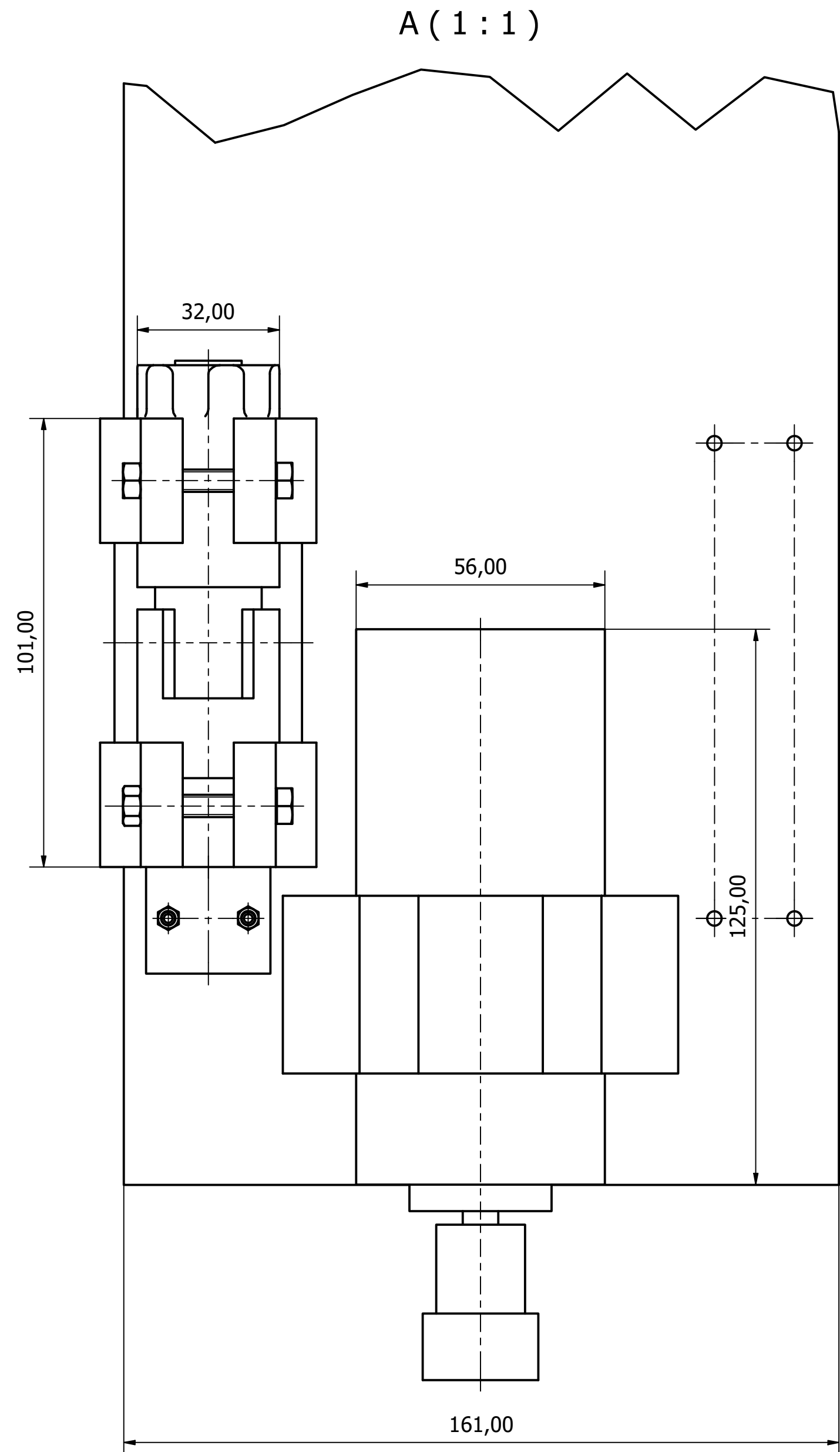






## **Annex 4: Drawings**

H  
G  
F  
E  
D  
C  
B  
A



Technical conditions for camera operation:

1600X 8LED 2MP USB Digital Microscope.

