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Grado en Ingeniería Electrónica industrial y Automática

Sensor táctil de 3 ejes para Robot

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Valladolid, junio, 2022.

TFG REALIZADO EN PROGRAMA DE INTERCAMBIO

TÍTULO:	3-axis touching sensor for Robot
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FECHA:	07/06/2022
CENTRO:	Faculty of Mechanics
UNIVERSIDAD:	Vilnius Tech
TUTOR:	Vytautas Bučinskas

Abstract:

Este proyecto se ha llevado cabo para realizar un sensor que pueda medir la forma de un objeto solo tocando y obteniendo las coordenadas del punto de contacto entre el sensor y el objeto. El cuerpo del sensor contara en su interior con 6 sensores táctiles en su interior hechos de cobre y el material Velostat. Cuando el robot se acerque al objeto y lo toque, solo 3 de los 6 sensores táctiles se comprimirán cuando el sensor toque al objeto, con la información de esos 6 sensores obtendremos mediante un algoritmo las coordenadas de la posición del punto de contacto entre ambos objetos. Todas las piezas se han diseñado manual y posteriormente se han impreso con una impresora 3D utilizando Acido Poliláctico (PLA).

Palabras clave:

táctil, velostat, compresión, cobre, robot

Abstract:

This project has been carried out to realize a sensor that can measure the shape of an object just by touching it and obtaining the coordinates of the contact point between the sensor and the object. The body of the sensor will have 6 touch sensors inside it made of copper and Velostat material. When the robot approaches the object and touches it, only 3 of the 6 tactile sensors will be compressed when the sensor touches the object, with the information of those 6 sensors we will obtain by means of an algorithm the coordinates of the position of the point of contact between both objects. All parts have been designed manually and then printed with a 3D printer using Polylactic Acid (PLA).

Keywords:

Tactile, velostat, compression, copper, robot

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

FACULTY OF MECHANICS

DEPARTMENT OF MECHATRONICS, ROBOTICS AND DIGITAL MANUFACTURING

Daniel Calvo Sanz

THREE AXIS TOUCHING SENSOR FOR ROBOT

Final Bachelor's Project

Study programme MECHATRONICS AND ROBOTICS,

Code 612H73002

Vilnius, 2022

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Daniel Calvo Sanz

THREE AXIS TOUCHING SENSOR FOR ROBOT

Final Bachelor's Project

Study programme MECHATRONICS AND ROBOTICS,
Code 612H73002

Supervisor: Vytautas Bučinskas (Title, Name, Surname) (Signature) 2022 05 24 (Date)

Vilnius, 2022

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COURSE PROJECT (WORK, INTEGRATED PROJECT)

DECLARATION OF ACADEMIC INTEGRITY

10/05/2022

(Date)

I confirm, that my course project (work, integrated project), which topic is Three Axis Touching Sensor for Robot

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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There is no contribution of other persons to the course project (work, integrated project). I have not paid any statutory sums of money for this work.

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TASK FOR BACHELOR THESIS

11 May 2022 No. 1
Vilnius

For student Daniel Calvo Sanz.

Bachelor Thesis title: 3 Axis Touching Sensor for Robot

Approved on.

The Final work has to be completed by 13 May, 2020.

TASK FOR FINAL THESIS:

Initial data:
The sensor designed will touch an object surface and provide information about the coordiantes of the contact point between the surface and the sensor. The sensor will be attached to Motoman SSF2000 Robot and will count with Motoman NX1000 Controller. In the sensor there will be 6 small touching sensor made with Velostat and Copper contacts that will measure difference in resistance. The small touching sensors measures will be connected to a Arduino Mega.

Explanatory part:
1. Introduction. Analysis of analogical devices. Substantation of the taken technical decision.
2. Calculations needed for the design process. Design of the sensor parts.
3. Description of the construction and operational principle. Electric block Scheme. Algorithm of management of the device
4. Work safety. General provision and requirements for safe working. Calibration of Designed sensor. Assembly of sensor
6. Evaluation of economic indicators of the designed or upgraded device.
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. Adaptor component (0.25 sheet A1); 4. Holder 2 component (0.25 sheet A1); 5. Electric block scheme (0.5 sheet A1); 6. Algorithm of control of the device (0.5 sheet A1); 7. Economic indicators (0.5 sheet A1).

Supervisor .... (Signature) prof. dr. Vytautas Bučinskas
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2022-05-11
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Vilnius Gediminas Technical University
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Title: **3 Axis touching sensor for Robot**

Author **Daniel Calvo Sanz** Academic supervisor **Vytautas Bučinskas**

Thesis language

	Lithuanian
X	Foreign (English)

Annotation

Measurement of objects is a posibility when working with a robotic arm, the precision and variety of accurate movements is a good factor when measuring objects. The project is about creatinng a sensor capable of being atached to a robotic arm and to be able to measure some objects and surfaces only by touching the surface.
The sensor is completely designed using 3D modeling softaware and is 3D printed using Polylactid Acid (PLA) as prinitng material. The sesnor have differente parts that are assembled together, this parts will be an adaptor to conect the proper sensor to the robot arm, the body of the sensor, called Holder, the cover of the sensor, called Holder 2 and the last designed part is the touching stick, that has a tipp ball wich makes contact with the objects surface.
The sesning part is composed of 6 small touchin sensors that are made with 2 Copper contatcs making a sandwich with Velostat semiconductor. With this touching sesnor is measured decreased in resistance betweeen the coppere conatcts, if the resistance decrease, the sesnor is being compressed. Three of this touching sensors will be placed on top of the touhcing stick component, and the other 3 will be placed on the bottom.
The sensor will measure the coordinates when the tip ball touches the objects surface, after that, 3 of the sensors will be compressed and get the resistance decreased. With the values of the resistances of the 3 sensor and the position of them, the coordiantes of the contatc point are calculated and saved.

Structure: introduction, overview of analogic construction, calculation of project, description of the construction and operational principle,work safety, economic calculations conclusions and suggestions, references.

Thesis consist of: 48 p. text without appendixes, 32 pictures, 4 tables, 18 bibliographical entries.

Appendixes included.

Keywords: sensor, robotic arm, touching sesnor, Velostat, copper
…………………………………………………………………………………………………..

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INTRODUCTION

Investigation problem. Describe the problem of a device that is being developed or upgraded.

Objects have not always a planar surface, they normally have different forms that are difficult to copy when you are looking at the object. These surfaces can be curved, have corners, defects, etc; so that, trying to measure them can be, in fact, a problem when you don't have the proper machine or in other cases the proper tool.

Robots have a good accuracy; they can be used to be moved into complicated positions without problem in most of the cases. Adding a touching tool will prevent these problems and help to know where the coordinates of the point that is being touched is. Then saving all that point you can know the exact form of the piece you are measuring.

Object of Project. Present the object that you're creating or modernizing.

The object I am creating is a 3-D axis touching sensor. It will be a sensor attached to the robot like one of the robot tools and will stay always vertically so always touches the sloped surfaces with the tip and stops to know the coordinates in the space of the contact point.

It will count with 4 different big parts in this object. The first part is the combination of Holder and Holder2, they will be assembled and have the other 3 important parts in the hole that is inside the assembly. In second place, it will be the touching stick, it's the piece that will make contact at the same time with the sensor and the surface we will want to measure. The object that is going to be in touch with the surface will be a ball attached with a tube to the proper sensor. Inside the sensor there will be the last 2 important parts of the object, copper contacts around a sensitive material platform, made of Velostat, that is where the resistance difference are going to be measured.

The sensor will be attached to the robot with a compliment piece, an adapter. The use of this adaptor is necessary because of the position of screw holes in the design of the sensor holder.

The aims and purposes of the project. Present aims of the project.

The principal aim of this project is to create a touching sensor that will be attached to a robotic arm. This sensor will need to be able to touch a surface, and make the robot stop when the surface is touched. From the coordinates of the axis of the robot, the sensor will provide the location of the contact point between the object surface and the touching part of the sensor, that will be a tip ball.

This location is going to have the 3 coordinates of the space, because it is going to be calculated from the edge of the robot (the robot arm knows what the position of its edge during the execution of the program is), so from that information, the measures of the sensor and the calculations that the sensor is going to do, these coordinates will be obtained.

The use of this sensor wants to obtain a good efficiency, but also really good accuracy. One of the purposes of this project is to be able to measure different objects with different forms and be able to obtain a good vision of the forma that the object has. This will be achieved by repeating the coordinate acquisition procedure in a big number of significant points, so a cloud of coordinates is obtained and the form of the object that is being measured is fully obtained.

The sensor is being developed in this project is design in a way that into only one model of robotic arm can use it, but it can be used by a wide variety of robotic arms. That is why a part has been designed to serve as an adaptor between the sensor itself and the robot arm. That Adaptor piece can be easily modified to the anchors that the robotic arm needed for the work has.

This touching sensor has some advantages and disadvantages that need to be explain. On one hand, the advantages are following:

- Easy assembly. The assembly of the sensor will be explained deeper in the project, but the assembly is mostly made up of bolts and nuts.
- Appropriate for different robot models, due to the capacity of changing the Adaptor
- No force needed. The sensing parts are going to be made of velostat which a semiconductor, so the sensor will measure difference in resistance instead od forces, which makes the calculations easier.
- The sensor can be done in smaller size if the different parts are scaled.

On the other hand, the disadvantages of the object are the following:

- The collection of the points is slow, it is needed to move the robot from different angles to obtain the complete cloud of coordinate points.
- Not all the objects can be measured. Due to the position of the sensor, vertically, the objects that have projections cannot be completely measured because the touching stick will collide with the projection while trying to touch the surface behind it.
- When scaling the different pieces, scaling the six touching sensors can be difficult because the location of copper contacts when they are small can affect more to the conductivity.
- If the force applied is high, the touching stick can break. The different parts of the sensor are 3D printed, and the touching stick is the most fragile of all f them, reinforcing it may be a solution to this problem.

To achieve the necessary goals of project, need to be fulfilled in order these tasks:

1. Analysing of literatures sources
2. Review of the advantages and disadvantages of the object that you’re creating or modernizing.
3. Choosing necessary elements for system design according to the parameters provided.
4. Make calculations of the device or unit strengths.
5. To create and describe the control schemes of a device or unit that is being developed or upgraded.
6. To carry out the evaluation of economic indicators of a device or unit being developed or upgraded.
7. Present conclusions and recommendations.

1. OWERVIEW OF ANALOGIC CONSTRUCTIONS

1.1. F-Touch sensor, University of London

Device No.1. F-TOUCH Sensor for Three-Axis Forces Measurement and Geometry Observation.

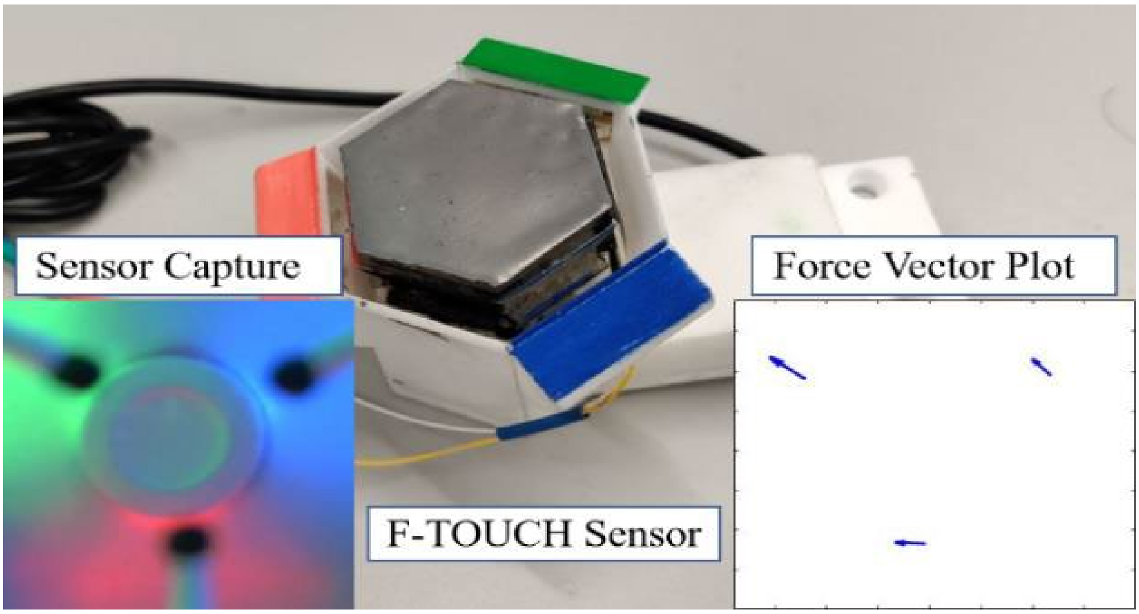

Figure 1 Prototype of the F-Touch Sensor

Wanlin Li. Yohan Noh. F-TOUCH Sensor for Three-Axis Forces Measurement and Geometry Observation

The sensor's name is F-TOUCH, it is inspired by GelSight Tactile sensor. It is as sensor that can measure multi axis forces information and can obtain geometry information with a vision-based system.

The F-TOUCH sensor (Wanlin Li., 2020) empowered has the ability to measure 3 axis forces with an internal elastic structure that is placed under the elastomer layer. It uses a conventional force sensor calibration method too. A camera is used in the sensor to record the mechanical deformation that the elastic structure has the distortion in the surface of the elastomer layer (the purpose is geometry observation).

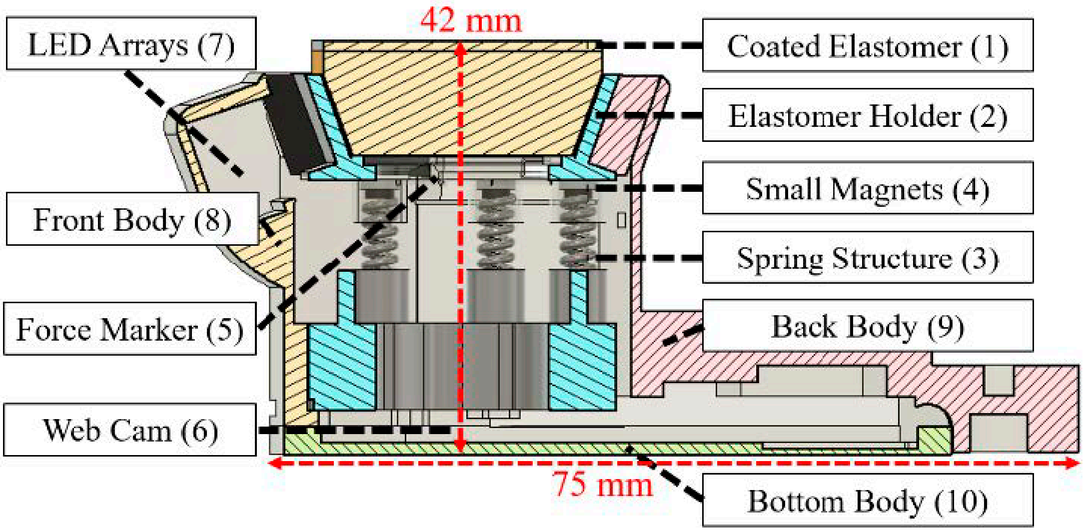

Figure 2 Schematic design of the F-TOUCH sensor

Wanlin Li. Yohan Noh. F-TOUCH Sensor for Three-Axis Forces Measurement and Geometry Observation

As we can see in Figure 2 the design of the sensor in three different parts. First is the coated elastomer (1) that isolates the Ambient light interference and reveals the tactile information. In second place, is the spring mechanism structure, composed with elastomer holder (2), springs (3), magnets (4) and force maker (5). Last part has 2 components, Logitech webcam (6) and SMD LED arrays (7) which are used for illumination and data capture.

Coated elastomer is one of the parts that form the core oof the F-TOUCH design because sensitivity of the sensor can be affected by elastomers properties. Elastomer layer is composed by a reflective coating membrane and a transparent silicon base.

Under the silicon elastomer is placed the internal spring mechanism structure (Figure 3). The structure is made up of a 3D printer elastomer holder, 24 magnets, 6 compression springs, 3 spherical markers in charge of measuring the three-axis force components and last one is a 3D printed bottom platform. Magnets connections are used to stabilize the overall structure and linearity of the structure is ensured by springs.

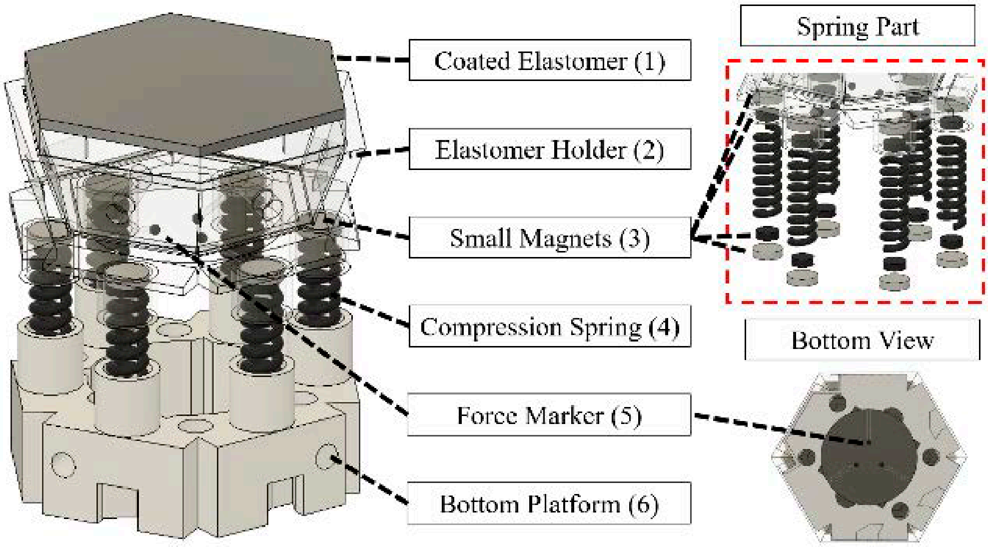

Figure 3 CAD design of the spring mechanism structure

Wanlin Li. Yohan Noh. F-TOUCH Sensor for Three-Axis Forces Measurement and Geometry Observation

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Movement of the marked are attached with springs' deformation, the three markers made a plane that is always parallel with the bottom surface of the elastomer layer. When the sensor interacts with an object, the contact made compress the 6 springs and the platform which contains the 3 black markers is moved. The camera is used to capture the movement of the markers and the area changes that occur.

1.2. Optical Three-axis Tactile Sensor

Device No. 2. Optical Three-axis Tactile Sensor by Ohka, M. Graduate School of Information Science, Nagoya University. Japan.

The optical uni-axis tactile sensor (Masahiro Ohka, 2007) shown in Figure 4 includes an optical waveguide plate made of transparent acrylic and has a light source that illuminates the sensor along its edge. The light addressed to the plate remains inside it because of the total internal reflection that is generated. A rubber sheet with an array of conical feelers is place on the place on order to keep the contact between plate and array surface.

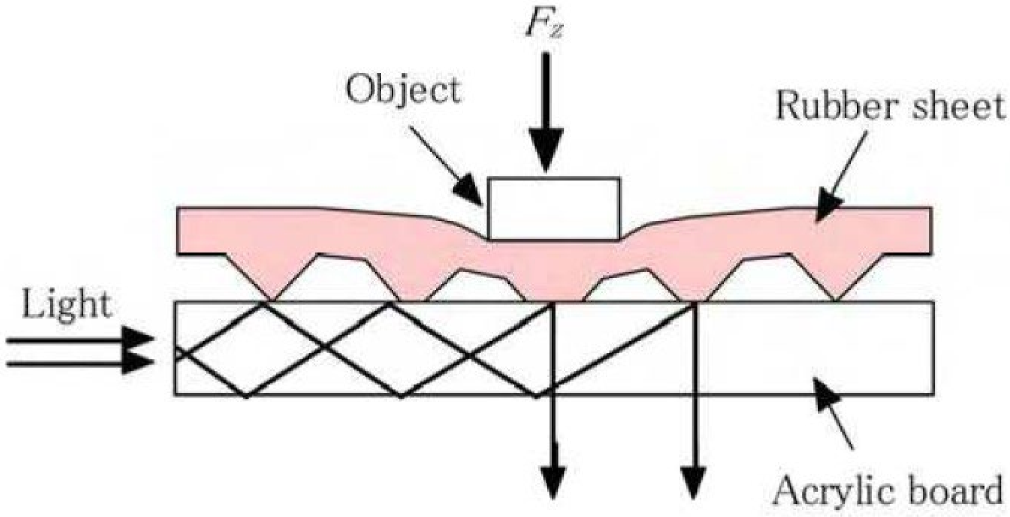

Figure 4 Optical uni-axis tactile sensor

Masahiro Ohka, Yasunaga Mitsuya. An Experimental Optical Three-axis Tactile Sensor for Micro-Robots

When an object makes contact (with pressure) with rubber sheet, the feelers collapse, in that point of contact of the feelers, light is in a diffuse way reflected out of the plate. This is in fact, because of the refractive index both materials have, rubber has it higher than the plate. The bright spots that are seen from plate's reverse surface, is what allows to make the calculus of the distribution of contact pressure.

