LELME2002 - Project in Mechatronics

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Preliminary project: report

TutAnkhaBot

Group 4

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General cohesion of the units, figure referencing, etc. done by Nicolas.

1 Introduction

Written by Théau

This report outlines the first designing steps of Group 4 in the 2021-2022 Project in Mechatronics at EPL, UCLouvain. The project goal is designing, programming and building a robot to compete in the 2022 Eurobot competition. Rules for the competition can be found on: eurobot.org.

Eurobot theme for this year is *Age of Bots*, this is why we decided to name our robot **Tutankhabot**. It will be themed around ancient egypt.

The different sections of this report can be seen in the table of contents, they are ordered following the chronological order of our work.

2 Strategy for the Belgian cup

Written by Théau and Diego

The first step of our design process is to determine the strategy our robot will execute during the matches. After reading the complete rules of the Eurobot competition, we gathered all ways of scoring points in the following table:

Missions	Points
Excavation square	+ 5 for each revealed excavation square of the team’s colour +5 additional if at least un excavation square is revealed, and the red square is not
Research	+1 for each sample removed from a distributor of the team
Analysis	+1 additional for each sample revealed and sorted inside the camp +3 additional for each sample revealed and sorted inside the gallery
Base camp	+1 for each sample inside the camp
Exhibition gallery	+3 for each sample inside the gallery
Work shed	+5 for each sample inside the work shed
Statuette and replica	+2 for installing the statuette on the pedestal +5 if the statuette is not on the pedestal at the end +10 if the replica is on the pedestal at the end +15 if the statuette is inside the display cabinet at the end
Display cabinet	+2 for installing a display cabinet during preparation time +5 additional if the cabinet is activated
Return to the excavation site or to the camp	+20 if the team robot is inside the camp or inside the excavation site
Estimate the performance	+ (0.3 x Score) – Delta between estimation and real score

Figure 1 presents our evaluation of the different actions depending on two parameters : the "rentability" (number of points scored) and the difficulty (time and resources needed to implement this function, a higher difficulty often implies a higher risk of failure). This will help us create balanced and relevant strategies.

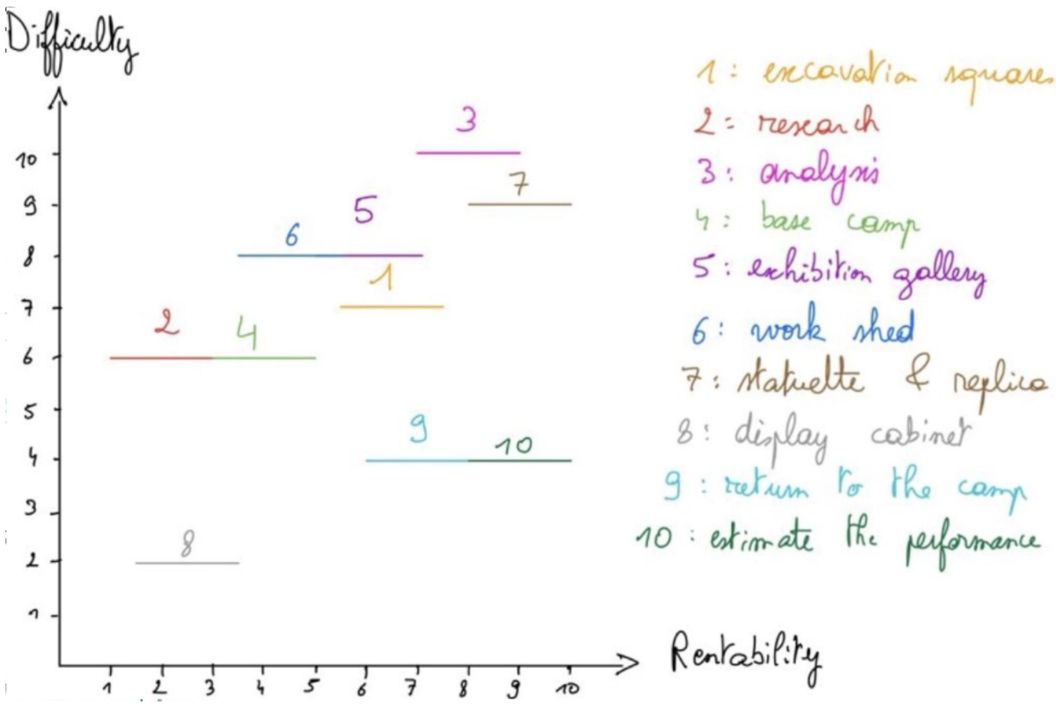


Figure 1: Evaluation of the different actions

With all these possibilities listed, we created several strategies to compare them and try to extract the best one. The details of this process are described in appendix A.

The three criteria used to evaluate the strategies are:

- **Points scored**.
- **Speed**: A faster strategy allows for more unplanned delay during the match.
- **Reliability**: A high scoring strategy is not a good idea if it often fails. The robot will have to take part in multiple matches.