Maximum Image Resolution: 640 x 480p  
Focus Range: Approx. 15~40mm  
Frame rates up to 30 FPS

Material: ABS

USB power 5V DC

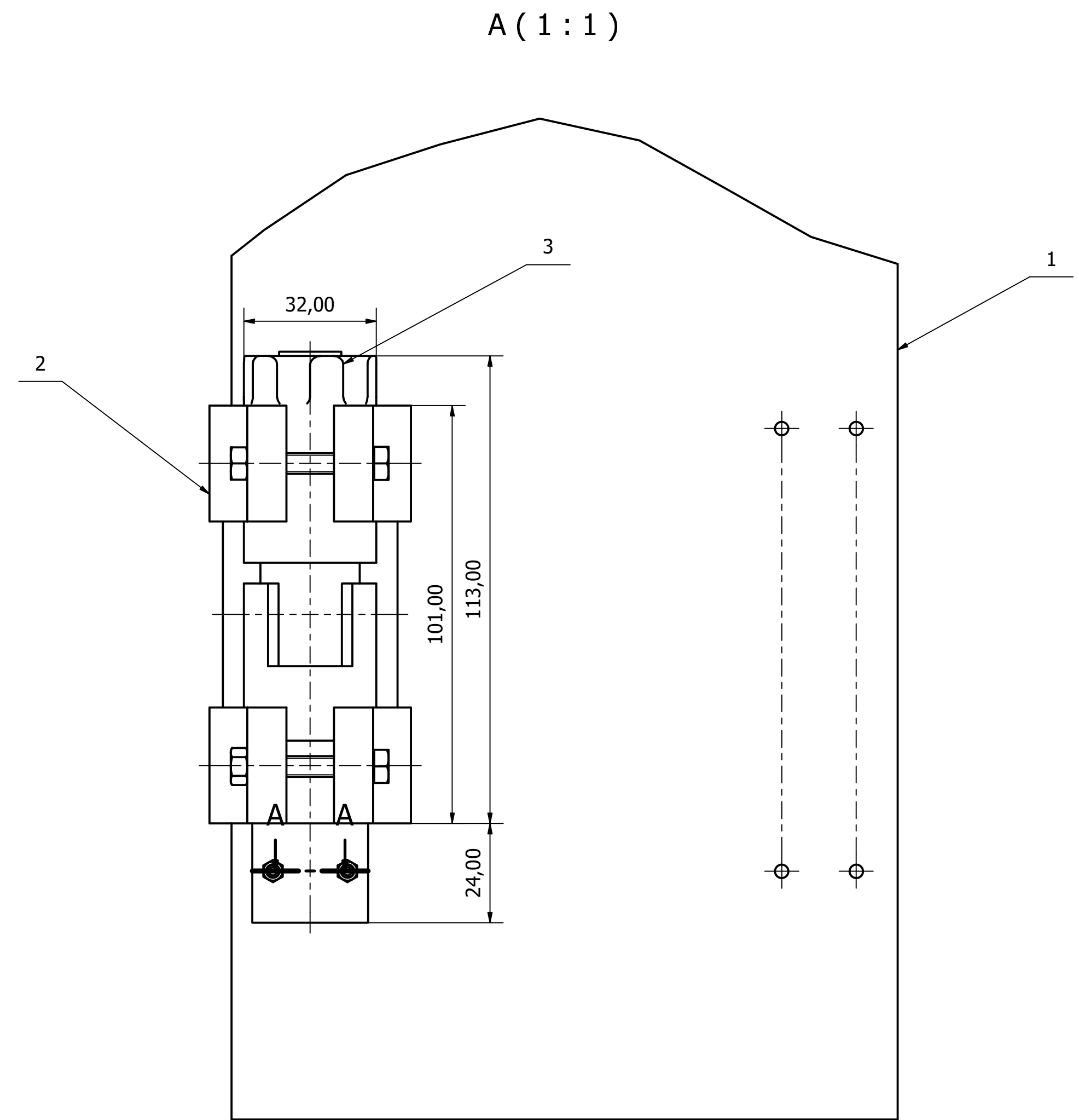
CNC machine motor operating conditions:

Power: 400W  
Operating voltage: 48V DC.  
Maximum working current: 8A  
Rotation speed: 12000r/min.  
Torque: 343mN.m.  
Diameter: 52mm  
Accuracy: 0.01mm  
Chuck: ER11

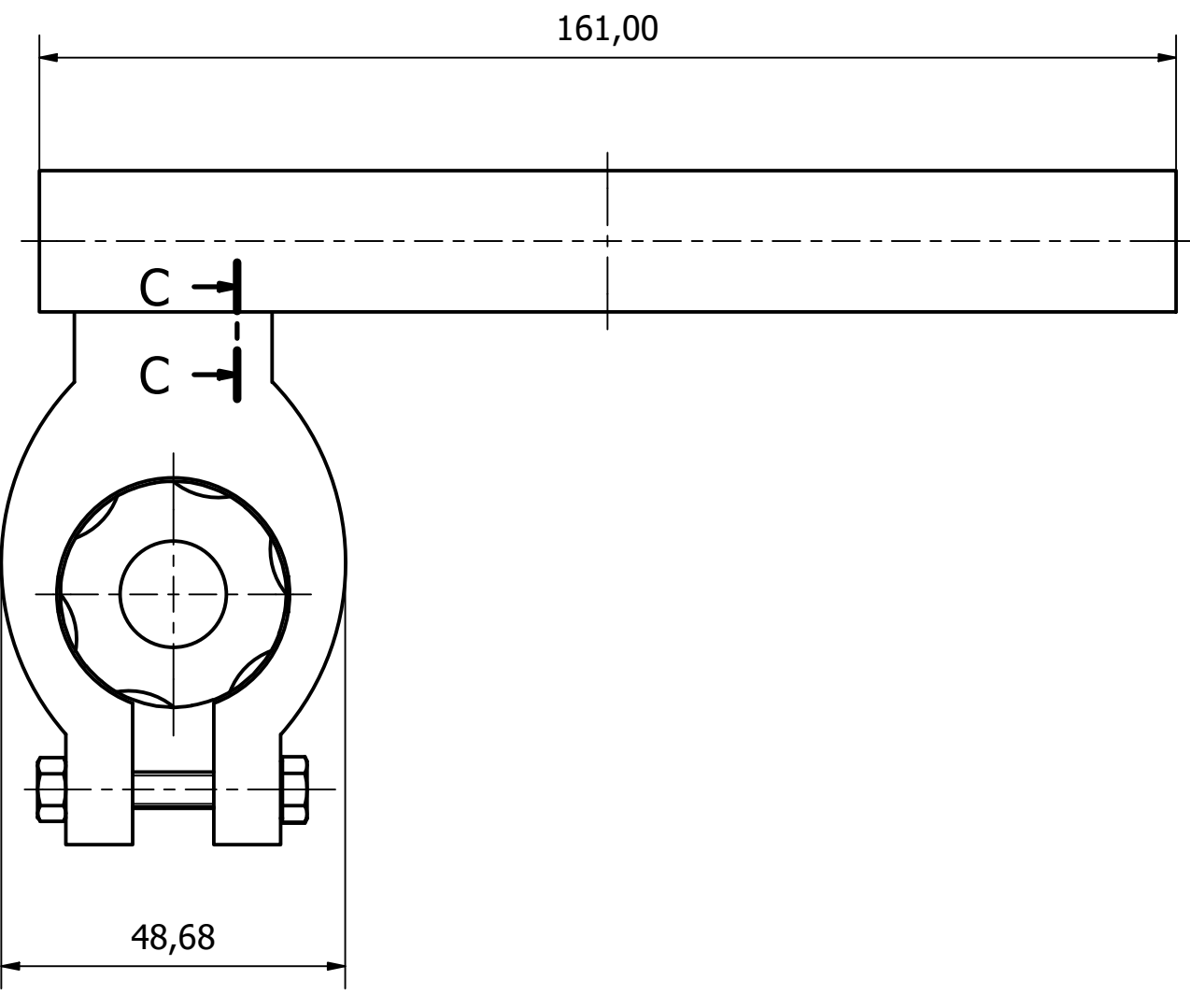
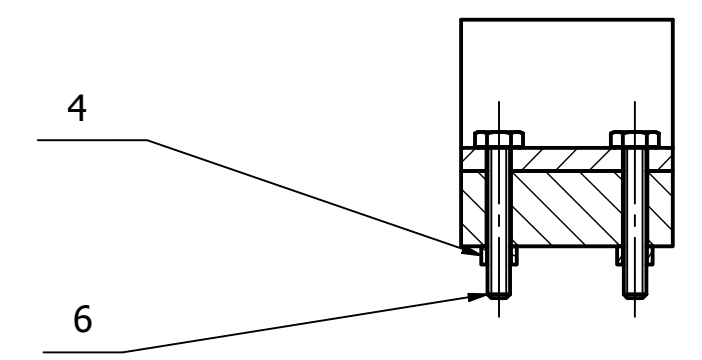
Case No.	Additional information	Material	Scale 1:1
Responsible department Engineering	Consulted by	Type of document Drawing	Document status Educational
Owner VG TU	Drawn by: Pablo Ricardo Duenas Fernandez Approved by: Andrius Dziedzickis	Title General drawing	Sign MERSBM 22 01 01 00 00 GD Release Date 2022/05/11 Page EN 1/6