Although, with this type of sensor can only detect forces that applied in a vertical way to the surface, so there will be some different methods to improve the uni-axial tactile sensor into three-axis sensor. One of this solution is to use a sparse matrix of columnar feelers which will make contact with the object. Another solution y a dense matrix of conical feelers that will be in contact with the plate. The columnar feeler is organised with few conical feelers, then when a force is pressing against the conical feeler you can obtain three components of the force by its contact area.

The structure of the three-axis sensor tis shown in Figure 5, will count with a rubber sheet, an acrylic plate, a light source, and a CCD camera.

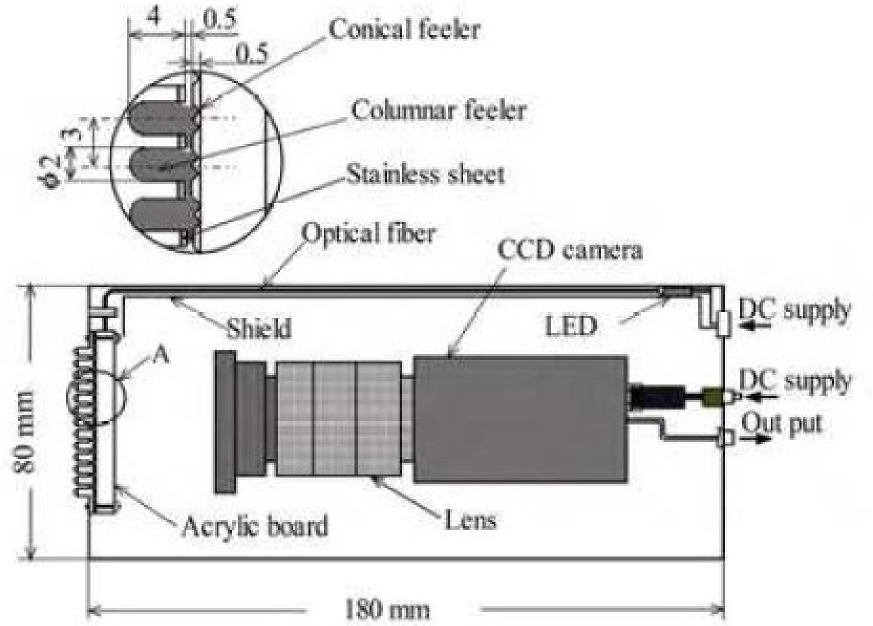

Figure 5 One columnar and four conical feelers three-axis sensor

Masahiro Ohka, Yasunaga Mitsuya. An Experimental Optical Three-axis Tactile Sensor for Micro-Robots

Detection surface and reverse surface will have 2 matrixes of columnar feelers with their conical feelers, respectively. The material which feelers are made is silicon rubber.

The composition of the sensing elements of the tactile sensor is one columnar feeler followed by 4 conical feelers attached to the bottom of the columnar feeler. This is shown in Figure 6 (a)

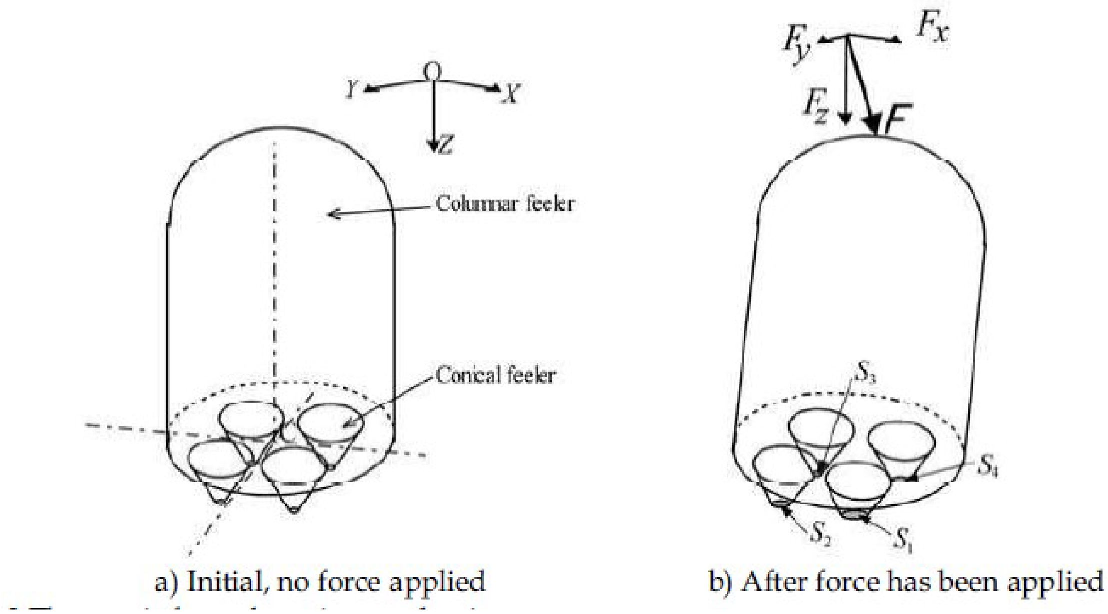

Figure 6 Three axis force detection mechanism

Masahiro Ohka, Yasunaga Mitsuya. An Experimental Optical Three-axis Tactile Sensor for Micro-Robots

When the columnar feeler touches something and a force is pressing the feelers, the apex of the conical feeler gets tighten and collapse. With the area of the surface that conical feelers made with the sheet, the forces can be calculated.

1.3. Three-dimensional touch probe using three fibre optic displacement sensors

Device No. 3. Three-dimensional touch probe using three fibre optic displacement sensors by Takaaki Oiwa and Hiroshi Nishitani.

Most of the 3D touching sensors are a ball-stylus system, that has a ball as the touching part and then a tube that leads into de sensing zone, so there will be distance between the touching point and the sensor where the force is going to be measured.

With the use of displacement sensor installed at the shaft, the displacement and direction measurement is done on the touching ball directly. The displuming sensor that are going to be used in this touch probe are high resolution fibre optic sensors (Takaaki Oiwa, 2004).

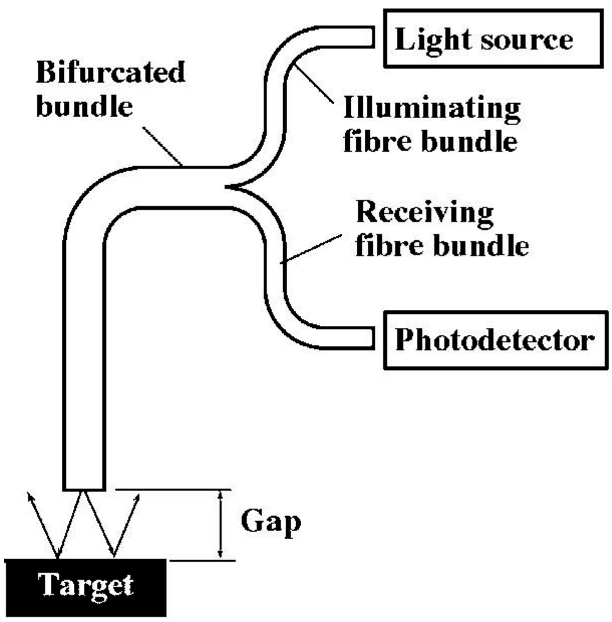

Figure 7 Schematic of fibre optic displacement sensor

Ohka, M. Optical Three-axis Tactile Sensor

Basic fibre optic displacement sensor is how in Figure 7. The components this sensor usually has are a light source, a photodetector, and a bifurcated optical fibre bundle. This optical fibre bundle will serve as illuminating fibres as well as receiving fibres. The operation of this sensor starts with the light leaving the light source and entering the illuminating fibres, then it's going to go out and radiate the target surface. Some of the light is going to be reflected into the receiving fibres and will be detected by the photodetector.

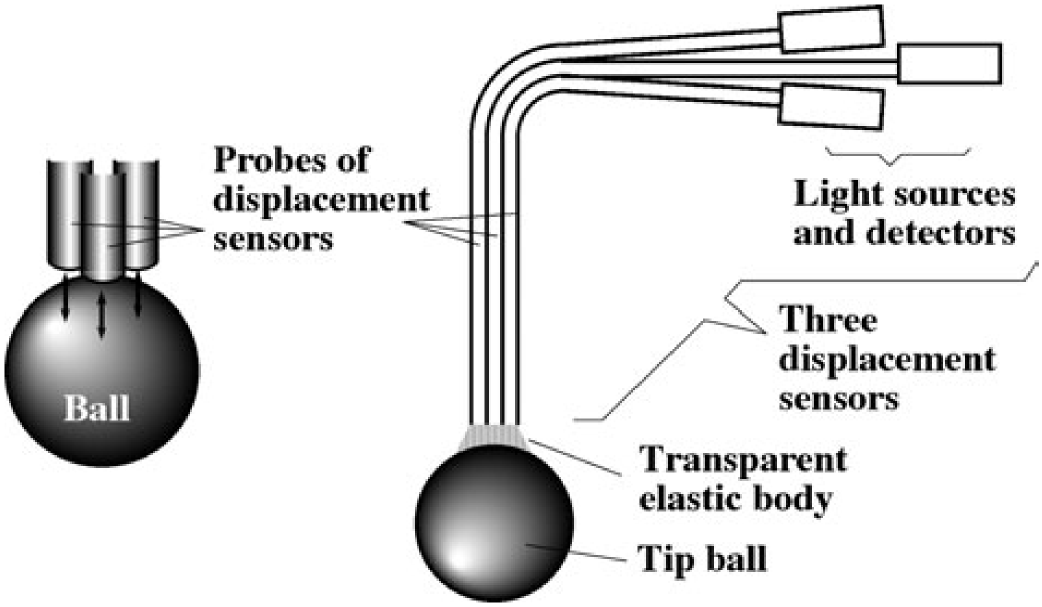

Figure 8 Basic 3D probe using three displacement sensors

Ohka, M. Optical Three-axis Tactile Sensor

Starting to talk about the 3D probe, in Figure 8 it's shown a basic scheme of how it looks a 3D probe that uses three displacement sensors. In this type of sensor, an elastic material is going to connect the sensor tips with the ball. At the moment of touching the workpiece, the external force will move elastically the ball. Then the three-displacement sensor will measure the direction and displacement of the ball. The 3D probe has some advantages over the normal probe: accuracy should be higher; the three sensor measures the direction of the tip ball apart from the displacement; it is a possibility to miniaturize the probe system, friction has no influence except for the contact point; if the tube length increases, it will not have more than little effect in probe's performance.

The probe system it's going to be used is shown in Figure 9. The fibre sensor used are the same I mentioned before. In this case, the tip of the shaft is lower than the rest of saft body to the tip being deflected by the contact of small forces. Instead, o the elastic body that is deformed used previously, in this case stem tip is going to do that work. To eliminate thermal expansion the shaft that is used will me made of Super-Invar. The ceramic ball and a gold-plated mirror are attached with rapid adhesive to the shaft tip. The displacement sensor will be located with angle difference of 120º between them

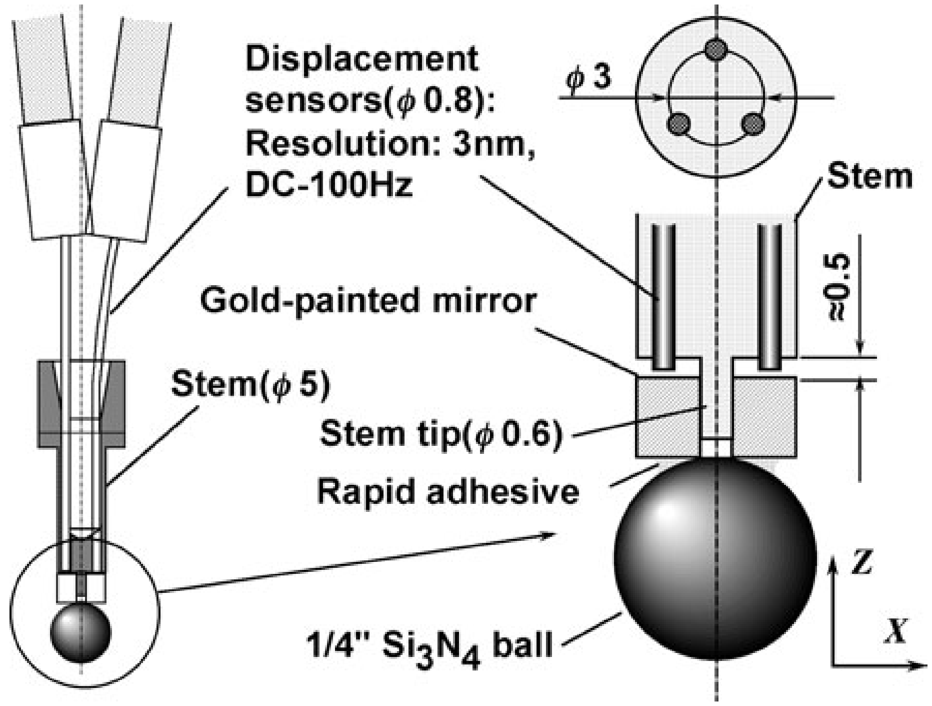

Figure 9 Sectional and detailed view of the probe system with three displacement sensors

Ohka, M. Optical Three-axis Tactile Sensor

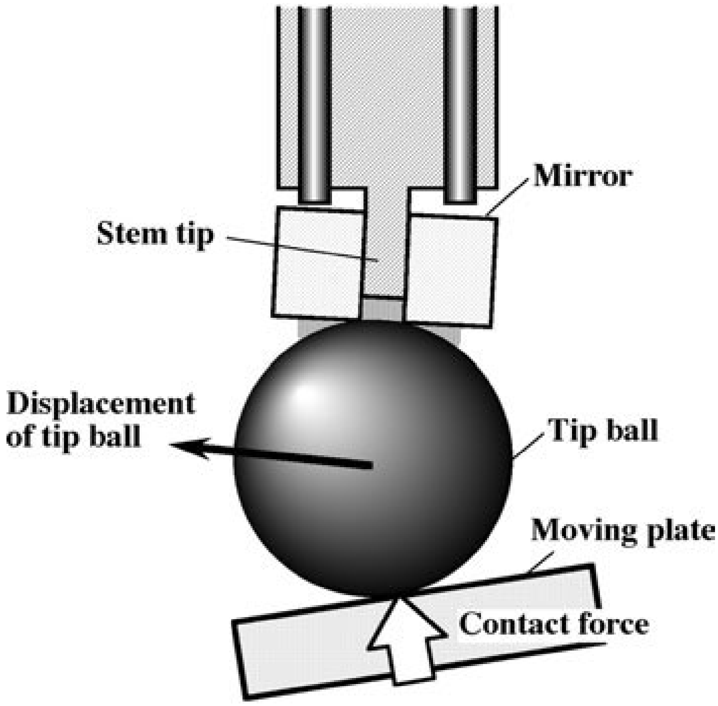

Figure 10 Movement of the tip ball approaching a surface

Ohka, M. Optical Three-axis Tactile Sensor

The movement of the ball and the mirror will increase or decrease the distance from the mirror to each of the displacement sensor. With that distances, displacement vector of the tip can be calculated. In Figure 10 we have an example of how the tip ball approaches a surface and it show the movement of the ball and how the mirror inclines in different direction of the movement.

1.4. Normal force measuring touch probe (NFMT)

Device No. 4. Normal force measuring touching probe by Jae-jun Park and Kihwan Kwon. Reference 4

Normal force measuring Touch probe (NFMT) (Jae-jun Park, 2006) is s sensor that will be used for coordinate measuring machines (CMMs). These machines can measure coordinates of spatial points only by touch the surfaces where this point is. This sensor normally has a stylus and attached to it a tip ball that is what will be in touch with the surface.

It is preferred that data is collected from the tip ball contact pint with the measuring surface. But normally, in this area of study, most of the sensor used for CMMs measure the coordinate by reading the position of the centre of the tip ball as its seen in Figure 11. Then they estimate the contact point from the radius of the tip ball.

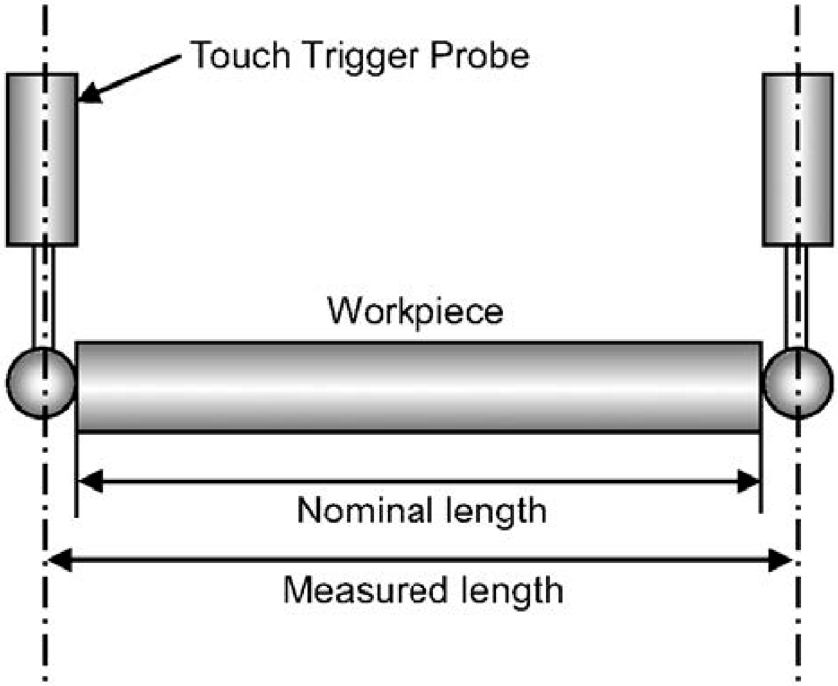

Figure 11 Movement of the tip ball approaching a surface

Jae-jun Park, Kihwan Kwon. Development of a coordinate measuring machine (CMM) touch probe using a multi-axis force sensor

By the way, the exact contact point of the probe tip is almost impossible to calculate if the surface of studying is inclined and pretravel errors exists. Al of this errors can be compensated if the touching probe can give sufficient three-dimensional information about the forces it is measuring.

With NFMT probe orthogonal vectors are used to stand for the probing forces and can estimate pretravel variation and the contact point between the workpiece and the tip ball. NFMT is a sensor that will measure the contact force vector, this vector is normal to the touching surface in the point of contact. The structure of the NFMT, shown in Figure 12, consists of a stylus with an attached tip ball, then it has a 3 elastic legs in form of a tripod structure that is elastically deformed when the probing force is applied.