Our **final strategy** therefore is (in chronological order):

1. Bring six samples to our campsite. We want Tutankhabot to be able to move three samples at a time, so this step requires two trips to the campsite. The six samples are shown in figure 2.
2. Flip all of our excavation squares, as seen in Figure 3.
3. Put both samples placed above our workshed in it, as seen in Figure 4.
4. Swap the statuette and the replica, the replica being stored in the robot from the start of the match.
5. Go to our excavation site before the end of the match and display the robot estimation for the score.

Figure 2: Samples brought to campsite during the first step of the strategy.

Figure 3: Excavation squares, second step of our strategy.

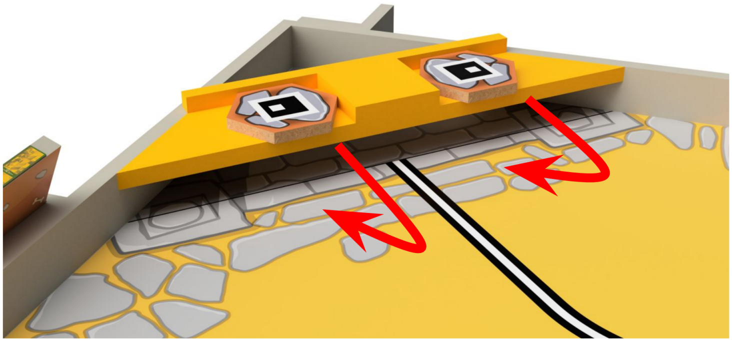


Figure 4: Workshed, the two samples are put in the work shed during the third step of our strategy.

We wanted to do first the operations with the samples, as these samples can be picked up by the enemy team: the sooner the robot does it, the lower the chance for the enemy to pick them up. All the other actions of our robot can only be done by our team, their order is chosen for the shortest travel time.

It is important to note that the process of finding an optimal strategy is iterative, some aspects of our strategy changed during later steps of the designing work. And it is likely that we will adjust it throughout the year thanks to further work on the robot.

3 Design steps

Written by Théau

This section explains the design process of our robot. This includes the identification of the functions and sub-functions and their organization in functional graphs. For each sub-function, we found several solutions that are all listed in morphological graphs. We then created four different sets of solutions and selected the best one using multiple criteria.

3.1 Functions

Written by Théau

We began the designing process by identifying the functions our robot must be able to achieve to respect our strategy.

For Tutankhabot, we identified six main functions and multiple sub-functions. These are shown in the table in Figure 5.

Function	Subfunctions	
F1: Move	• F1.1: Evaluate position and orientation • F1.2: Detect obstacles nearby	• F1.3: Compute trajectory • F1.4: Move (backward, forward, turn)
F2: Toggle excavation squares	• F2.1: Put probes on both sides of the resistor • F2.2: Measure resistor value	• F2.3: Flip excavation square
F3: Operate the samples	• F3.1: Grab a sample • F3.2: Store/Unstore a sample • F3.3: Put down a sample	• F3.4: Put the two samples in the workshed - F3.4.1: Get the two samples - F3.4.2: Put in the workshed
F4: Move the statuette	• F4.1: Grab the statuette • F4.2: Move the statuette	• F4.3: Put the statuette in the display cabinet
F5: Move the replica	• F5.1: Move the replica • F5.2: Put the replica on the pedestal	
F6: Decision-making	• F6.1: Keep track of elapsed time • F6.2: Keep track of previous actions • F6.3: Evaluate positions on the table	• F6.4: Decide the best thing to do based on a defined strategy

Figure 5: Table gathering every function and sub-function of Tutankhabot

The six main functions are organized in a functional graph to describe the working of the robot. See figure 6.

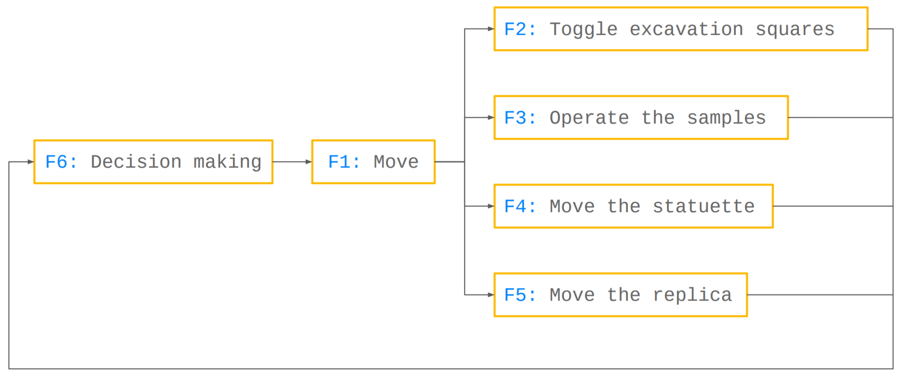


Figure 6: Main functional graph

Every function also has a functional graph to describe the working of its different sub-functions.