H  
G  
F  
E  
D  
C  
B  
A

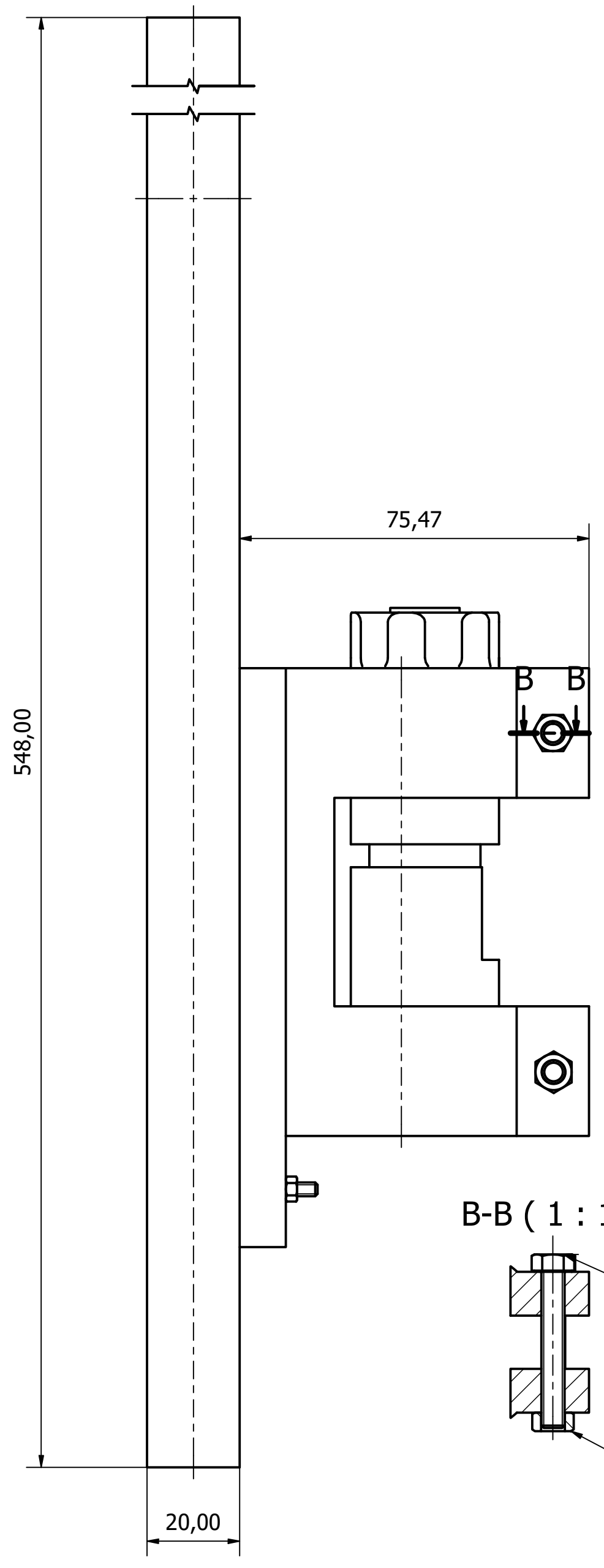
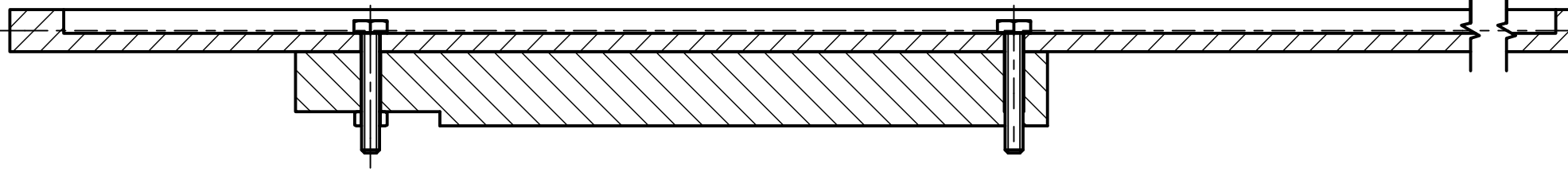
H  
G  
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E  
D  
C  
B  
A