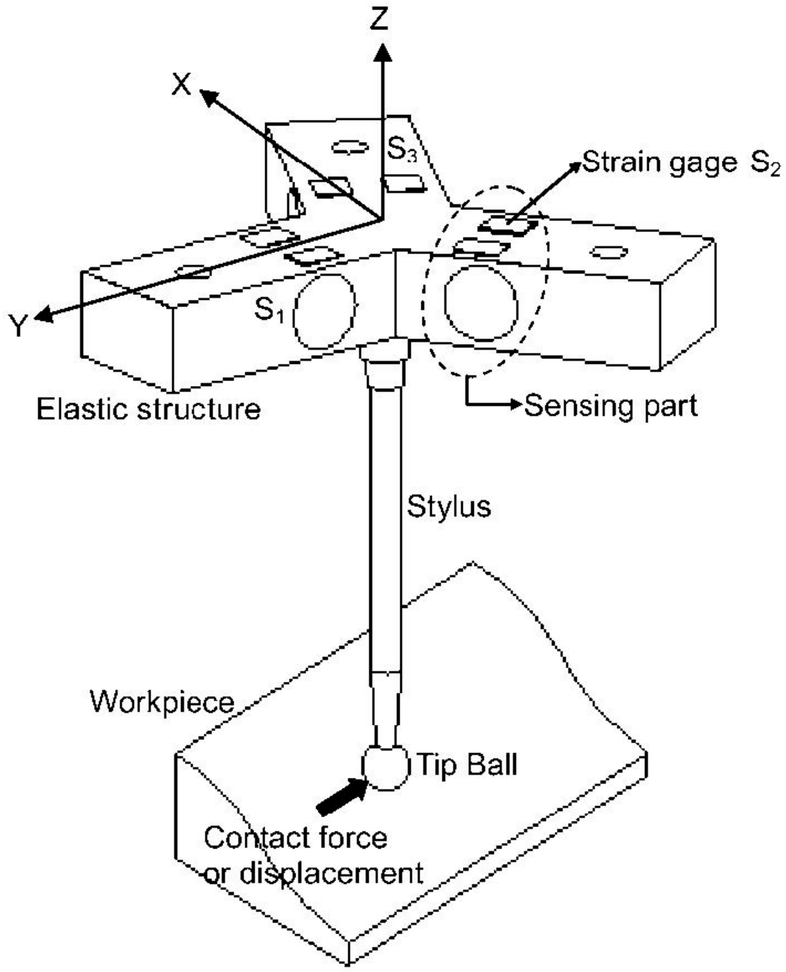

Figure 12 Structure of the NFMT

Jae-jun Park, Kihwan Kwon. Development of a coordinate measuring machine (CMM) touch probe using a multi-axis force sensor

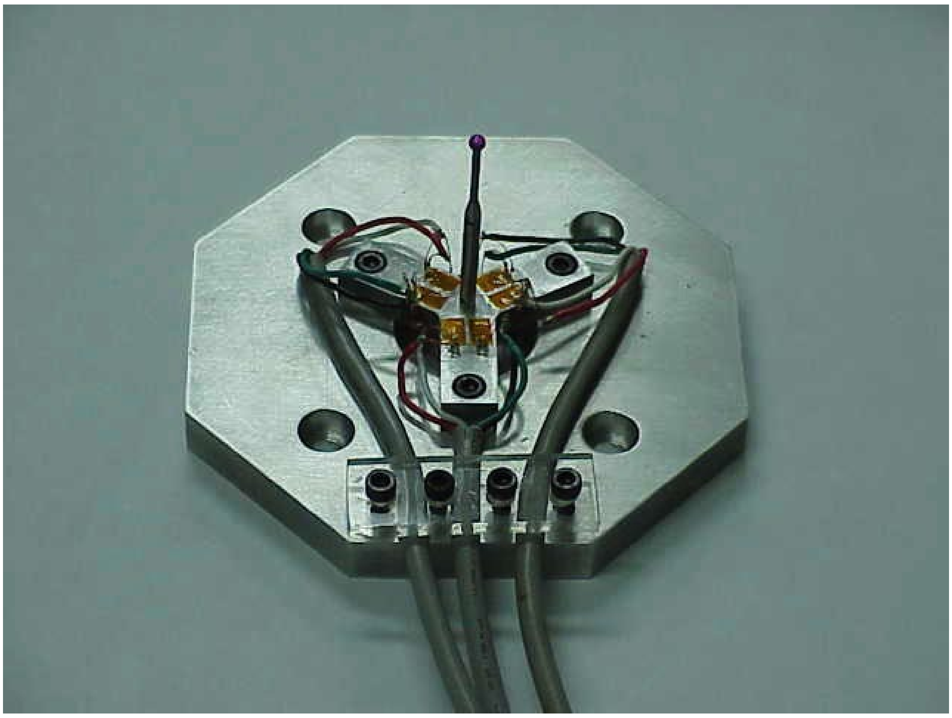

Figure 13 Prototype of the NFMT

Jae-jun Park, Kihwan Kwon. Development of a coordinate measuring machine (CMM) touch probe using a multi-axis force sensor

Each of the legs have four strain gauges which transduce the deformation of the leg into and electric signal, those four strain gauges are electrically connected to form a whetstone bridge circuit.

The tip ball is made of a spherical ruby, it has a diameter of 3 mm and is adhered to the stylus that is in the center of the tripod leg's structure. The stylus has a length of 40 mm and is made of stainless steel. The elastic deformable sensing part that each leg has is made from 7022 aluminum. The shape of the sensing part will be a rectangular cube with a hole of 6 mm of diameter crossing it. The positions of the strain gauges will be determined by FEM analysis. Th position where the strain is maximum is where the gauges will be attached in the sensing part. The resistance of the strain gauge is 350 Ω and the gauge factor 2095. The prototype of this sensor is shown in Figure 13.

1.5. Substantiation of the decision

As we have seen there a lot of types of touching sensor and machines to do the same work or a work that is similar. In the case of this paper, we are developing a touching sensor which will be attached to a robot. The sensor will not count with any vision system, not as we shaw in the first 2 examples (Sections 1.1 and 1.2). The touching part ill consists in a tip ball installed to a stylus in order to be vertical and touch the working surface with the ball, the design will be similar to the one observed in NFMT sensor (Section 1.4). In this case the solution provided in sensor described in Section 1.3, using adhesive to attach the tip ball to the mirror will be modified, because the tip ball will be 3D printed as the same time as the stylus and only in one piece.

The tip ball and stylus structure will end in a cylindrical structure that has been cutter, having 3 differenced legs, this design was inspired by the tripod structure of NFMT (Section 1.4). the attachment to the robot will be 3D printed, like the rest of the parts of the sensor. These parts are a holder, the part where the sensor is attached to the robot arm, and a cover that will be connected to the holder. In the space between the holder and the cover, is where the sensing part is located.

Instead of using strain gauges, the selection has been made for this project is the use of piezoresistive material, in concrete the chosen is Velostat (330 ohms, 2021). 6 pieces of resistive material are going to be located among the tripod surface. There will be 3 of them in the top part and the other 3 in the bottom part. Another important thing to count is that the resistive material needs to be accompanied in both surfaces by contacts (Stacey Mulcahy, 2015) (Electrjuanyu. 2019) (Sean, 2016). In this case the contacts that are going to be made of copper. The resistive material chosen can be cut in the shape wanted, so that this would be a circle. Then the Copper contact will have the shape of a circular trapezoid, then, the resistive material will always stay inside the copper contacts area.

Using this sensing system, the contact point of the tip ball with the working surface will be obtained from the measures of the 6 Velostat sensor. Velostat is a material that is affected by compression. When it is compressed, the resistance that goes through the resistive material decreases. So that, when the tip ball touches the working surface, only 3 out of the 6 sensors will be compressed. With the information of what sensor are compressed and what magnitude has the resistance decreased, the coordinates of the contact point will be calculated.

The robot where the sensor is going to be attached is MOTOMAN SF2000 (shown in Figure 14). This is a robot that counts with 6 liberty axes, a payload of 61 kg and has a total mass of 130 kg. The high reach of the Robot is 1378 mm and possesses a repeatability of ±0.08 mm.

Figure 14 Robot Motoman SF2000

The robot also counts with the Motoman NX100 controller that can control up to four robots with the same pendant. Includes a Windows CE programming pendant with touch-color screen high sped processing and has a memory of 60000 steps and 10000 instructions.

2. CALCULATION OF PROJECT

2.1. Static analysis

When forces are applied to a solid, the effect of the forces are transmitted into the solid and they deform the solid. Inside the solid, some internal forces are induced by the external forces in order to try to stabilize the solid and guide it to a equilibrium state. With the static analysis displacements, can be calculated. It can be calculated unitary deformations and reactive forces can be calculated

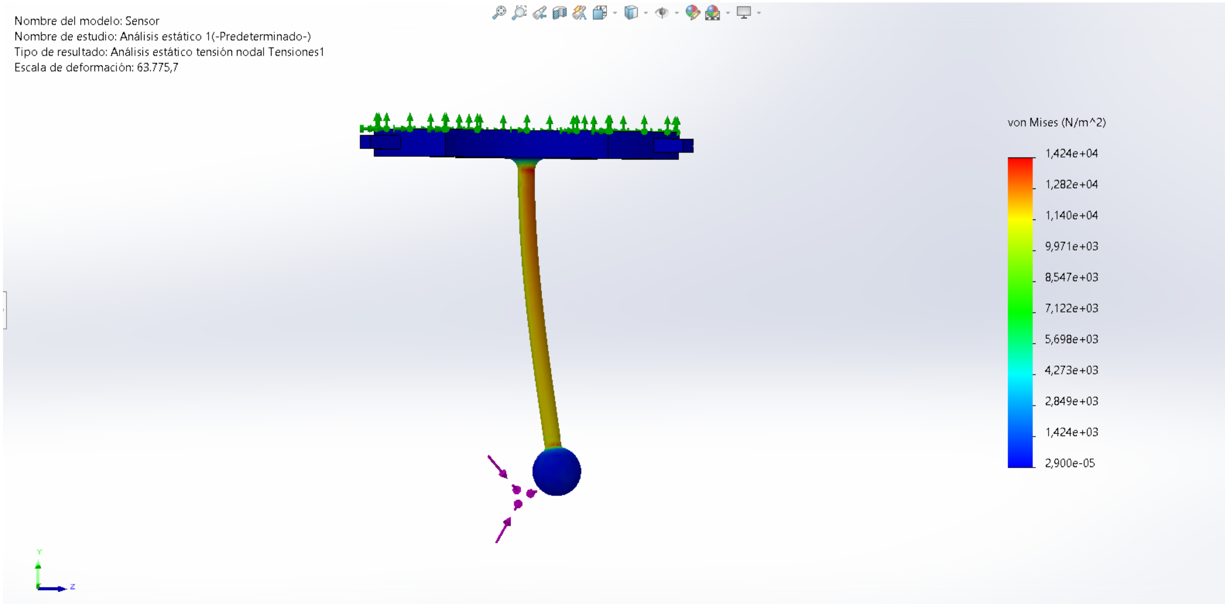

Figure 15 static analysis of sensor – tensions

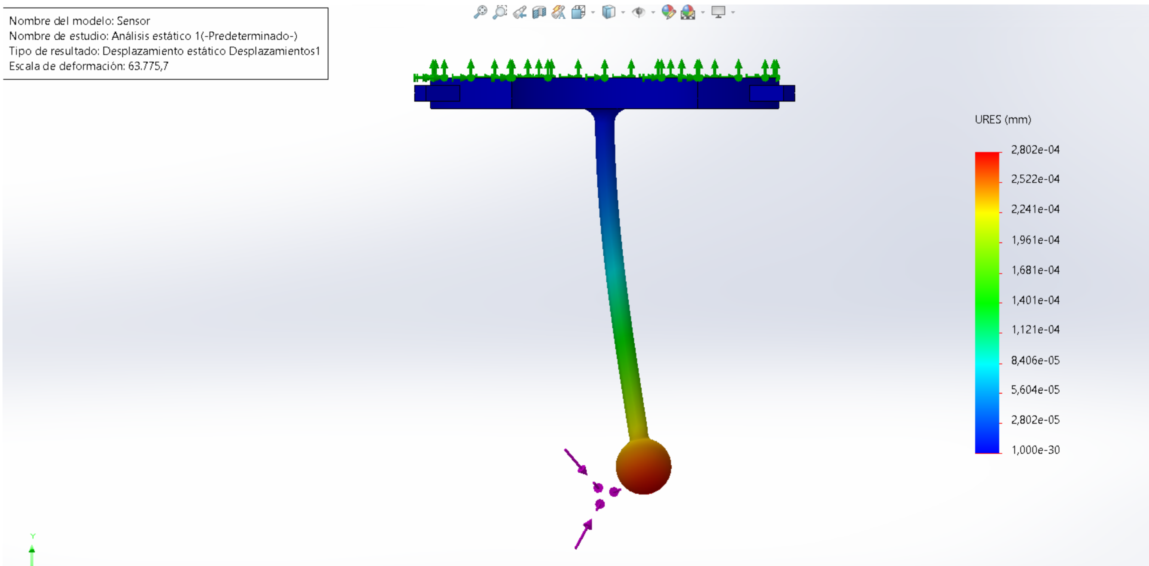

Figure 16 static analysis of the sensor – displacements

Analyzing the touching stick part of the design, a fastener is be put in the flat surface that is opposite to the tip ball. There is going to be a force of 5 N applied in the tip ball as well. The result of the simulation as showed if Figure 15, where we can see that the most problematic part of the design for the tensions in the stick itself. The ball and the flat surface don't suffer almost anything, but the stick gets deformed due to the force applied. The Figure 15 shows the tension among the whole pieces. Figure 16 shows the different displacements that occur to the piece after the force is applied. These displacements are not in a bug magnitude but can be a problem if the force applied is big. With this result of the analysis, we can observe that the design is done in a correct way and will withstand the force applied to him.

2.2. Frequency analysis

2.1.1. Touching stick Frequency analysis

The sensor design has a peculiar form that from outside can be deformed easily. With the frequency analysis we are going to see which parts of the piece's body are easily breakable or deformable.

As we can see in the Figure 17. the points where the designed piece suffers more is in the tip ball, that is due to the large stick that the piece has. We obtain the first harmonic in a frequency of 84,086 Hz, it's a small value of natural frequency, but knowing the characteristics of the piece, is a good result. The second harmonic is so similar as the first, but with an amplitude of 84.132 Hz. Where we see a difference is with the third harmonic, as shown in Figure 18., the problem at those frequencies instead of being in the tip ball is in the stick itself, we can see a deformation at 791.58 Hz.

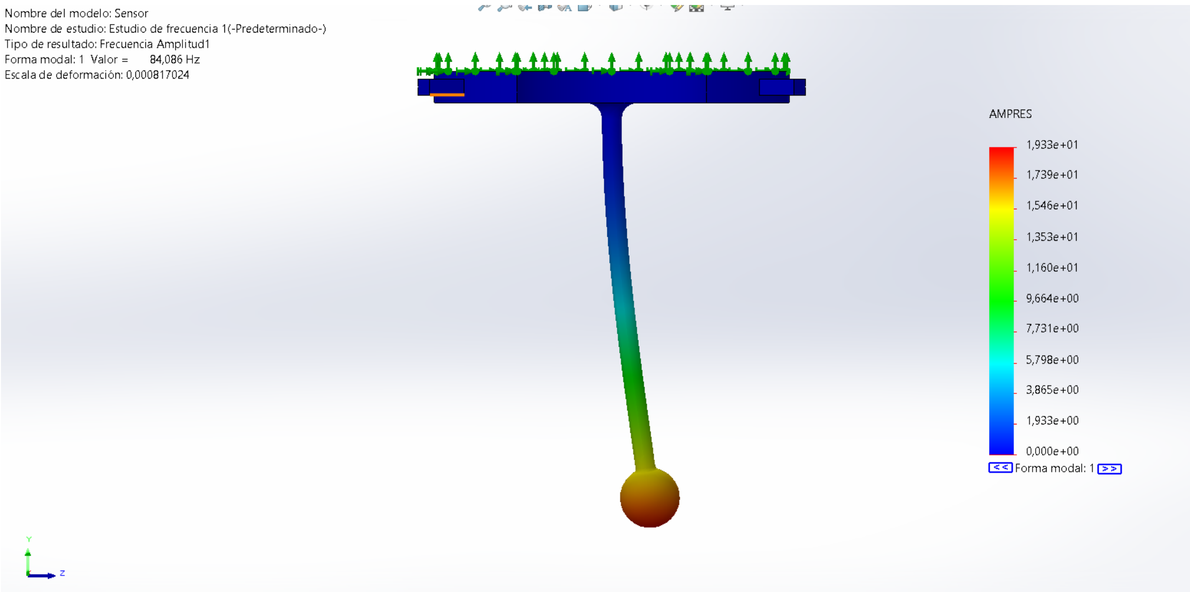

Figure 17 First Harmonic of Sensor design

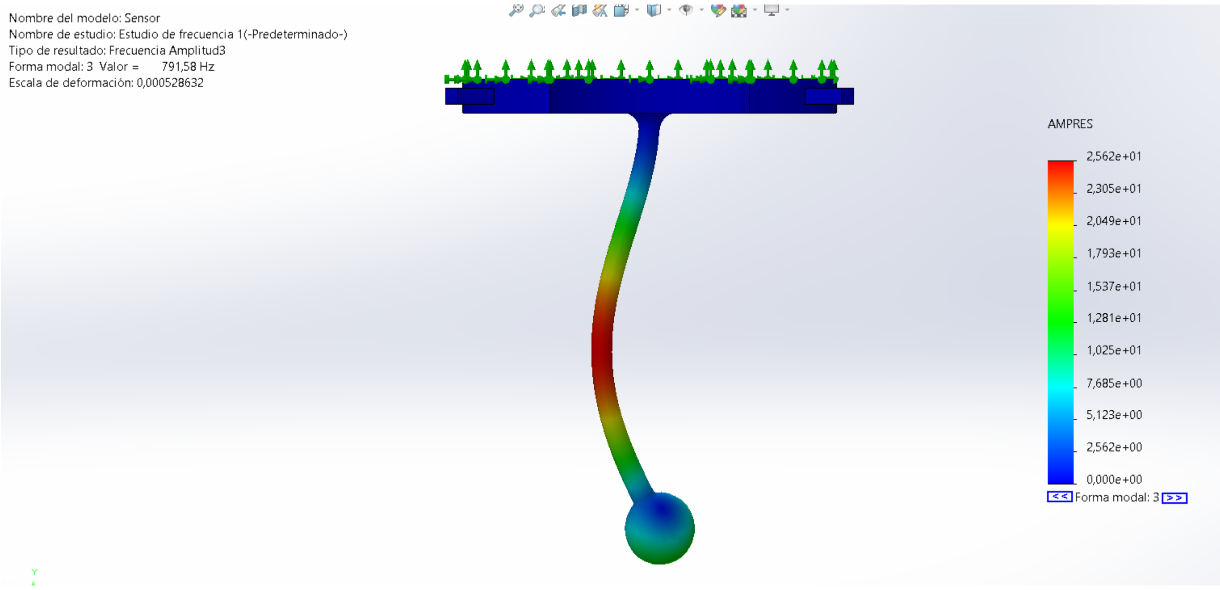

Figure 18 Third Harmonic of Sensor design

2.1.2. Holder Frequency analysis

This is the frequency analysis os the assembly between the pieces called Adaptor, Holder, and Holder 2. As we count with an assembly of 3 different pieces, this time we need to put some connectors where the bolts and nuts will go. The top part of the adaptor will go attached to the robot arm, that is why the fastening has been putted in that flatted surface. The result of the frequency analysis is shown in Figure 19. As it can be expected, the farthest part of the assembly is more deformed than the rest. The natural frequency of the first harmonic is 180.91, in this case, the value of the amplitude is bigger that the sensor design, that is because this design is more compact than the other. The frequency is good because it takes longer to start having big deformations.

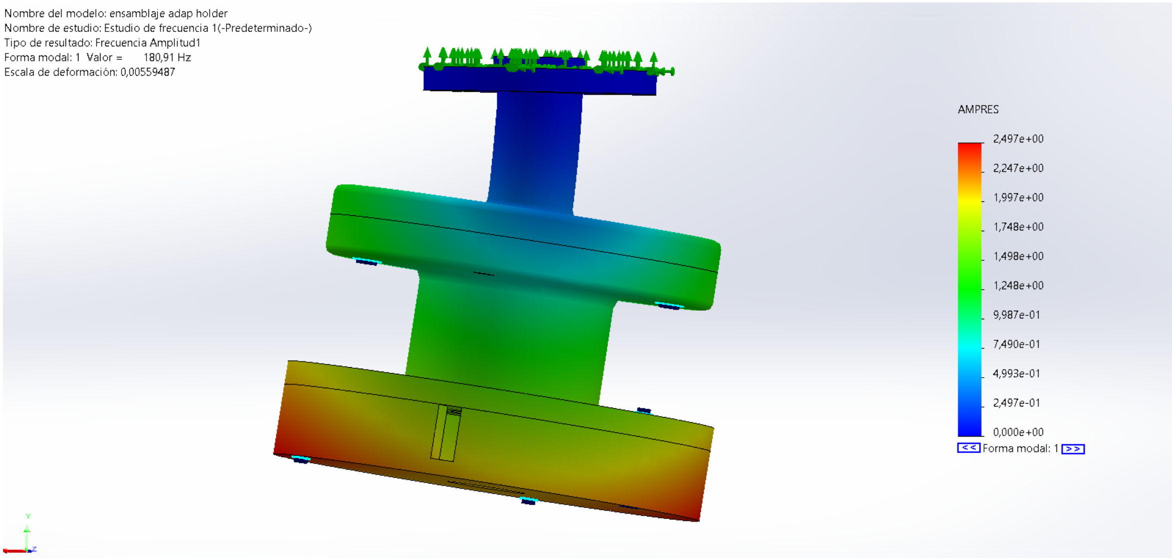

Figure 19 First Harmonic of Holder assembly

2.3. Design of the sensor parts

In this part of the thesis is where the different constructions that have been made are going to be shown and explained. All of the parts that are described in this section are printed in Polylactic acid (PLA) with different percentage of infill, due to the necessity of being stronger. The first is going to be the touching stick.

2.3.1. Touching Stick

The touching stick consists in a cylindric base, with 3 apertures to quit material and make less time printing. The base without these 3 apertures has the sensation of having 3 different legs, which was the intention of doing it among the previous reason. The design of the part is shown in Figure 20. Attached to the cylindrical base it's the stick, that connects the base with the tip ball. The tip ball will be the touching part, the part of the sensor that is going to be in contact with the contact surface. There are 3 guidance projections that would fit with holes in Holder 2 part.

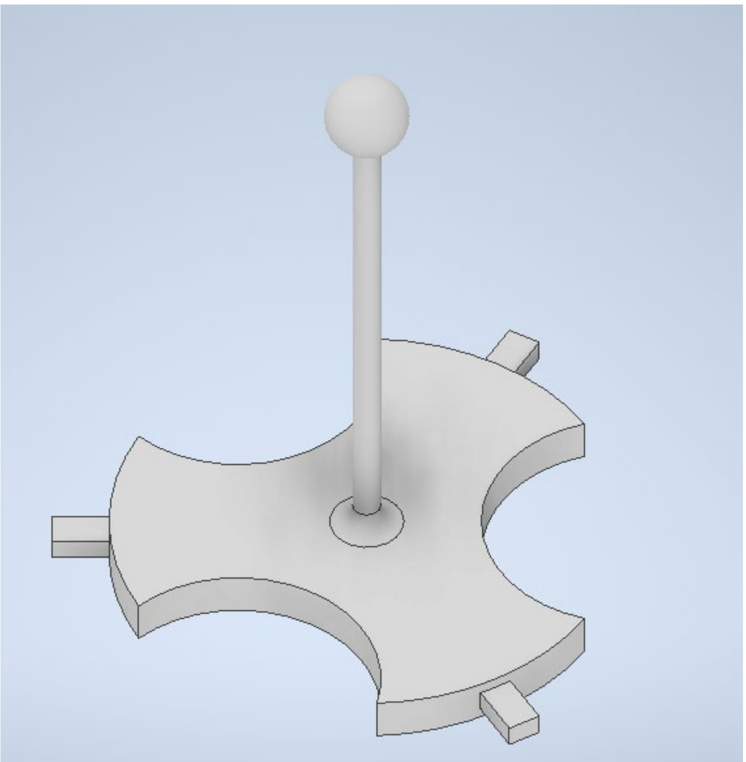

Figure 20 Touching stick part of the sensor

2.3.2. Holder 2

This part of the sensor is in charge of having inside the copper contacts, the resistive material, and the cylindrical base of the sensor stick. As it is shown in Figure 21, there are 3 rectangular holes in the design, that is because cables connected to the resistive material are going to go through these holes.

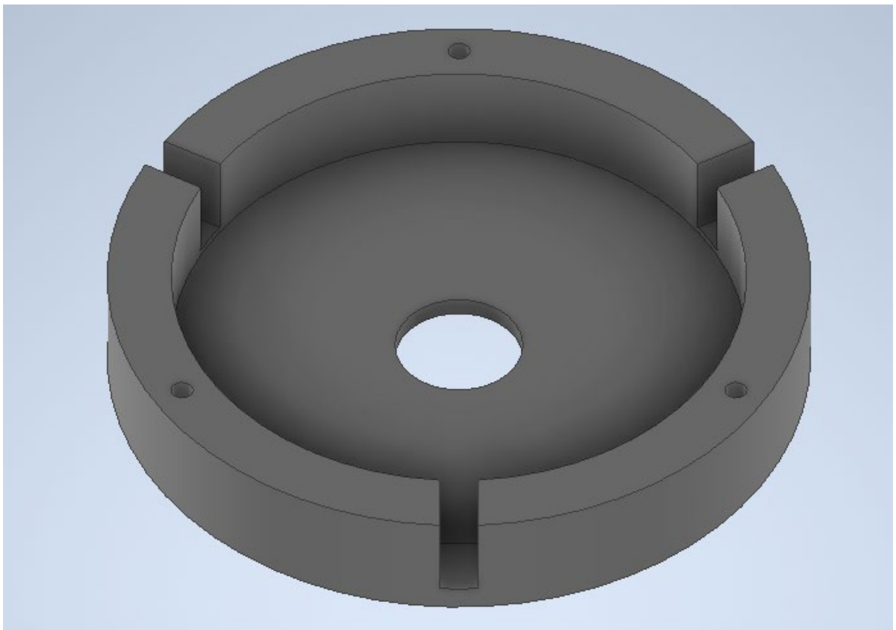

Figure 21 Holder 2 part of the sensor

As well the 3 guidance projections that the touching stick has, have the same size as these holes to make the touching stick unable to rotate about his Z-axis.

2.4. Calculation of touching coordinates

The purpose of the touching sensor is to calculate the coordinates of the contact point between the tip ball and the touching surface. The algorithm for the calculus will consist in the following steps. The first thing will be to obtain which 3 touching sensors are compressed; with that information the calculation part can start. The robot sensing part is going to be distributed like shown in Figure 22. With the areas ABC in the bottom part and DEF in the top part of the sensing zone.

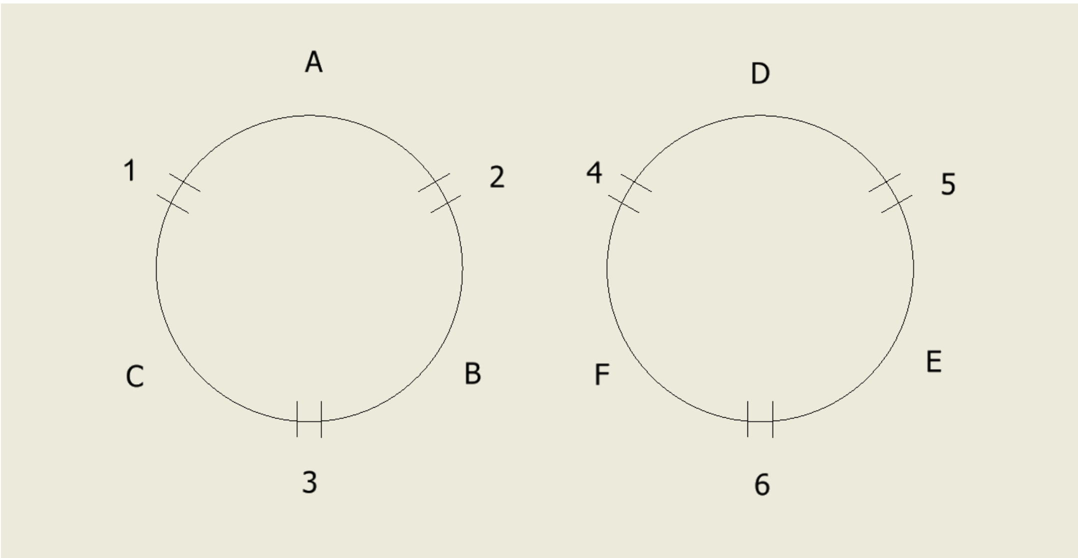

Figure 22 Contact zones

These different zones are obtained with the measure of the 3 sensors that are being compressed. Each of the zone is composed with the next combination of sensors:

Zone A: 1-2-6

Zone B: 2-3-4

Zone C: 3-1-5

Zone D: 4-5-3

Zone E: 5-6-1

Zone F: 6-4-2

Knowing the zone is the first par for obtaining the coordinates of the contact point. The coordinates will be calculated from the coordinates of the sensor. Each of the sensors (1 to 6) will have the coordinate of the angle they made with the horizontal reference of the robot.

Each of the touching zones that are described in this section have a similarity, in all of them there are 2 sensor that are in the same part of the sensing zone (top or bottom), for the next calculations we are only going to work with those 2 sensors information that will provide X and Y coordinates. Then with the sensor in the other part the Z coordinate will be obtained.

When calculating the arc length, we will use Equation 1. In this equation we have some data needed to obtain the result: R, is the radius of the arc, in pour case it will be the radius of the tip ball; α, is the angle that the arc has from the reference point, the position where you want to calculate the arc length.

$$L_{\alpha} = \frac{2 \cdot \pi \cdot R \cdot \alpha}{360} \tag{1}$$

The problem now we have is how to get the angle. This is going to be calculated with formula that has Equation 2. There, we take the reference of the sensor that is in the left and use the resistance information to calculate the contact angle between them.

$$R_1 \cdot P = R_2 \cdot (120 - P) \tag{2}$$

R1 is the resistance value of the sensor that is placed more left in the circle between both. R2 is the resistance value of the other sensor. P is the value of angle where the force is applied, it is referenced to the position of R1. R1 can be any of the 6 sensors, when knowing what 2 sensors are we working with, the reference coordinate of R1 will be added to know the exact angle that the contact point has with the reference axis of the robot.

After knowing the angle, we can obtain the coordinates x y and z of the touching point. The z coordinate is going to be calculated with a direct proportion of the resistance on the other side that has been compressed.

$$R = \sqrt{x^2 + y^2 + z^2} \tag{3}$$

$$x = R \cdot \cos(\alpha) \tag{4}$$

$$y = R \cdot \text{sen}\ (\alpha) \tag{5}$$

In the Equation 3, the values of x and y coordinates can be changed for the value of Equations 4 and 5. Its only needed to change 1 of the equations because the z value is known, and the value of R, the radius of the tip ball, is known too. After that both values are obtained, and the touching point coordinate can be represented in the space.

2.5. Description of sensor operation

The design of the sensor and the operation of this one is the goal of this project. The sensor is a tool that is going to be attached to a robotic arm. As all the tools that are used in a robotic arm, this sensor has a specific purpose and has a specific operation principle. As is has been previously said, the sensor will have purpose of touch the object surface and get the coordinates in the space from the contact point between the sensor and the object surface.

The operational principle of the sensor is the following. The complete sensor counts with 6 small touching sensor that are made with Copper and Velostat, these sensors will analyze the variation in resistance that occurs between the 2 copper contacts. When the resistance between the contacts decreases, pression is being applied to the touching sensor. That is because velostat is a semiconductor that works at compression. The robotic arm with the sensor as his tool will approach the surface of the object that is being analyzed. When the contact is made, three of the small touching sensors will experiment decrease in resistance. Only three out of the six sensors will experiment resistance decrease, and it is because of the location of the sensor. Like it was shown in Figure 22, there will be 2 touching sensors placed in the same location, one in the top surface and the other y the bottom surface, so only one of the two sensors will be compressed.

With the resistance values of the sensor the 3 sensors, a calculation algorithm will be implemented and will get the value of the contact point coordinates in the space. When all the coordinates are obtained, the object form can be reproduced and analyzed.

3. DESCRIPTION OF THE CONSTRUCTION AND OPERATIONAL PRINCIPLE

3.1. Electric block scheme

The electric-block scheme, shown in Figure 23, is composed of 2 differenced parts that are connected to each other. The first one is the electric scheme of the Motoman robot, it will count with the 380 V power source connected to the Motoman NX1000 controller (Robots.com), NX1000 controller is the one in charge of sending the instructions. The controller will not send the information directly to the motors, each motor has a driver to control it and the information will be sent there. After that, the driver controls the motor movement.

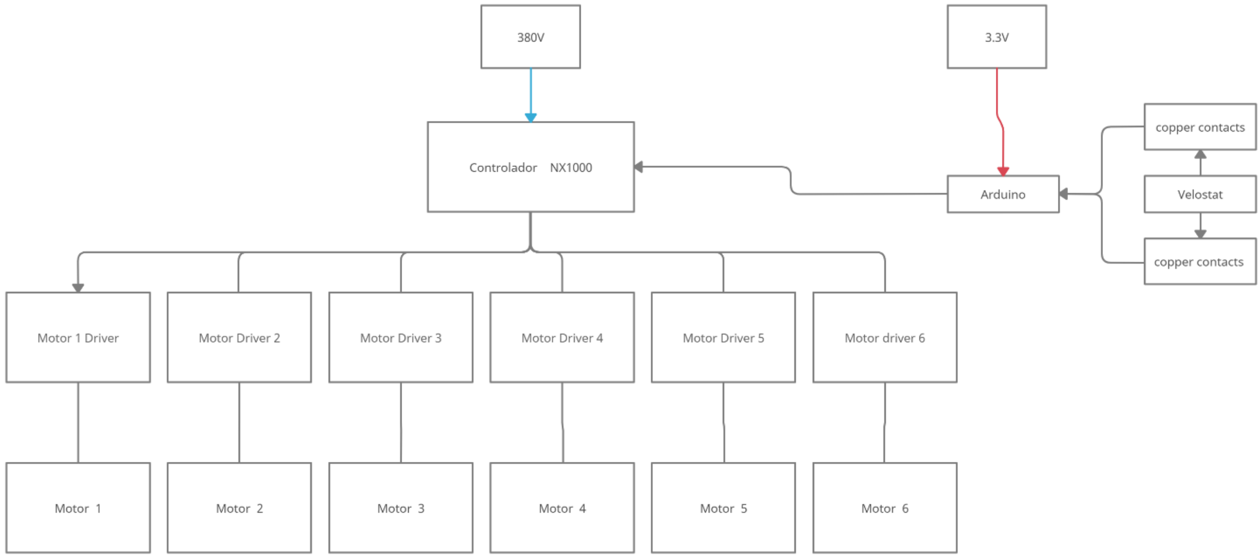

Figure 23 Electrical block scheme

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The other part of the electric-block scheme is the part connected to the touching sensors. This sensor will count with 2 copper contacts connected to an Arduino forming a similar object like a potentiometer. This sensor part is connected to and Arduino, then the Arduino will be connected to Motoman NX1000 controller and will tell him what coordinates it needs to record.

3.2. Algorithm of management of device or node

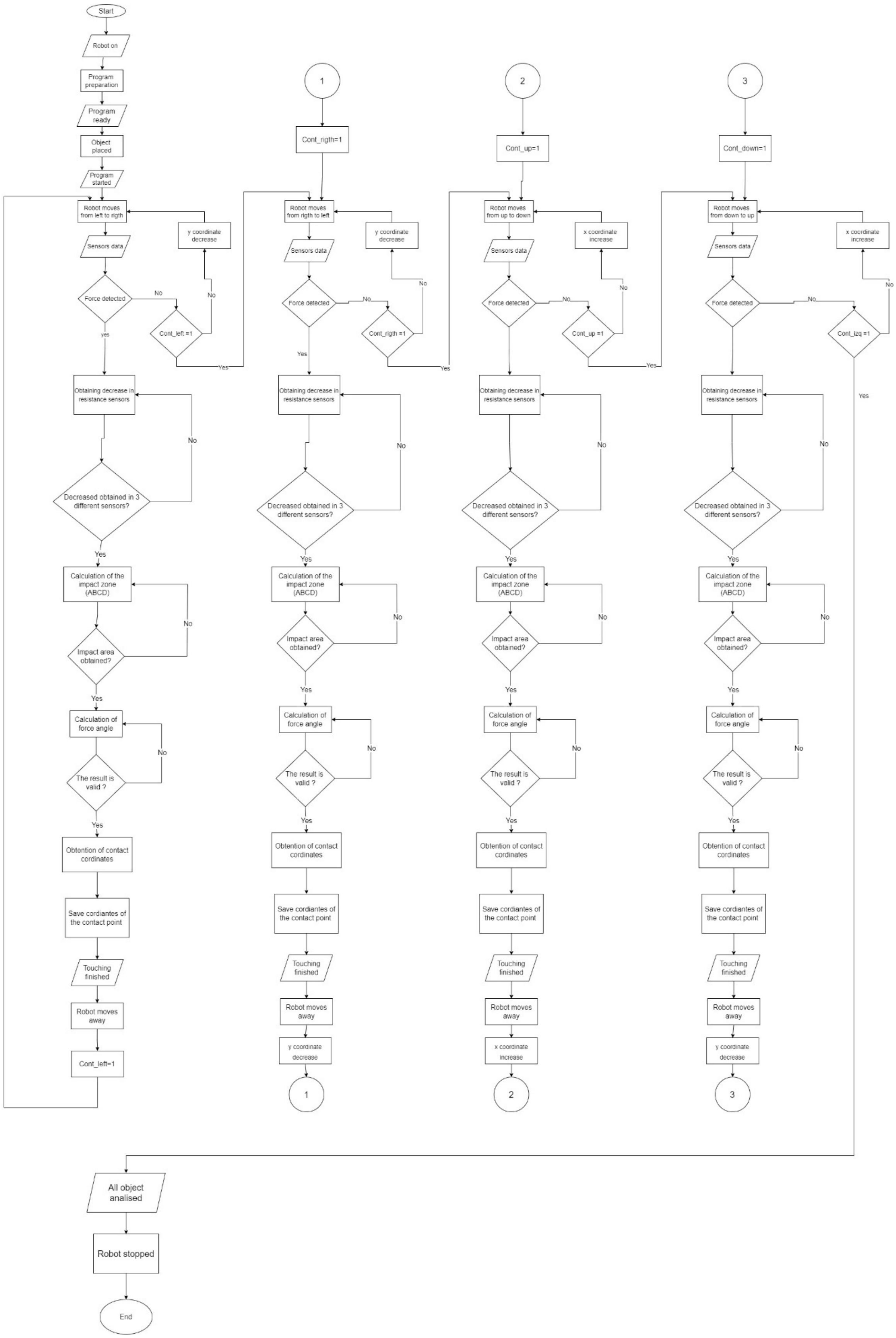

Figure 24 Control algorithm

Control scheme of the project, shown in Figure 24, introduce to the operation of the project. This control algorithm will start with robot being turned on, it's the first step to begin the execution of the program in a proper way. Then it's the time to prepare the program and insert it in the robot. When the program is ready to be executed, the object that it is going to be measured is placed in the working area of the robot, and the execution of the program starts.

Like it can be seen in Figure 24, the control algorithm has 4 big set of blocks that are repeated, this is because the direction movement of the robot will change but the calculation algorithm of the touching coordinate will be the same for every movement.

The movement of the robot will have 4 different paths, from left to right, form right to left, from up to down and from down to up. This have been chosen because with these 4 paths of movement, all the surface of the object can be measured.

The robot will move the arm starting from left to right as shown in Figure 25, the following movements of the robot will be with the same direction but changing the y coordinate. The robot starts the movement and gets data from the sensor, if the robots finish the movement without detecting any force (no change in the data that is obtain from the sensor), the coordinate y of the movement will be decreased and the movement will start gain, as long as any pressure has been previously detected.

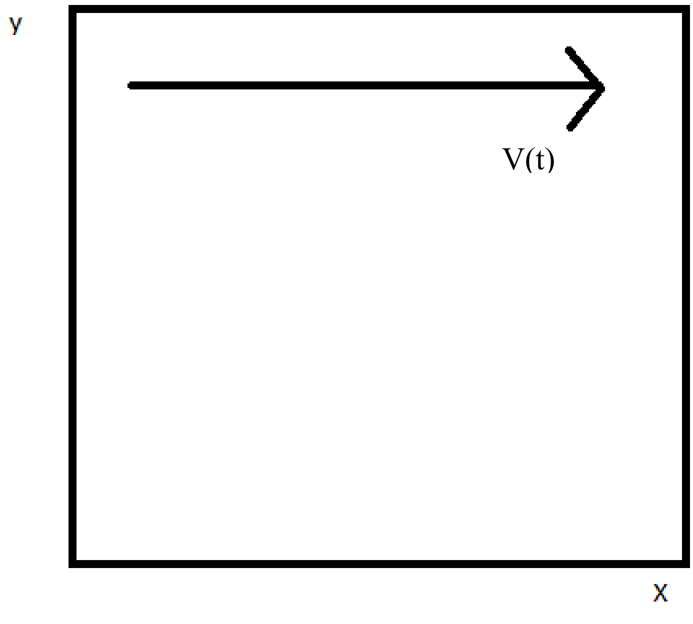

Figure 25 Movement path of the of the robot

If there is pressure detected, the program will look for the touching sensors (sandwich made with copper and velostat) that have their resistance decreased. Even if there are 6 touching sensors, only 3 of them will have their resistance decreased and with that information it can be known where the touching come from.