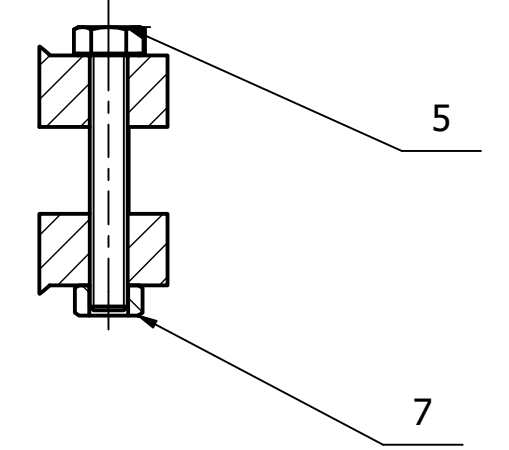
A-A (1:1)



C-C (1:1)



B-B (1:1)



ASSEMBLY COMMENTS

To attach 2 to 1, need to screw four screws referenced as 6

To attach 3 to 2, need to:  
First fit 2 into holes of 2.  
Then screw two screws referenced as 5 to tighten the support

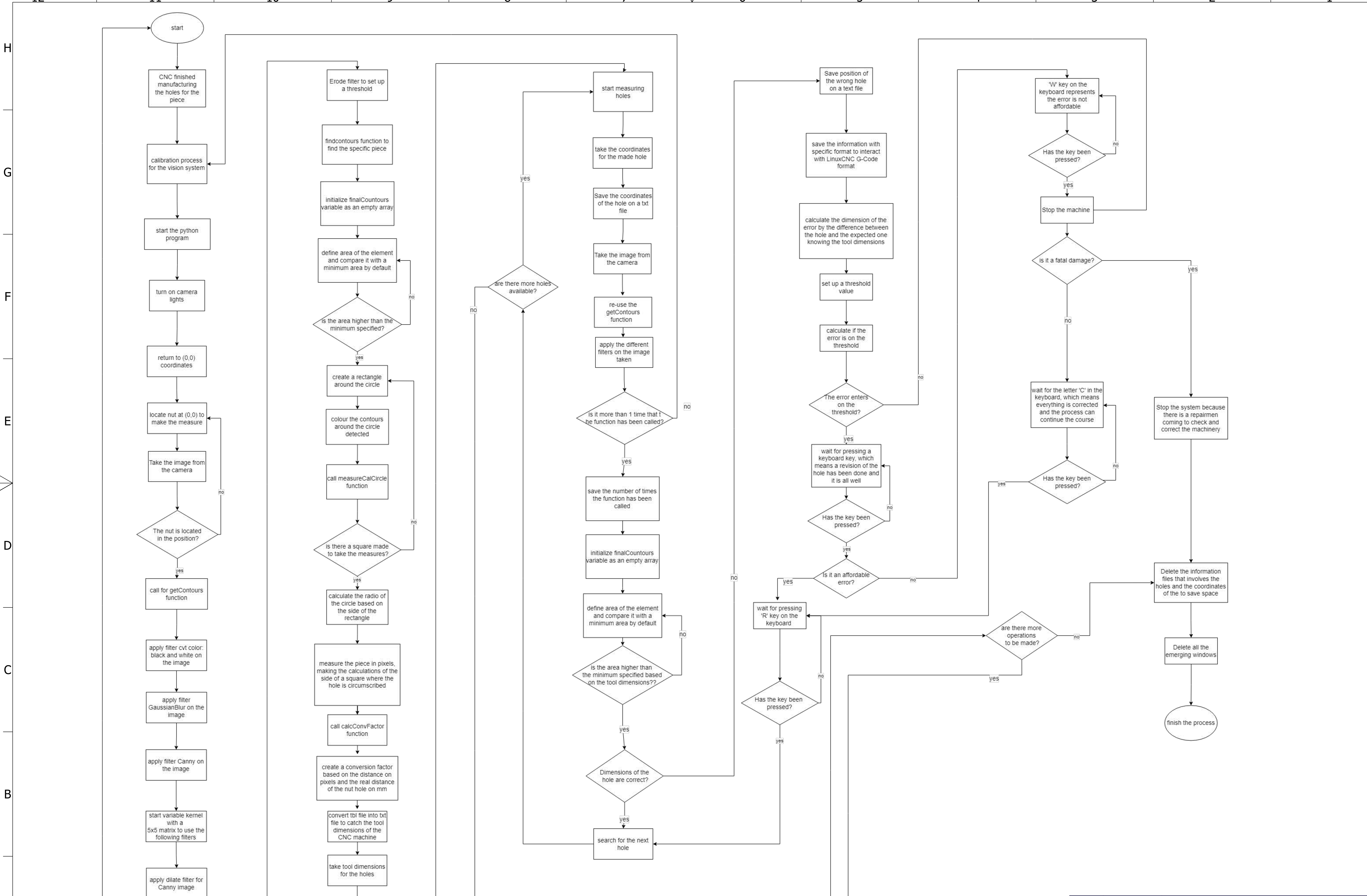
2 needs to be in the border of the second hole, almost poking out on the other side

For the screws and nuts related as 4, 5, 6 and 7, 5 and 6 need to be screwed. 4 and 7 only need to be threaded.

Case No.	Additional information	Material	Scale 1:1
Responsible department Engineering	Consulted by	Type of document Drawing	Document status Educational
Owner VGTV	Drawn by: Pablo Ricardo Dueñas Fernández Approved by: Andrius Dzedzickis	Title Assembly drawing	Sign MERSBM 22 01 01 00 AD Release Date 2022/05/11 Language Page EN 2/6

H  
G  
F  
E  
D  
C  
B  
A





Case No.		Additional information		Material		Scale	
Responsible department Engineering		Consulted by		Type of document Scheme		Document status Educational	
Owner VG TU		Drawn by: Pablo Ricardo Duenas Fernandez		Title Flow chart		Sign	
		Approved by: Andrius Dziedzickis				Release Date 2022/05/11	
						Language Page EN 3/6	