When the 3 sensors are obtained, the impact zone where the touching point is located is calculated next. After that the algorithm to calculate the angle and the coordinates of the contact point. The calculus will only be made with the information of the 3 sensors that are selected in the previous step.

When the angle is calculated, the next step is to get the coordinates of the contact point from that angle information and the diameter of the tip ball. If the calculated angle is not valid, the calculation will be repeated until a valid result is obtained. These coordinates will be saved.

After the calculations are finished, the coordinates information are saved. The touching finishes in the moment the coordinates are saved, and the robot then proceeds to move away to do the next movement. After that there is one variable that gets the value “1”. This variable is called “Cont” and is the indicator that the sensor has touched at least in 1 occasion the working object. Finally the coordinates for the starting of the next movement are upgraded. If this variable “Cont” has the value 1, and the robot finishes his movement without touching any part of the working object, it’s the indicator that indicates the finalizing of the analysis of the object with that movement direction. The robot will change the path to the next path that has been programed. The algorithm is exactly the same as it has been describen, the only different thing will be the direction of the movement and the name of the variable “Cont” that will have the address of the path that the movement is following.

At the time the fourth paths are finished, finally, the object is completely analyzed, and the robot will stop in a safe position. After that the execution of the program ends.

4. WORK SAFETY

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

The creatin object will wok attached to a robot arm. Safety when working with robots is always a necessary thing because workers and students that work with the robot can get hurt if the necessary precautions are not taken. Here we are going to discuss the safe initial set up and safety procedures that are important. There are some important standards in work safety with robots (Illinois Robotic Group), these are the following: ISO/TS 15066 specifies requirements of security for collaborative robots' systems and their work environment.

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

Safety rules while working with robots:

- Remove the obstructions can be on the robot area
- Revise if the Robot is damaged
- When approaching to a damage part, remove the power and wear protective clothes
- Remove clothes that are loose fitting like sleeves, ties, scarves…
- In case of long hair, it is needed to have it tied up
- Headphones or anything that can distract you must not be
- Remove all the technological pendant the workspace
- Locate emergency stop pushbutton. Emergency stop pushbutton must be accessible for operators who work inear the robot area. This button stops the power of the robot and all the external devices. The position where devices must go after that is a save position
- Use of protective equipment: safety glasses, boots
- All people must be outside the working area of the robot. This can be done in different ways:
    - Light curtains: A beam of light can be used to stop people from entering the working area forming a light grid. The light grid works as an emergency stop pushbutton when a person come into the work area of the robot.
    - Barricades: physical obstruction can prevent people from entering the zone.
    - Safety mats: they have pressure sensor that notices when someone steps in and disconnect the robot.
    - Sign and tape: around the working area can be placed a lot of warning signs. The workspace of the robot should be marked with black and yellow tape around it, to advise about the zone.

4.2 Calibration of the designing sensor

The use of the sensor made with Velostat (Sean, 2016), and copper contacts can have irregularities in the results of the resistance that are obtained. Therefore, the calibration, and the colocation of this sensors are crucial for obtaining the best result as possible. In order to make the less possible errors while measuring, the position where the copper contact is going to be placed will be marked and every week the position of the copper contacts will be checked.

The velostat plate will not move, because it will have the exact size, this will help because calibration of this part of the sensor will not be needed, and it prevents failures in the measures to happen.

Apart from the check in the position of the copper contacts, it is needed to know if the measures of the contact point are okey, so there will be provided some calibration models and simulations that will run the program to check the correct operation of the sensor.

The calibration method that is going to be used is the following:

1. Check position of copper contacts
2. Complete assembly
3. Mount in the robot
4. Approaching perpendicularly to the top surface od the calibration model
5. Measuring of some calibration points
6. Verification of the results obtained

4.3. Assembly of the sensor

The sensor that has been designed has a multiple of pieces that need to be assembled. Due to the variation of the different assemblies, each of them will be discuss individually, and then the assembly of the whole sensor is going to be explained.

The first part to be assembled is the Adaptor, this piece is going to be used to join the arm of the robot with the Holder component of the sensor. This Adaptor has 3 differenced pieces that will need to assemble, the first one, is the base of the piece, that counts with 2 cylinders, one bigger for the base and one smaller for the body. The body cylinder will be assembled with this piece through glue, and the glue will be used in the flatted part and the wall as its shown in Figure 26.

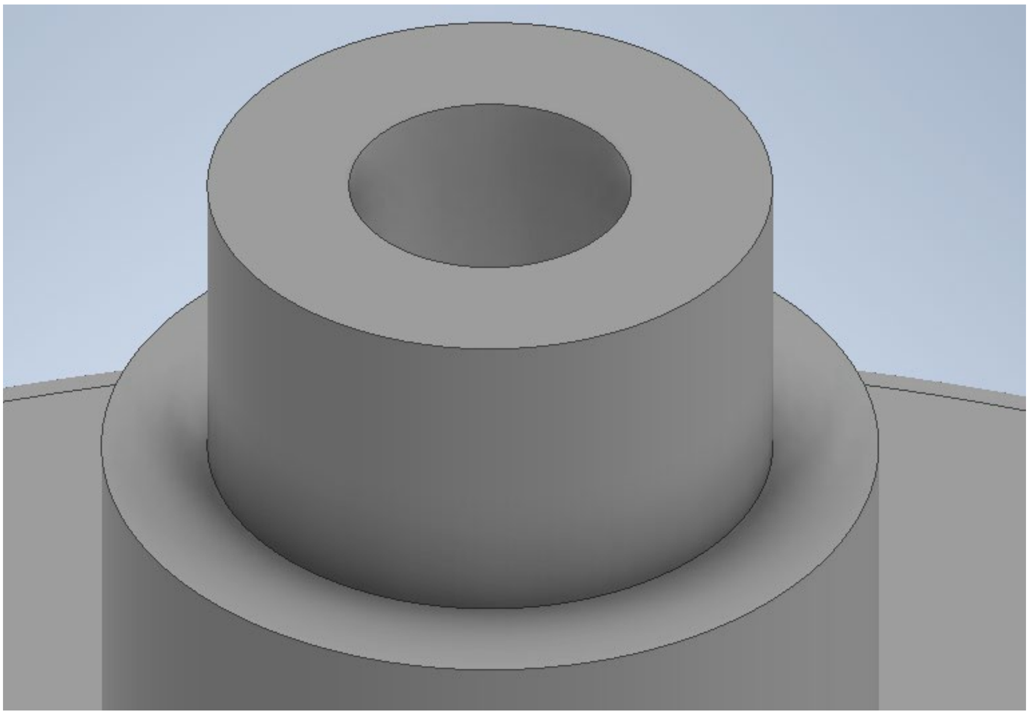

Figure 26 Gluing zone in Adaptor

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In this piece, there is another assembly that is needed to do, this is the assembly of the bottom centering tool for the attachment between the Adaptor and the holder. This centering tool will be a small cylinder that will fit in the hole sown in Figure 27. This cylinder will be attached using glue between both flat surfaces, the one in the cylinder and the flat surface in the hole.

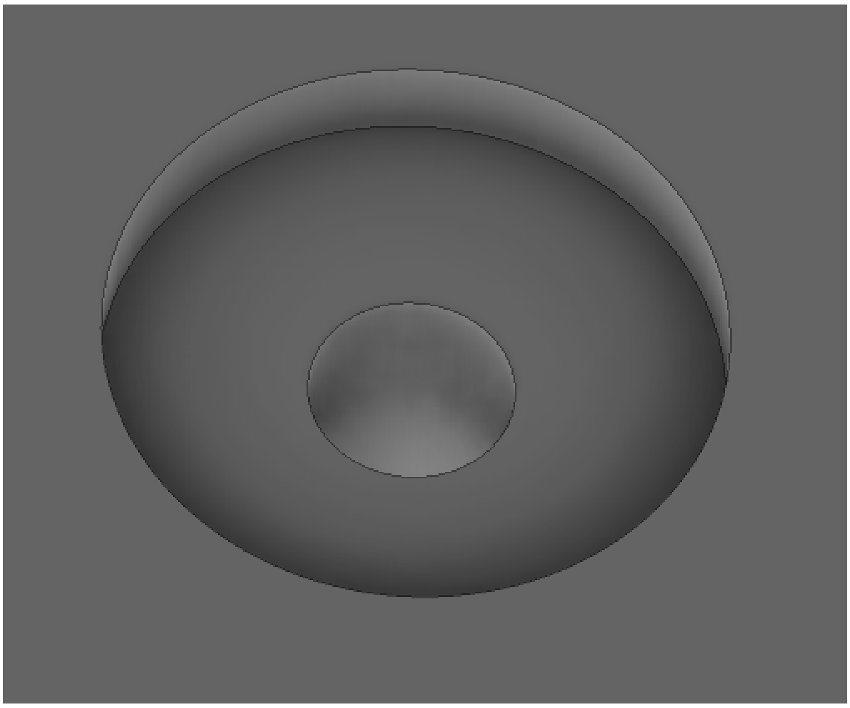

Figure 27 Hole for centering part

The next assembly that is going to be done, is the assembly of the Holder. This assembly is done in the same way, the first part of the holder has the base and the body, and the second part will be a cylinder that will feet in the flat surface that is going to be glued in the same way as Figure 25. The Holder will count with a hole across the whole body, this hole will fit the bottom centering tool that is part of the Adaptor.

These two are the only assemblies with are done using glue, that is because the pieces are difficult to print, so that a lot of printing support would have been needed. These could have led to the waste of unnecessary plastic, so the printing time and the price of the sensor would have been increased a lot.

The following assemblies that will be done, use bolts and nuts. They will be treated separately each of them. There will be used 3 different assemblies will 3 different bolts metric.

For the Adaptor and the Holder connection, there will be used 4 bolts M5x25 and M5 nuts. At both sides of the connection M5 washer will be needed in order not to damage the contact surface that the bolt and nut will have with the plastic material.

Connection between the Holder and the Holder 2 components will need smaller bolts and nuts because the holes are located in the wall if the Holder 2 construct. In this case there are only 3 points of connection, there will be used M3x30 bolts, M3 nuts and again M3 washers to protect the plastic surface.

The last connection that will need these elements to make the assembly will between Adaptor and the robot arm. The robot arm on the edge count with holes of M6 in different radial positions. For this connection only 4 M6x12 bolts bill be used. The bolts will be located within a cross position.

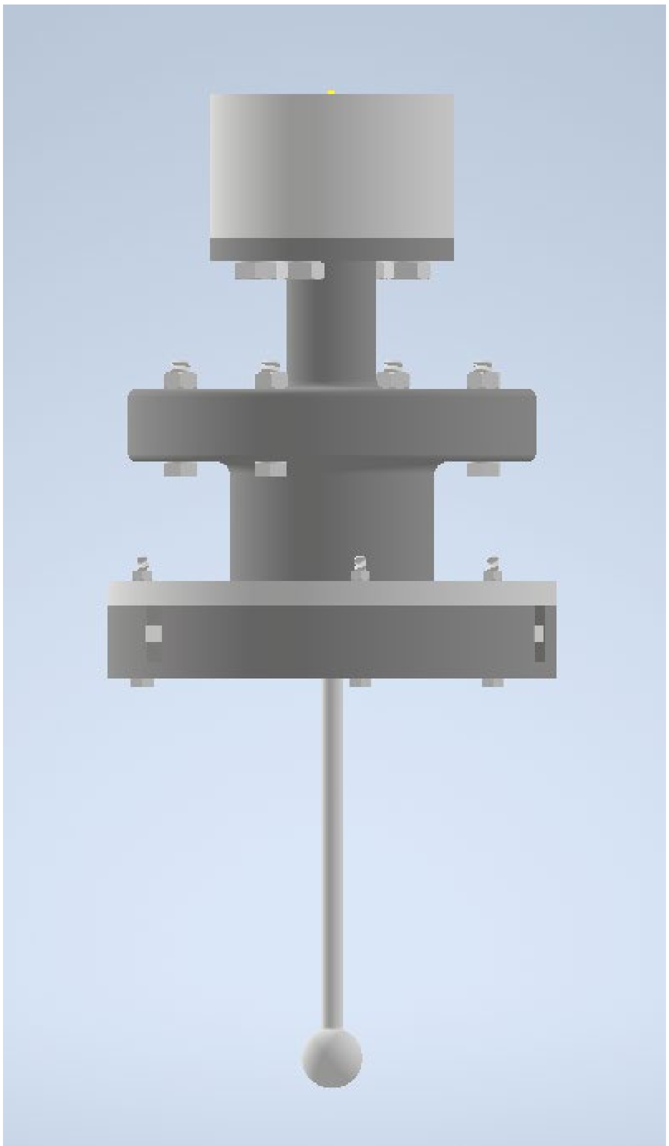

Figure 28 General assembly of the sensor to the robot

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Now that all the different assemblies are explained, it is the turn to explain how to assemble the sensor together and the order of the steps to mount the sensor itself and then to the robot. The complete assembly is shown in Figure 28.

Steps that need to be followed to mount the robot:

1. Gluing of Adaptor
2. Gluing of Holder
3. Placement of 6 touching sensors
4. Placement of touching stick
5. Assembly between Holder and Holder 2
6. Assembly between Holder and Adaptor
7. Connection of the complete sensor to the robot arm

5. ECONOMIC CALCULATION

This section provides an economic assessment of a device or assembly under construction or upgrading.

In this section the economics calculation is being done, and they are distributed in different parts. Fist, we have the cost of the pieces that are printed; then, the cost of the connecting elements; after that, its turn for manufacturing costs; and finally, it's time to the fixed cost that this project has.

Table 1 Cost of printing pieces

Printing piece	Quantity (g)	Printing time (hours)
Holder 1	81	5.76 h
Holder 2	43	3.45 h
Touching stick	21	2.72 h
Adaptor	71	4.73 h
Union Adap+Holder	2	0.183 h
Total	218 g	15.85 h

We have a total quantity of printing material, which is going to be Polylactic acid (PLA), of 218g. As the price of the PLA is approximately 16.1€/Kg, the total cost of the printing pieces will be 3.51 €.

Apart from the printing pieces, in order to assembly the sensor we need some connecting elements. These elements will be bolts, nuts and washers, form different measures and different purposes. The cost of these parts will be shown in Table 2.

Table 2 Elements of connection

Tools	Quant	Price/u
M3x30 Bolt	3	0,224
M3 Nut	3	0,0763
M3 Washer	6	0,051
M5x25 Bold	4	0,28
M5 Nut	4	0,08
M5 Washer	8	0,015
M6x12 Bold	2	0,09
Velostat 30x30	1	1,17
Copper contacts	1	6
Total		10,11356667

As we can see the total cost of the elements of connection will be 10.11 €, and this will be added to plastic cost.

The next calculation is going to be done is the price of the manufacturing of the sensor. This is translated in the cost of the electricity and the time the 3D printer is going to be working. The cost of electricity is 1.1477 €/KWh. As we sow in Table 1, the total printing time of the pieces is 15.85 hours. Assuming the energy consumption of the 3D printer is 0.5, the use cost of the printing parts will be 1.17€. Additionally, to this, there will be necessary to hire an employee to do the working part, the manual working of the worker is paid additionally to his salary, and it will be 700€/month. This employee will work 21 days a month and 8 hours a day. The manual work will require a time of 10 min.

$$Workforce\ salary\ = \left(700\ \frac{€}{\text{month}} \cdot \frac{1\ month}{21\ days} \cdot \frac{1\ day}{8\ hours} \cdot \frac{1\ hour}{60\ min}\right) \cdot 10\ min = 0.694\ € \quad (6)$$

The last addition to the calculations will be the fixed costs of the project. There are some requirements needed to work properly in the project, the first one is hiring an employee to work in the project, this employee will have a base salary of 730€ and then will have the salary for the workforce he does in every sensor, the more sensors he constructs, the more he is paid. The second fixed cost is the renting of a place to work in. This place will be an office or a laboratory where the machine will be placed, and the employee can work. A 3D printer is going to be bought to make all the different pieces and will be placed in the renting place. The price of the 3D printer will be 800€. All of the fixed costs will be shown in Table 3.

Table 3 Fixed costs per month

Fixed costs	costs
min salary	730
officne	500
3D printer	500

Table 4 Variable cost per unit

Manufacture cost per unit	costs
3D printing	1,1705225
PLA	3,5098
workforce	0,69444444
Tools	10,1135667
Total	15,4883336

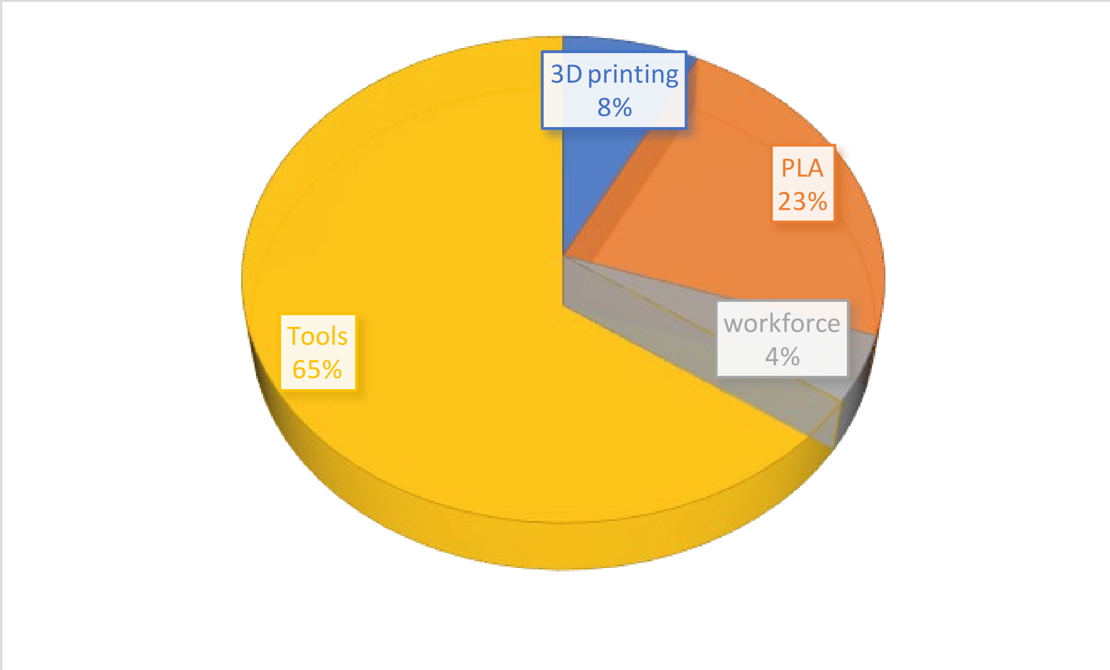

Figure 29 Manufacture cost of the sensor

Daniel Calvo Sanz, 2022

Total of manufacture cost as it is shown in Table 4 is 15,488€ per unit manufactured. The distribution of the different costs shown in Figure 29. The bigger manufacture costs are the connection elements and the price of the plastic used to print. The selling price for this product will be 22€ per unit.

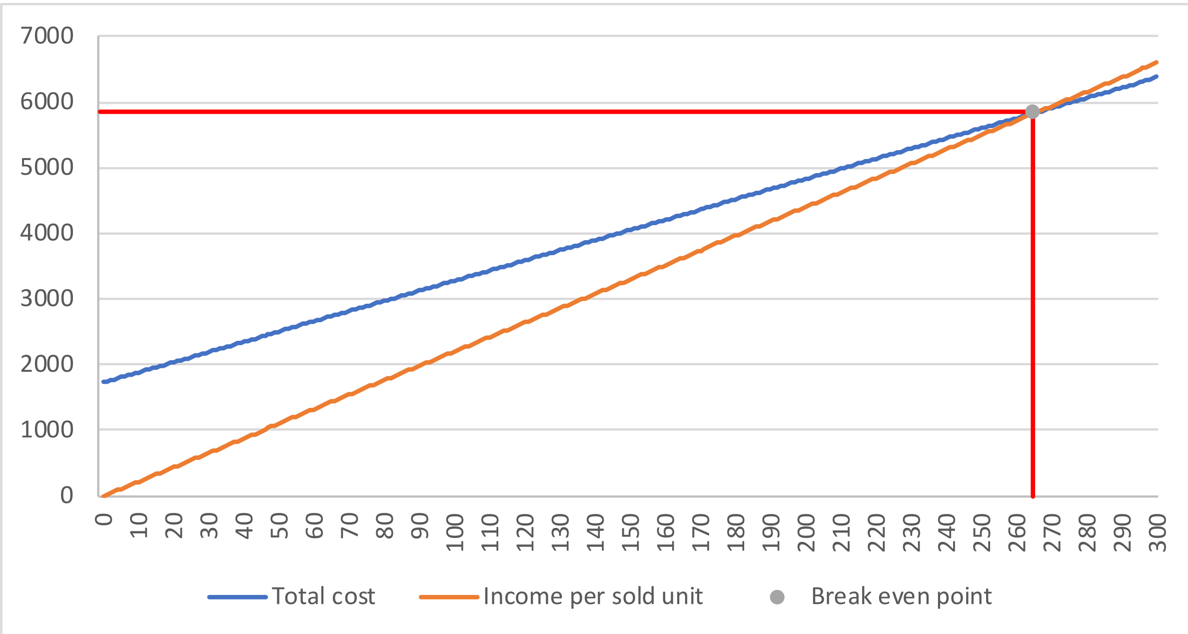

Figure 30 Break-even point between costs and benefits

Now, that it is known the total of the manufacture cost, the fixed cost and the selling, it is time to see what is the quantity of products that need to be sold in order to get profit about the selling's. This is displayed in Fig 30. Benefits will appear from the selling of 266 pieces, after that, the benefits start to get even bigger than the total of the costs. In order to verify the result of the break-even point obtained in Figure 30, the calculus will be shown (Martha Isabel Gutierrez, 2007).

$$B = Units\ sold \cdot Selling\ price = X\ \cdot 22 \quad (7)$$

$$C = Units\ manufactured \cdot Manufacture\ cost + fixed\ costs = \ X \cdot 15.488 + 1730 \quad (8)$$

.

$$X \cdot 22 = \ X \cdot 15.488 + 1730 \rightarrow X = 265.67 \quad (9)$$

The equation to calculate the benefit is equation 7 (Econosublime, 2021), in this equation the benefit (B) is calculated as the number of products sold multiplied by the selling price. The equation of the total cost (C) equation 8, its calculated as the manufacture cost multiplied by the number of products manufactured, and that number is added to the fixed cost of the project. If we make both equation equal, we obtain the number of sensors that are sold in the break-even point (X), this is shown in equation 9

As we can observe the result of the calculus is the same, 266 units of the product are needed to make profit in this project.

CONCLUSIONS

1. The research of similar sensor that are in the market have helped to improve the initial idea that the project has. All the information researched is in a way a possible solution for the work that can be done. But not all the research that have been shown are completely valid. Some of them have different characteristics or are used in other type of situation. Apart from that, they have different types of touching systems, some of them are more suitable for the work is needed in this project and other less but learning from the design and the different measure methods have helped to upgrade the initial design that the sensor has and the measure mechanism.

2. There are different calculations that have been done in this project. The first type of analysis that was executed was the static analysis, but in this case, it was the analysis of the touching stick only. This analysis showed that even the force being applied to the tip ball, the part that suffers more from tensions is the stick itself, but the part that has more displacement is the tip ball.

   The second of them is the frequency analysis of the designed components. In the analysis of the touching stick, the stick is the most problematic part, due to the fragility of the plastic, even it is printed with a 100% infill, it is hard not to be deformed if the frequency goes up. The first harmonic is obtained in the frequency of 84.13 Hz. A reinforcement will be added to give the stick more stiffness.

   In the frequency analysis of the assembly of parts formed by Adaptor, Holder, and Holder 2, it was needed to put all the fixed joints. The results will describe de most problematic part the Holder 2 component, that has a reason, because this component has only 3 joints with Holder part, added to that, the bolts that are used are smaller too. The first harmonic obtained in the frequency analysis fir this component is 180.91 Hz

   The calculation algorithm used to obtain the touching coordinates has a peculiar method and it is the division into different touching zones, this thing will make the code bigger but at the same time it will make it simple, because there will only be needed to make different cases and add the necessary value to the calculation variables.

3. The electric block scheme provides the information of how everything is connected in the sensor and from the sensor to the robot. The different connections that are present have different colours to differentiate between them.

In the control algorithms there was a large variety of possibilities about how to obtain the coordinates. The algorithm used is efficient because it finishes the path when there is no more object to analyse, that saves time and at the same time money. It was distributed in four different paths to prevent point to being forgotten to measure and to reinforce the measures accuracy in corners and edges.

4. Working with robotic arms could be a dangerous work, there is always a possibility to get injured if the robot fails or if a check is being applicated to the robot. That is the reason of the work safety section and the application of the rules and the different advises that are explained. If all the rules that are described in this section are followed there won't be any problem and the work with the robot will be done in a safety way.

   The calibration of the robot is done in the way that it doesn't causes any trouble for the proper work of the sensor and makes the less failures as possible.

   The assembly of the sensor has been designed to be as simple as possible using bolt and nuts as joint elements in the majority of the assembly. Due to the difference in the sensor parts different metrics were used to adapt the assembly and make it very resistant.

5. Everything has a cost of money; this project is not an exception. The design of the sensor was done in a way that printing material (PLA) and printing time are saved, this will make the sensor price lower. The business that is pretended to be done with this project is from the selling of the sensor. The profit will start when the number of sensors sold exceed 266. It is a normal number of selling due to the high amount of fixed cost that are included in the construction and preparation of the sensors.

LIST OF LITERATURE

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

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Annex 1: Prototype Pictures

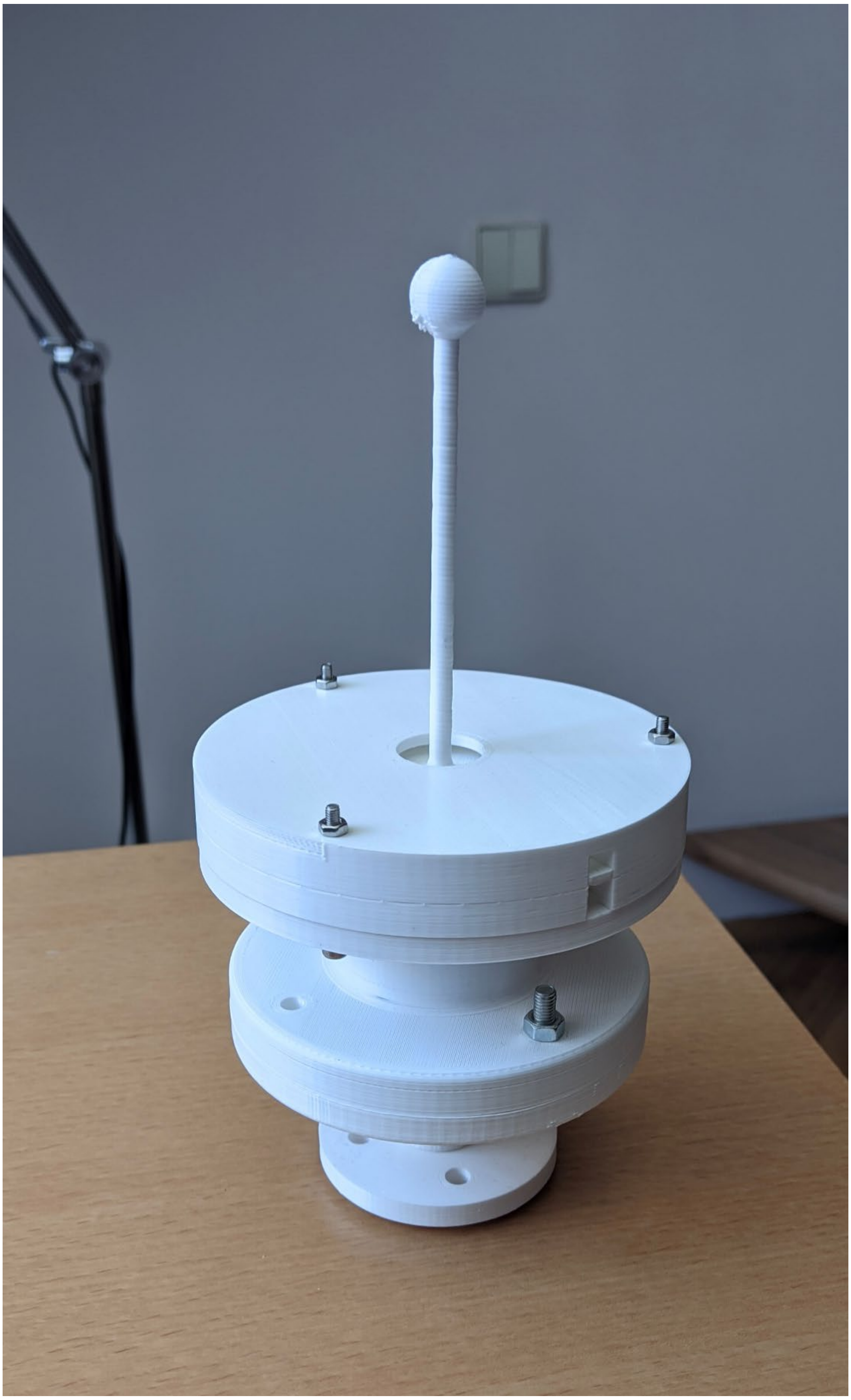


Figure 31 Prototype 1

Figure 32 Prototype 2

Annex 2: Arduino code

```
//A0, A1 y A2 will be the sensors conected to the botton part of the sensing zone
//A0, A4 y A5 will be the sensors conected to the top part of the sensing zone

void setup()
{
  pinMode(A0,INPUT);
  pinMode(A1,INPUT);
  pinMode(A2,INPUT);
  pinMode(A3,INPUT);
  pinMode(A4,INPUT);
  pinMode(A5,INPUT);
  Serial.begin(9600);
}
void loop()
{
  float volt0 = 3; //analogRead(A0);
  float  volt1 = 12;//analogRead(A1);
  float  volt2 = 16;//analogRead(A2);
  float  volt3 = 8;//analogRead(A3);
  float  volt4 = 25;//analogRead(A4);
  float volt5 = 5;//analogRead(A5);
  float  volts[] ={volt0, volt1, volt2, volt3, volt4, volt5};
  int maxind1=0;
  int maxind2=0;
  int maxind3=0;
  float max1=0;
  float max2=0;
  float max3=0;
  float V1;
  float V2;
  float V3;
  double angoff;
  double ang;
  double x;
```

```
double longc;
int R= 0.005;
double xcoord;
double ycoord;
for (int i=0; i<6; i++)
{
  float v= volts[i];

  if (v>=max1 && v>max2 && v>max3)
  {
    maxind3= maxind2;
    max3= max2;
    maxind2= maxind1;
    max2= max1;
    maxind1=i;
    max1=v;
    }
  if (v<max1 && v>max2 && v>max3)
     {
      maxind3= maxind2;
      max3= max2;
      maxind2= i;
      max2=v;
      }
  if (v<max1 && v<max2 && v>max3)
  {
    maxind3=i;
    max3=v;
    }
  }

if ((max1==0 && max2==1 && max3==5)||(max1==0 && max2==5 && max3==1)||(max1==1 && max2==0 && max3==5)||(max1==1 && max2==5 && max3==0)||(max1==5 && max2==0 && max3==1)||(max1==5 && max2==1 && max3==0))
{
```

```
// Zone A;
V1=volts[0];
V2=volts[1];
V3= volts[5];
angoff=0;
}
if ((max1==1 && max2==2 && max3==3)||(max1==1 && max2==3 && max3==2)||(max1==2 && max2==1 && max3==3)||(max1==2 && max2==3 && max3==1)||(max1==3 && max2==1 && max3==2)||(max1==3 && max2==2 && max3==1))
{
// Zone B
V1=volts[1];
V2=volts[2];
V3= volts[3];
angoff= 120;
}
if ((max1==0 && max2==2 && max3==4)||(max1==0 && max2==4 && max3==2)||(max1==2 && max2==0 && max3==4)||(max1==2 && max2==4 && max3==0)||(max1==4 && max2==0 && max3==2)||(max1==4 && max2==2 && max3==0))
{
// Zone C
V1=volts[0];
V2=volts[2];
V3= volts[4];
angoff= 240;
}

x= (V2/(V2+V1))*120;
ang = x + angoff;
xcoord=R*cos(ang);
ycoord=R*sin(ang);

delay(10000); // Delay 1ms
}
```

Annex 3: Bill of Materials

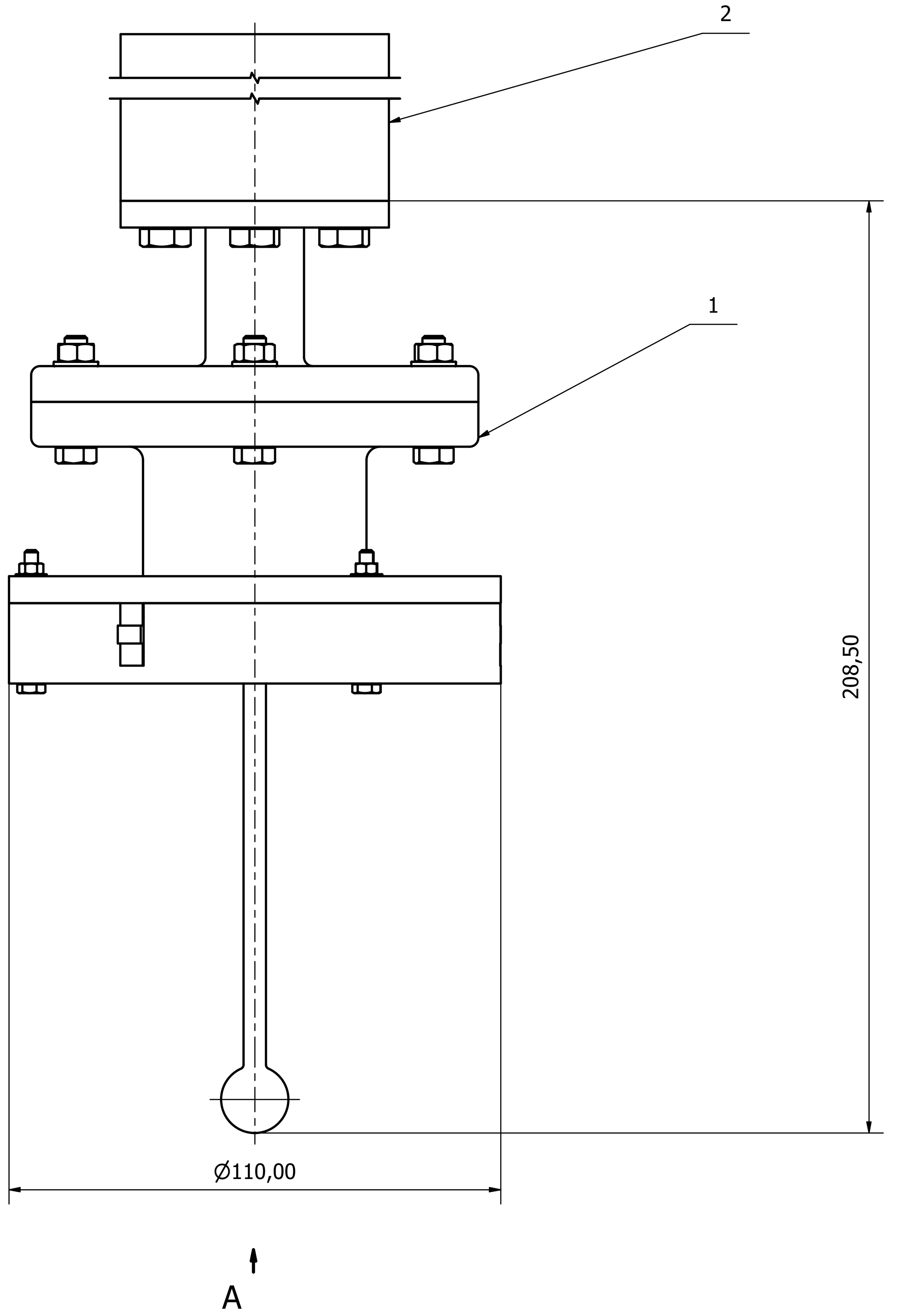
Format	Area	Item No.	Mark	Tittle	Quantity	Note
				Document		
A1			MERS BM 22 01 01 01 00 GV	General View Drawing		
				Subasemblies		
A1		1	MERS BM 22 01 01 01 00 AD	Sensor assembly	1	
		2	MERS BM 22 01 01 02 00 AD	Robot Arm	1	

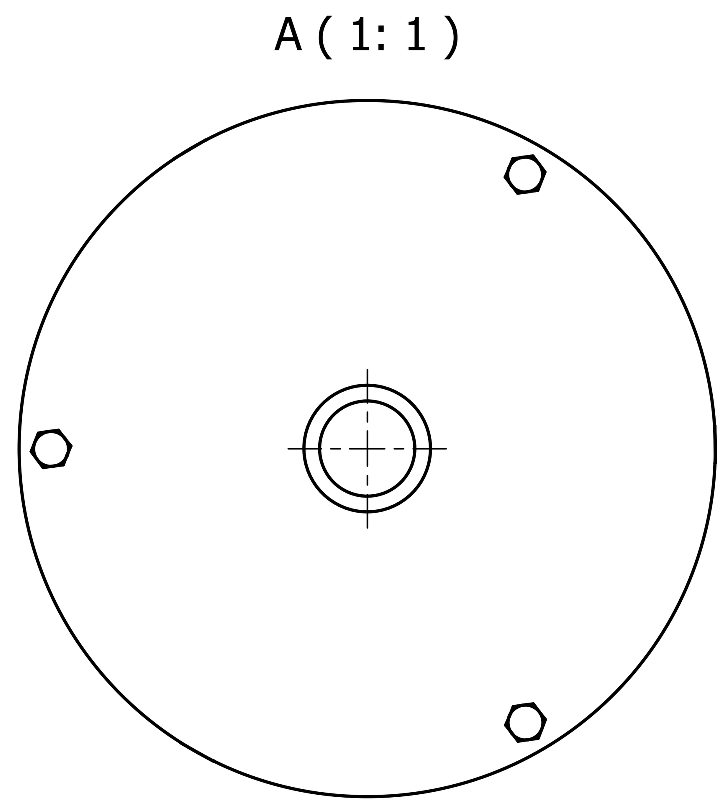
Responisible agency MERS dep.	Consultant	Document type Specification	Document Status Educational
Owner VGTU MRfuc - 18	Compiled Checked	Tittle General Drawing	Mark MERS BM 22 01 01 00 GV Rev / Date 20/05/2022 / Lan EN / Sheet 1

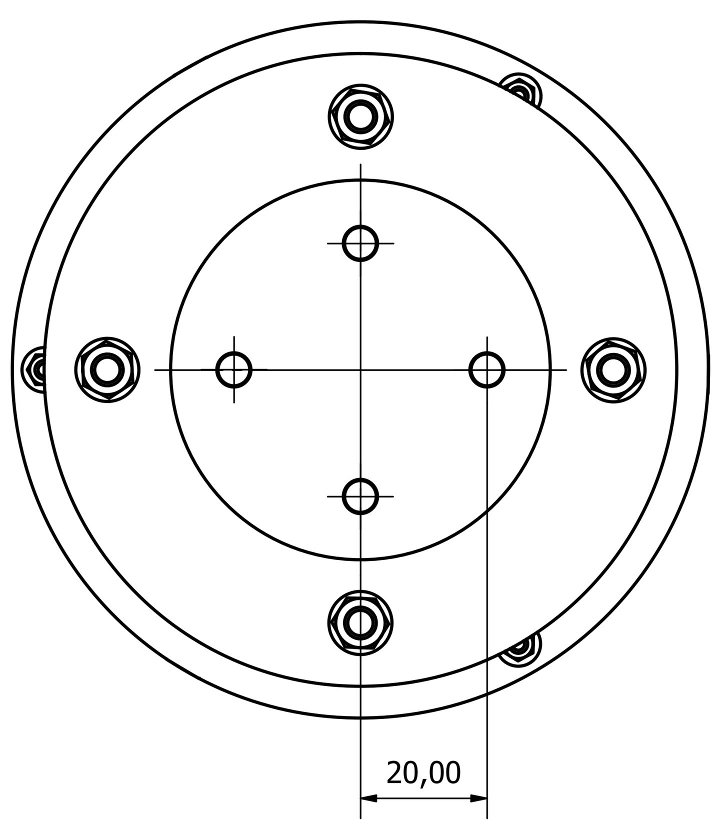
Format	Area	Item No.	Mark	Tittle	Quantity	Note
				Document		
A1			MERS BM 22 01 01 00 AD	Assembly Drawing		
				Parts		
A3		1	MERS BM 22 01 01 01 01	Adaptor	1	
		2	MERS BM 22 01 01 01 02	Holder	1	
		3	MERS BM 22 01 01 01 03	Touching stick	1	
A3		4	MERS BM 22 01 01 01 04	Holder 2	1	
		5	MERS BM 22 01 01 01 05	Copper contacts	12	
		6	MERS BM 22 01 01 01 06	Adaptor Top	1	
		7	MERS BM 22 01 01 01 07	Holder Top	1	
				Standard components		
		8		Bolt DIN 931 - M5 x 25	4	
		9		Nut DIN 934 - M5	4	
		10		Washer DIN 783- M5	4	
		11		Bolt DIN 931 - M3 x 30	3	
		12		Nut DIN 934 - M3	3	
		13		Washer DIN 125 - M3	3	
				Bolt DIN 933 - M6 X 12	4	

Responisible agency *MERS dep.*	*Consultant*	*Document type* *Specification*	*Document Status* *Educational*
Owner *VGTU* *MRfuc - 18*	*Compiled* / *Checked*	*Tittle* Sensor Assembly Drawing	*Mark* MERS BM 22 01 01 00 AD; *Rev*; *Date* 20/05/2022; *Lan* EN; *Sheet* 2

Annex 4: Drawings







The design of thissensor count with 12 copper contacts thta make a sandwich with Velostat material, so there are 6 sandwiches in total.

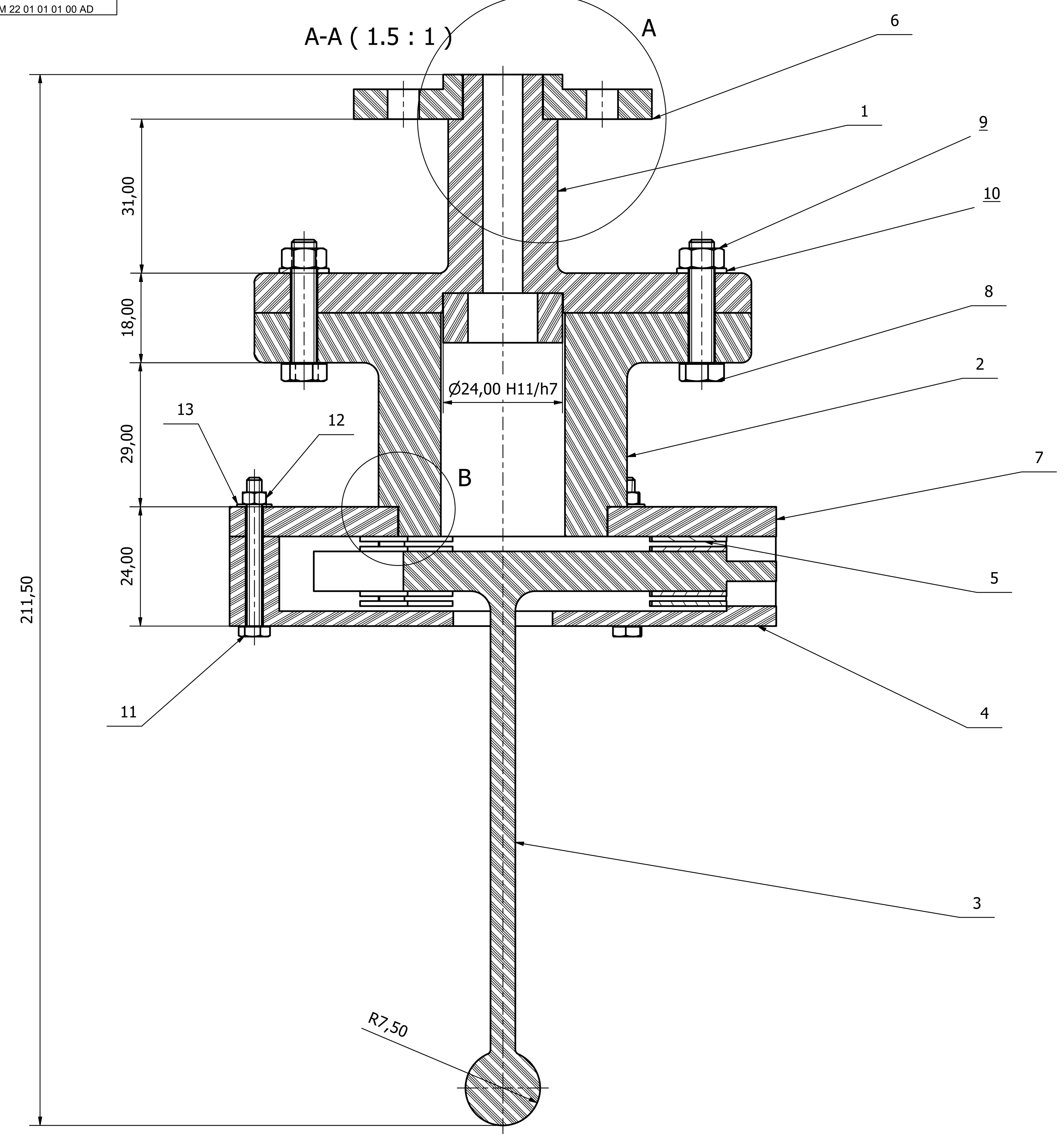
When the sanwich is done and the touching sensor is ready, one of the copper contacts is conected to ground and the other copper contact of the sensor is conected to one extreme of a resistance. That resistance is conected to an analog entrance of an Arduino,wich is conected to 3.3V . this conection method is the same for the other 5 touching sensors that this design has.

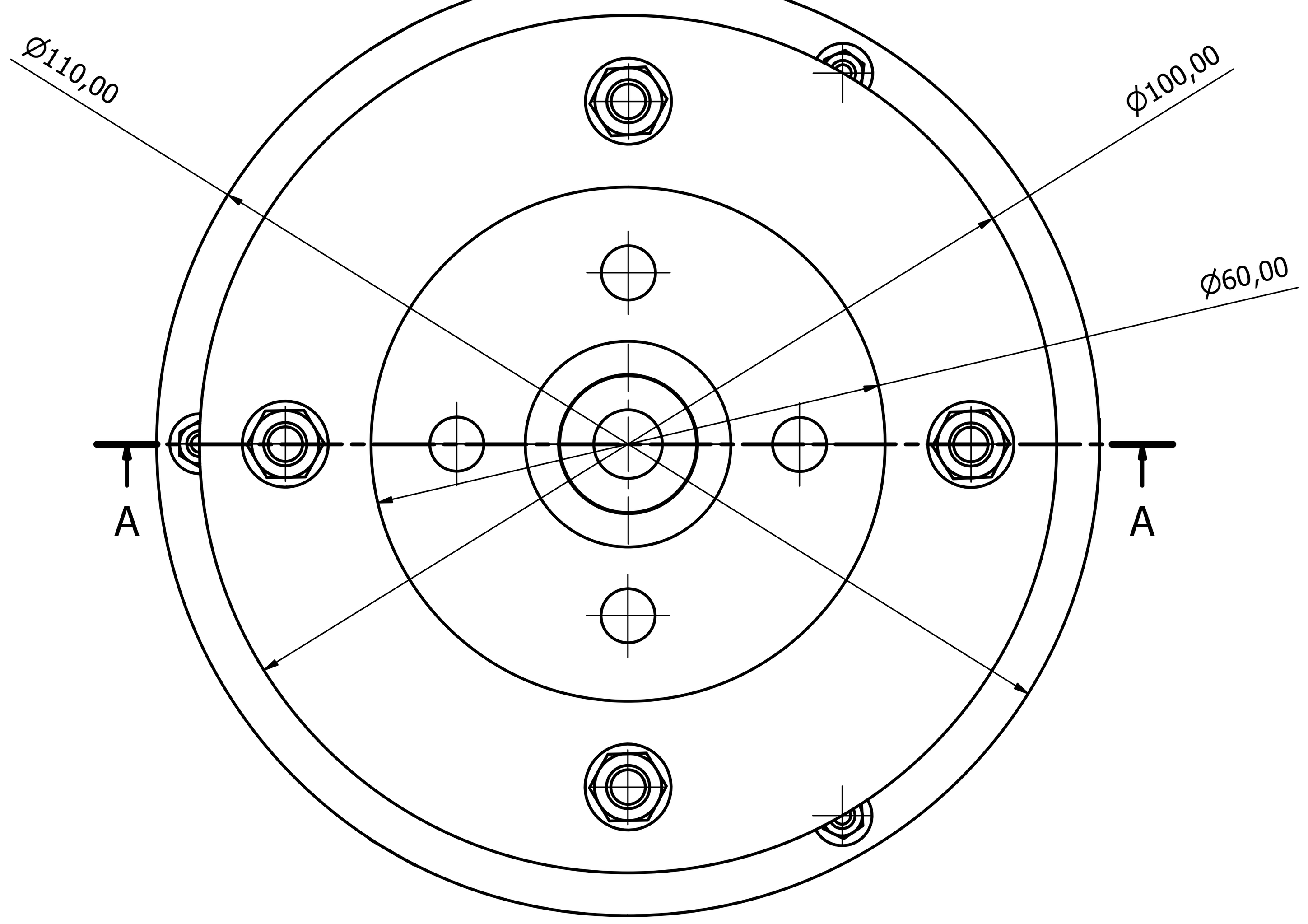
With the elemets conected to the arduino, program will analise wich of the sesnor are being compresed. Wiith that information and some formulas, it is obtained the position of the touching zone. That information will be sent to the robot controller to save it.

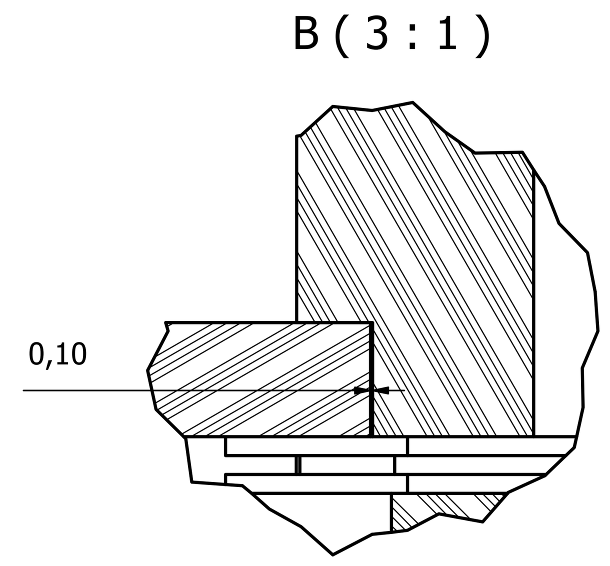
The robot, Motoman SSF2000 is conected to 380V through a the Motoman NX1000 controller. This system is in charge of the movement of the robot motors

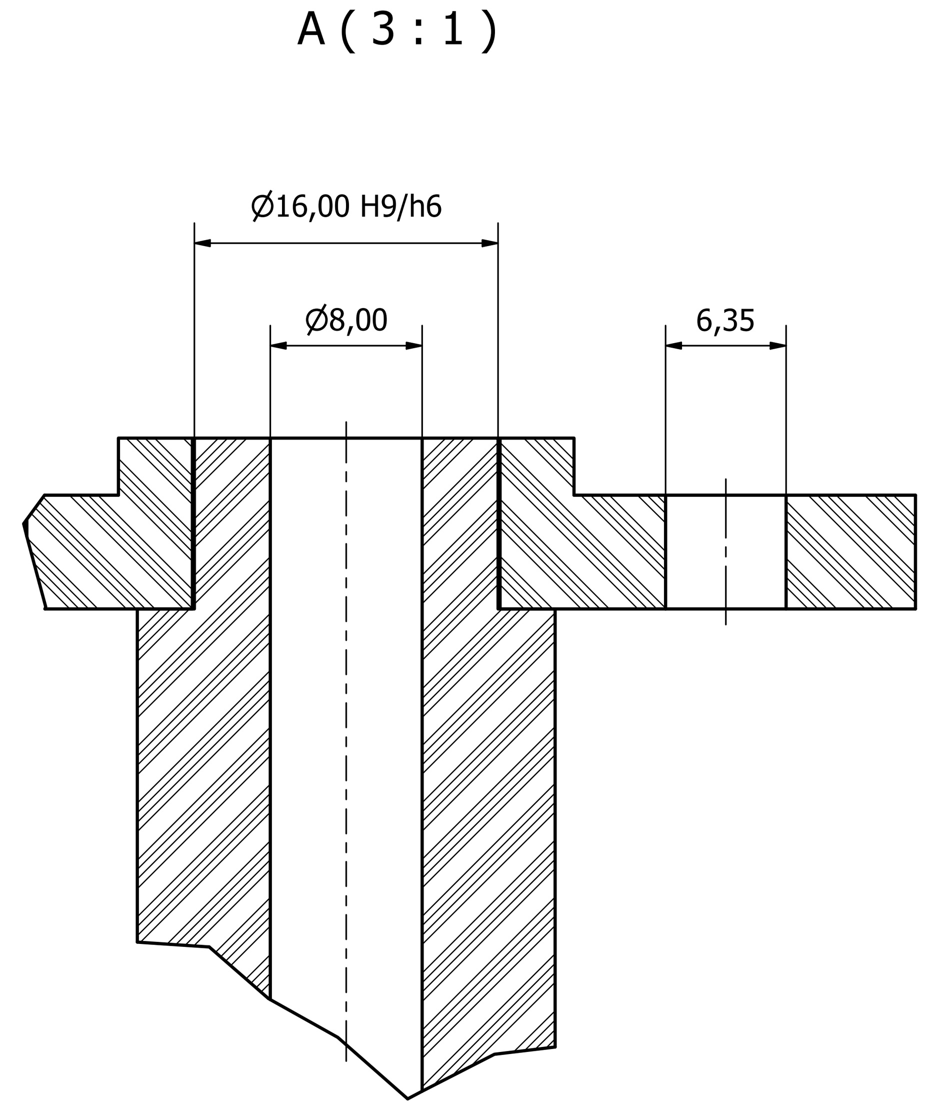
	Case No.	Additional information	Material	Scale 1.3:1
Responsible department Mechatronics	Consulted by	Type of document	Document status Educational	
Owner VGTU	Drown by: Daniel Calvo Sanz / Approved by	Tittle General View Drawing	Sign MERS BM 22 01 01 01 00 GV	Release · Date 13/05/2022 · Lan EN · Page 1/7

MERS BM 22 01 01 01 00 AD









All the pieces apart from copper contacts are 3D printed. The material used in the printing is PLA.

In case of part number 1, the 3 parts are atached using glue. The diamaters of the ataching zones have been designed with a tolerance of 0.2 mm

Element number 2 has the same atachement. The pieces have been designed to be atached in the same way, and with the same tolerance, 0.2 mm.

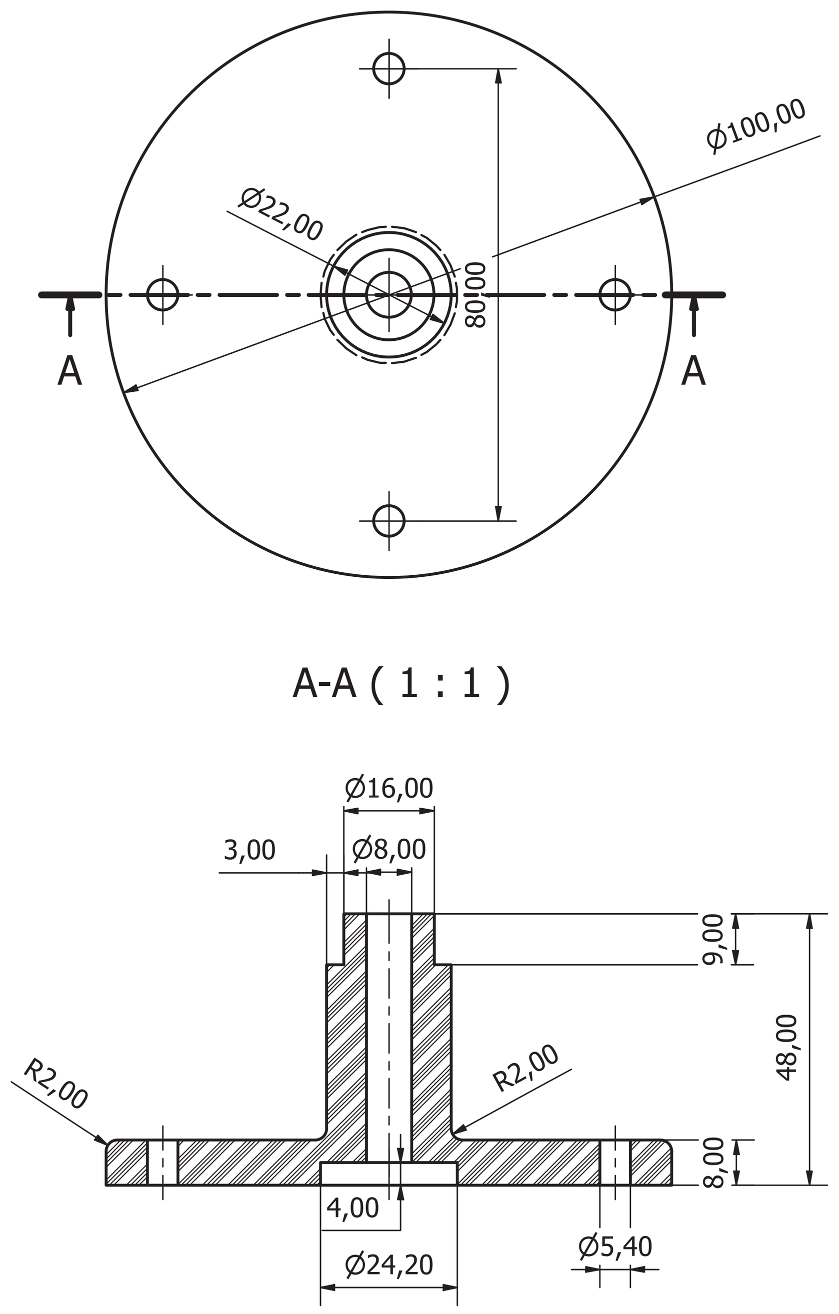
In this assembly different bolds and nuts are used. Te component number 1 will be conected to the robot in the bottom part adn to the component number 2 as it is shown in the drawing. The conection between components 1 and 2 is done by the use of four M5x25 bolds and M5 nuts. In case of being neccesary M5 washer will be used too. The assembly connection between components 2 and 3 is done by three M3x30 bolds and M3 nuts

The assembly of the design will follow the next steps:

1. Glue of Component 1
2. Glue of component 2
3. Touching sensor (copper sandwich) placement
4. Touching stick (component 5) placemet
5. Assembly of components 2 and 3
6. Assembly of components 1 and 2

	Case No.	Additional information	Material	Scale 1.5:1
Responsible department Mechatronics	Consulted by	Type of document	Document status Educational	
Owner VGTU	Drawn by: Daniel Calvo Sanz / Approved by	Tittle Assembly Drawing	Sign MERS BM 22 01 01 01 00 AD; Release; Date 13/05/2022; Lan EN; Page 2/7	

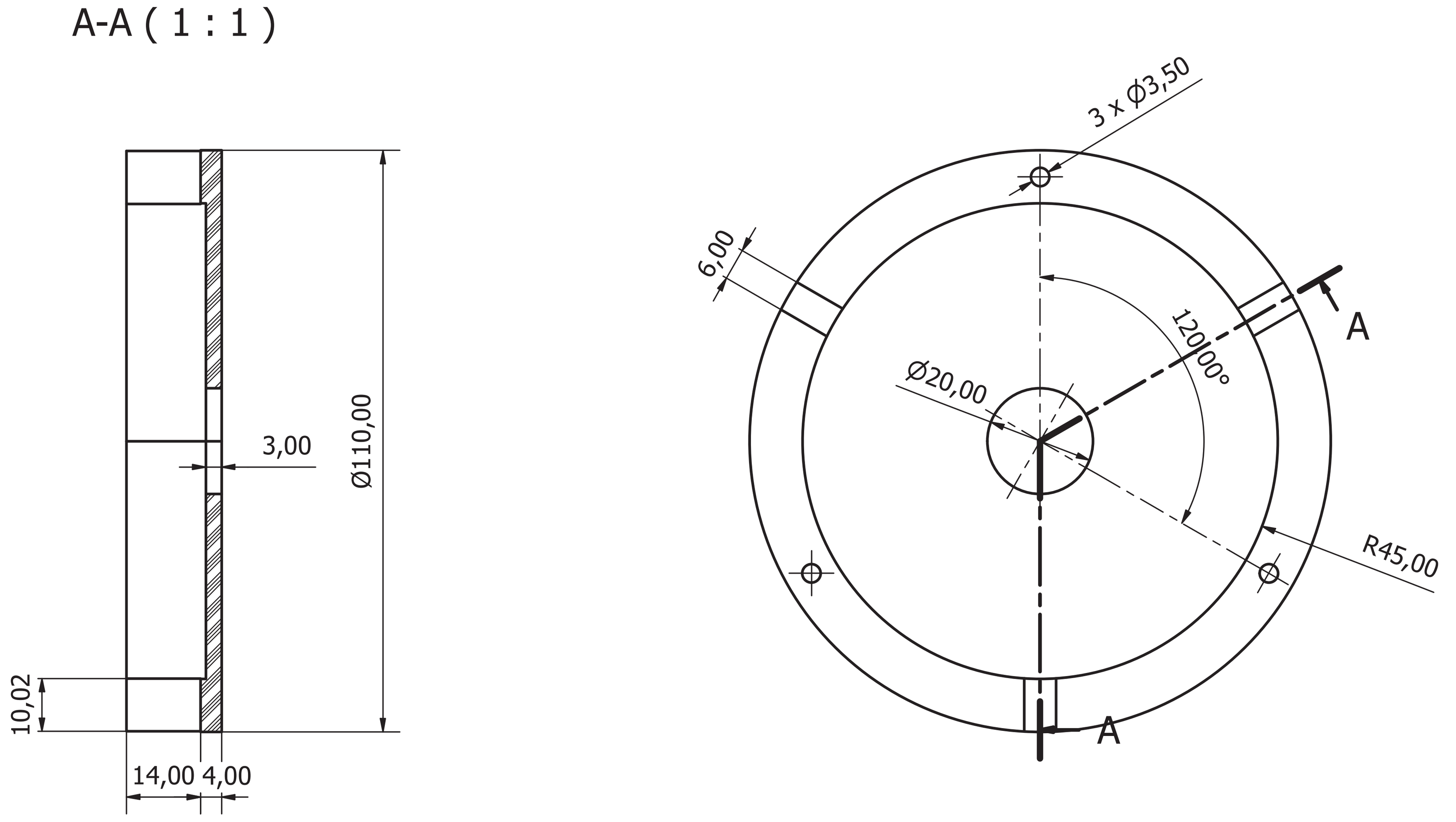
MERS BM 22 01 01 01 01



Not specified deviations in dimensions, position, and shape according to LST EN 22768-mK

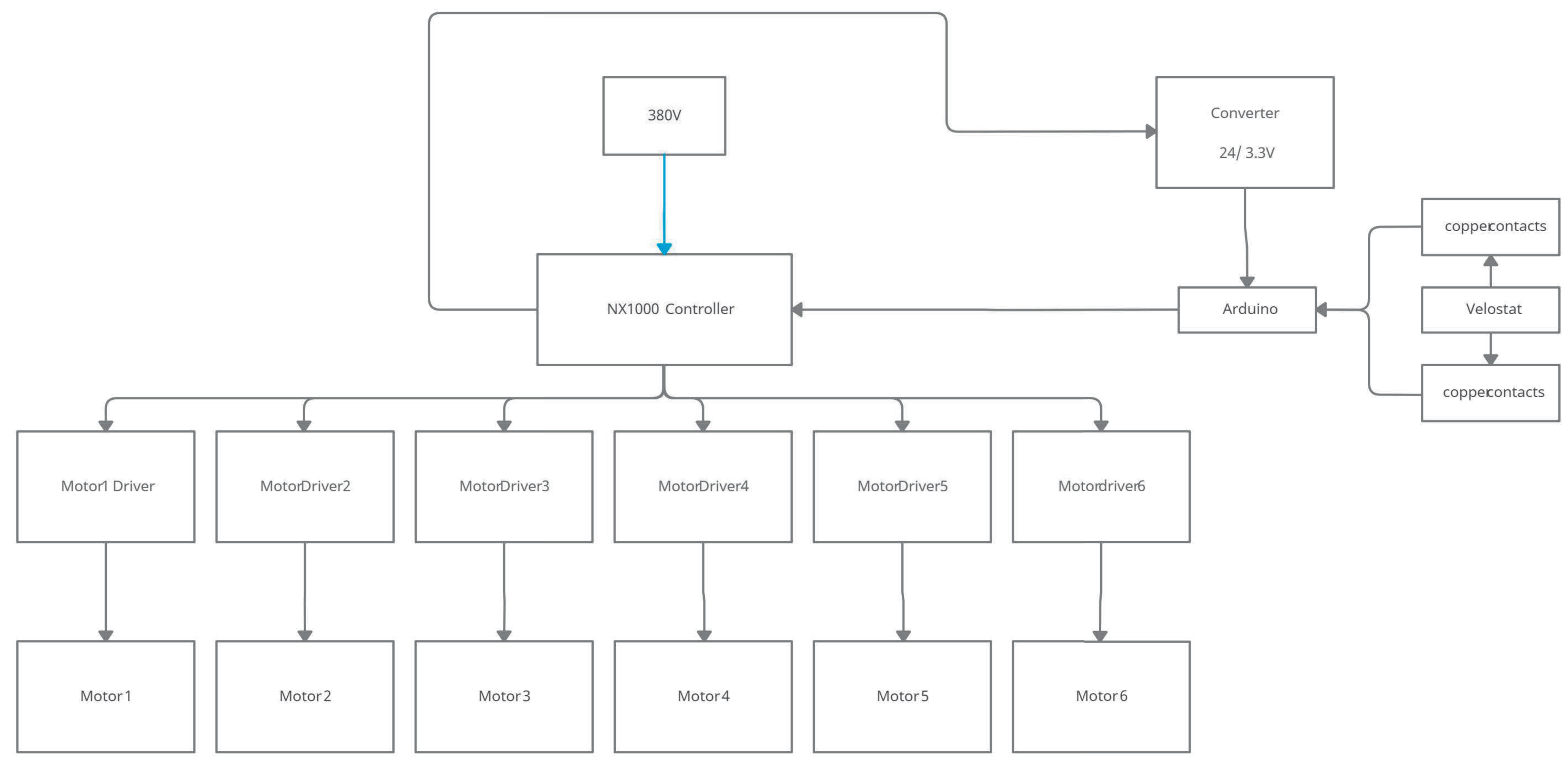
Case No.	Additional information	Material: Polylactic acid - ISO/ASTM 52903-1:2020	Scale: 1/1
Responsible department: Mechatronics	Consulted by	Type of document	Document status: Educational
Owner: VGTU	Drawn by: Daniel Calvo Sanz; Approved by	Tittle: Adaptor	Sign: MERS BM 22 01 01 01 01; Date: 13/05/2022; Lan: EN; Page: 3/7

MERS BM 22 01 01 01 04

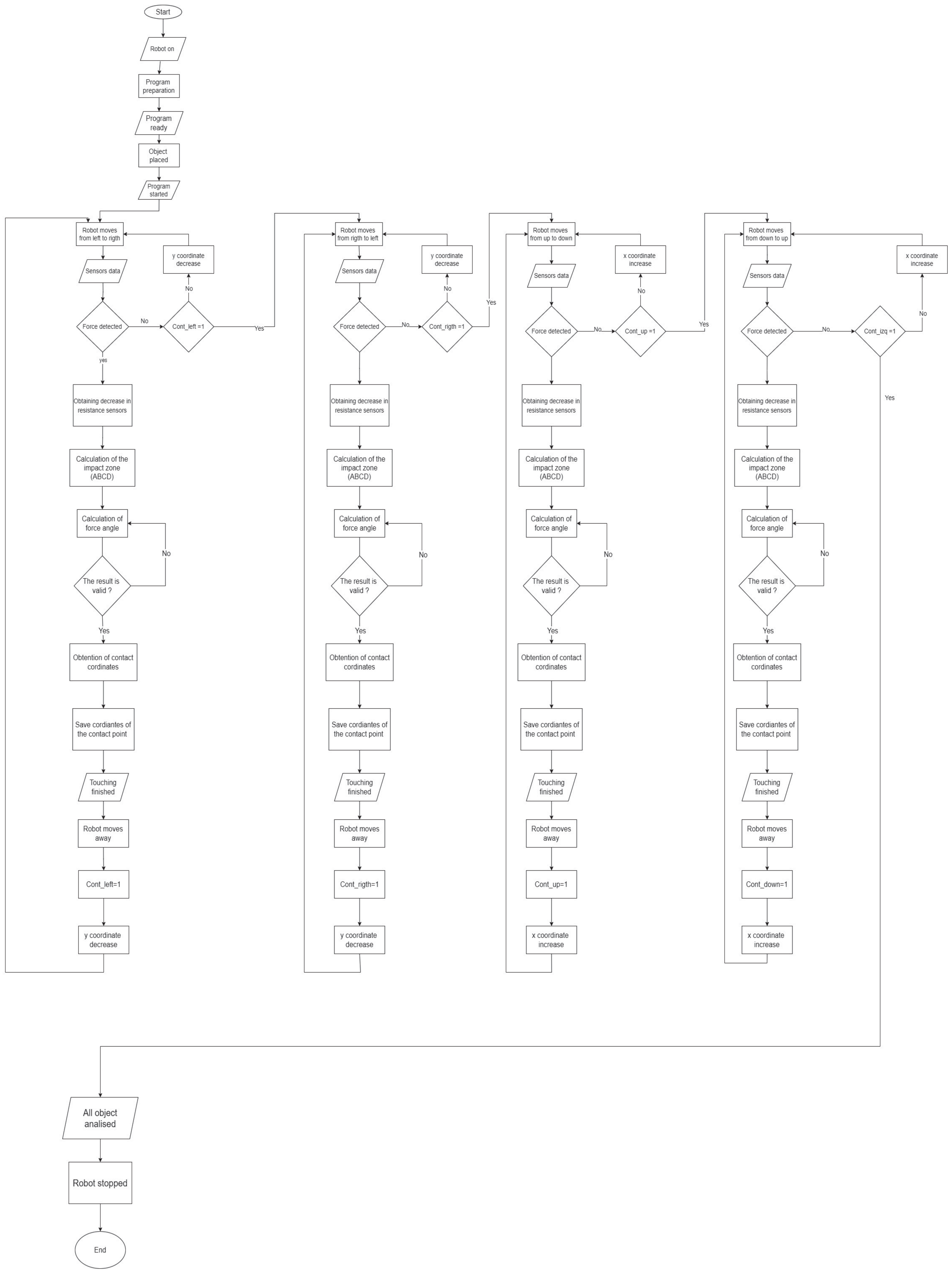


Not specified deviations in dimensions, position, and shape according to LST EN 22768-mK

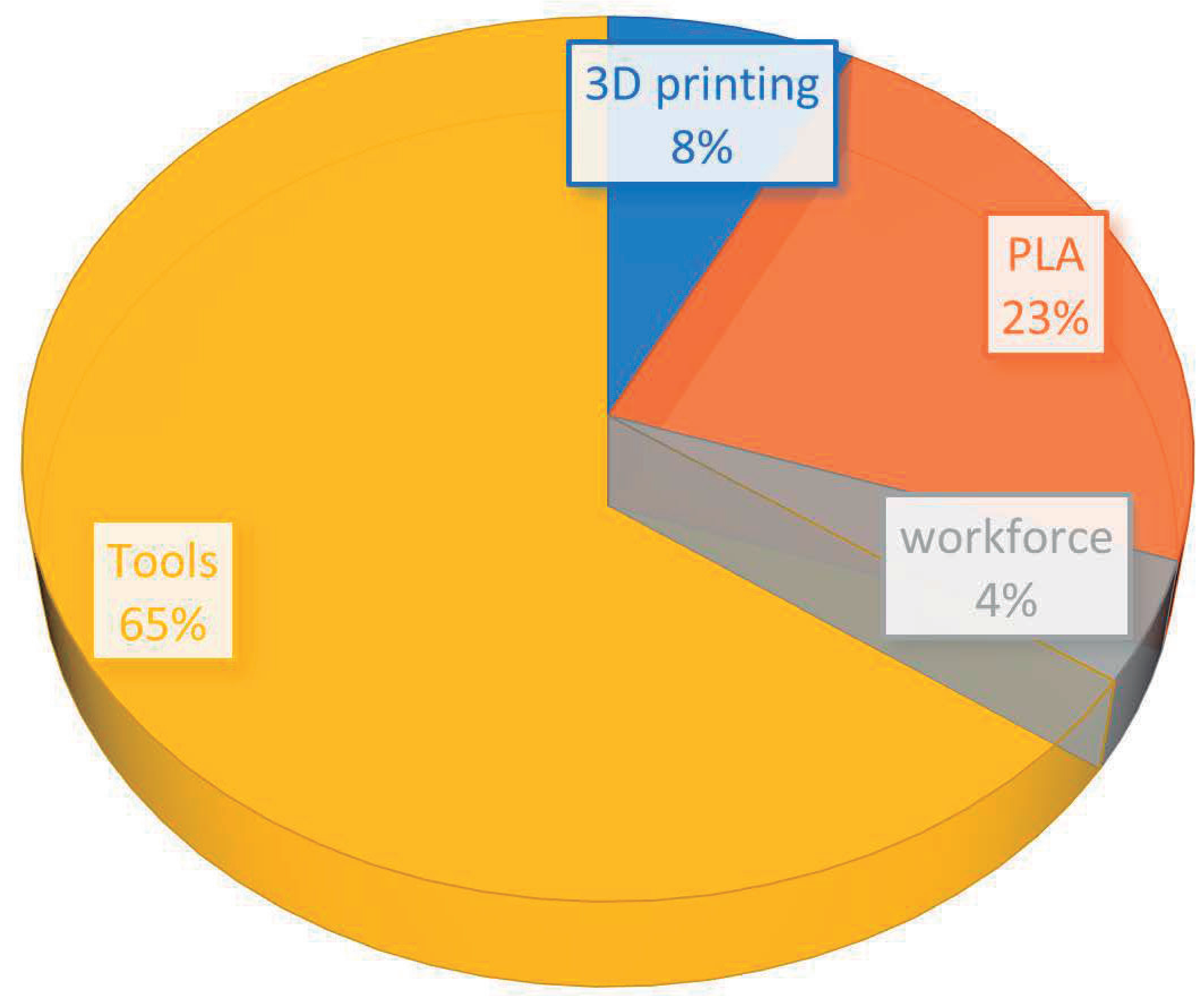
Case No.	Additional information	Material: Polylactic acid - ISO/ASTM 52903-1:2020	Scale: 1:1
Responsible department: Mechatronics	Consulted by	Type of document	Document status: Educational
Owner: VGTU	Drawn by: Daniel Calvo Sanz; Approved by	Tittle: Holder 2	Sign: MERS BM 22 01 01 01 04; Date: 13/05/2022; Lan: EN; Page: 4/7

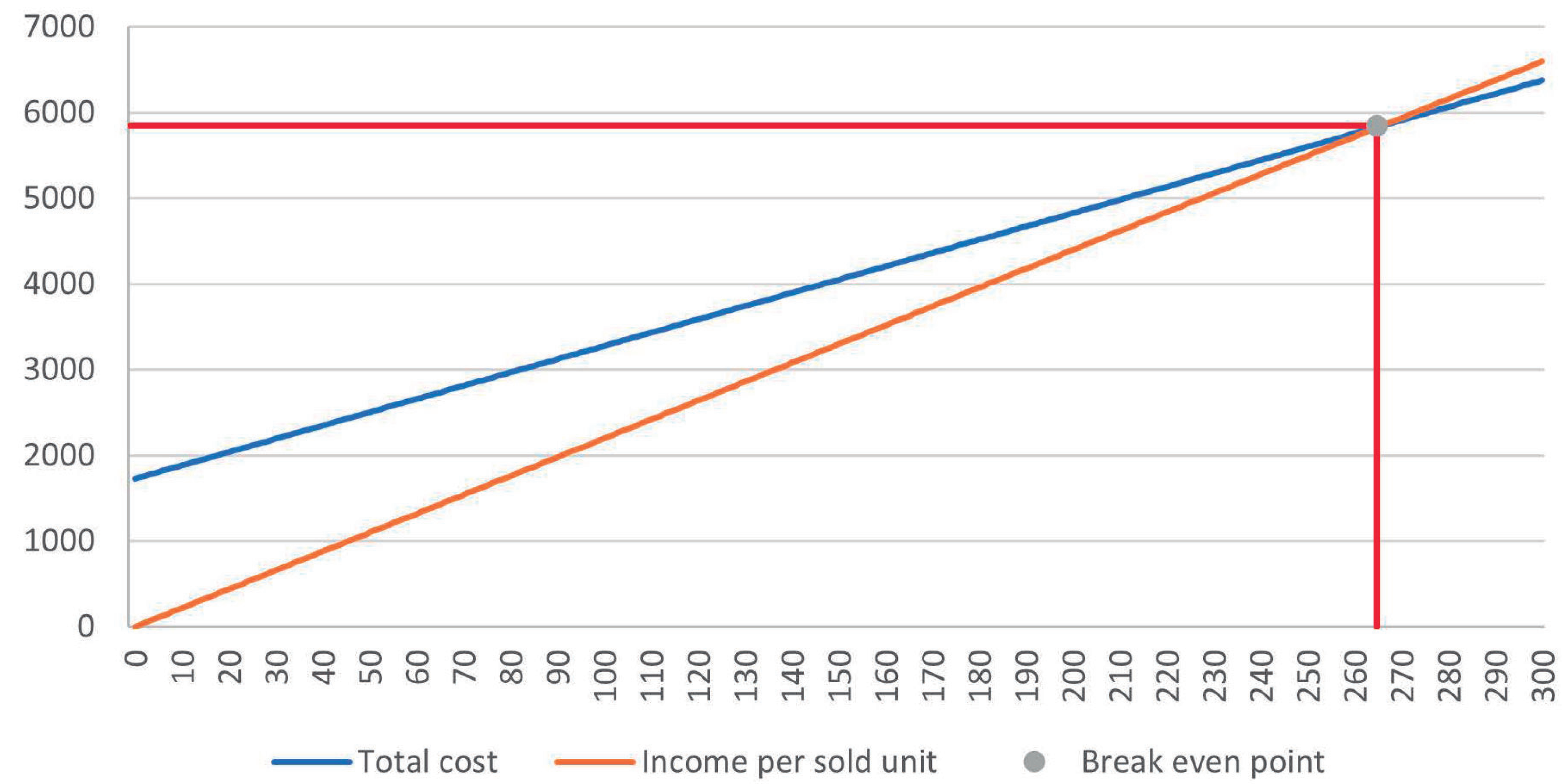


Case No.	Additional information	Material		Scale
Responsible department: Mechatronics	Consulted by	Type of document	Document status: Educational	
Owner: VGTU	Drawn by: Daniel Calvo Sanz; Approved by	Title: Electric Block Scheme	Sign	Date: 13/05/2022; Lan: EN; Page: 5/7



Case No.	Additional information	Material	Scale
Responsible department: Mechatronics	Consulted by	Type of document	Document status: Educational
Owner: VGTU	Drawn by: Daniel Calvo Sanz; Approved by	Tittle: Control Algorithm	Sign; Release; Date 13/05/2022; Lan EN; Page 6/7





Case No.	Additional information	Material	Scale
Responsible department: Mechatronics	Consulted by	Type of document	Document status: Educational
Owner: VGTU	Drawn by: Daniel Calvo Sanz; Approved by	Tittle: Economics	Sign; Release; Date 13/05/2022; Lan EN; Page 7/7