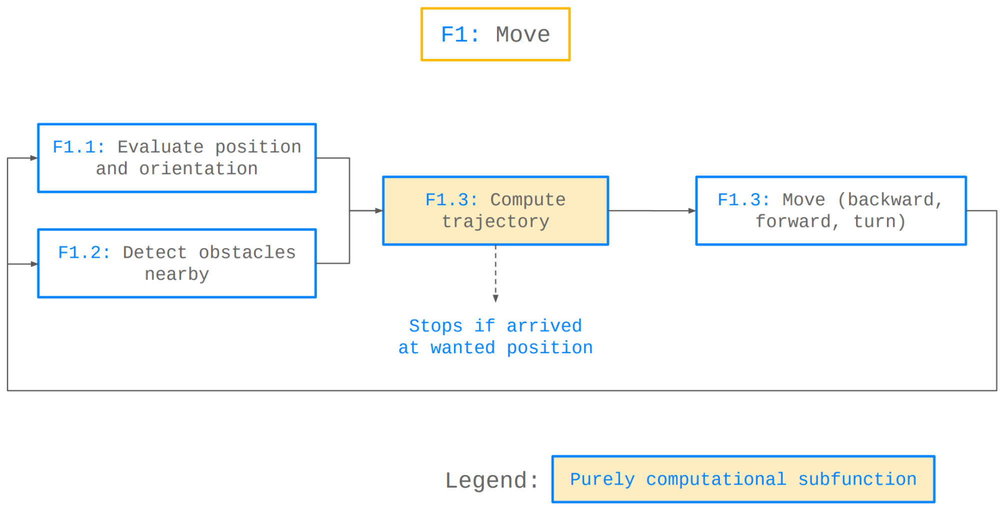


Figure 7: Functional graph of F1

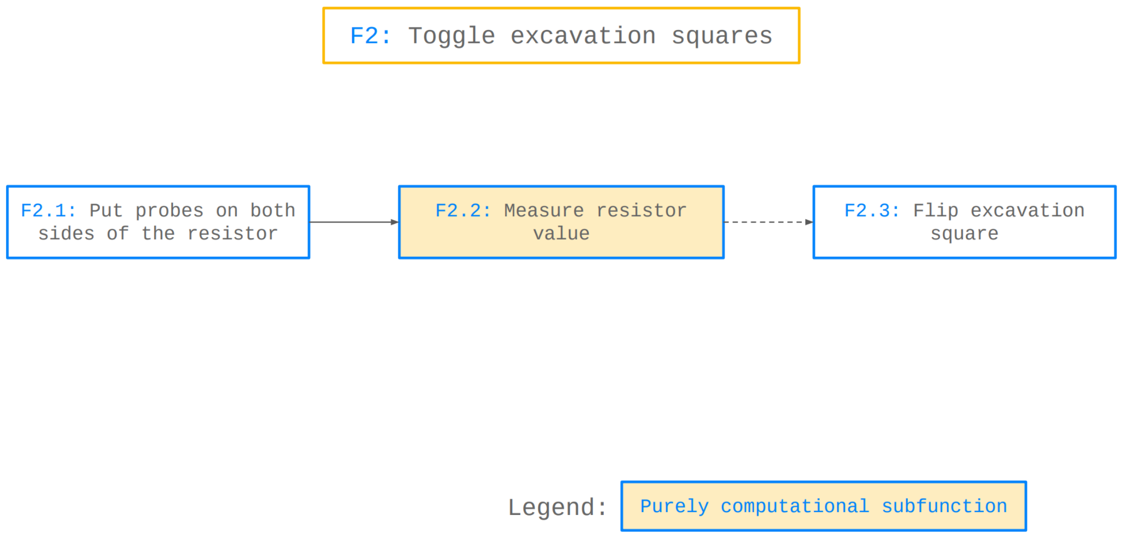


Figure 8: Functional graph of F2

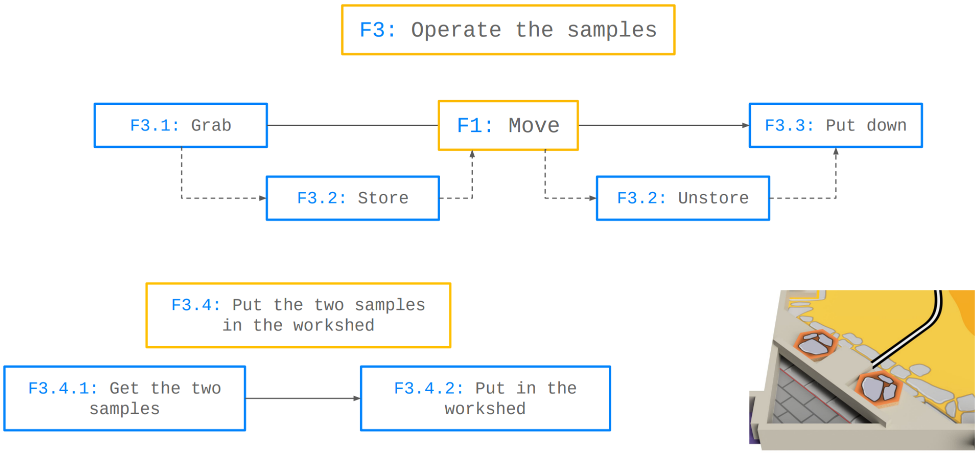


Figure 9: Functional graph of F3

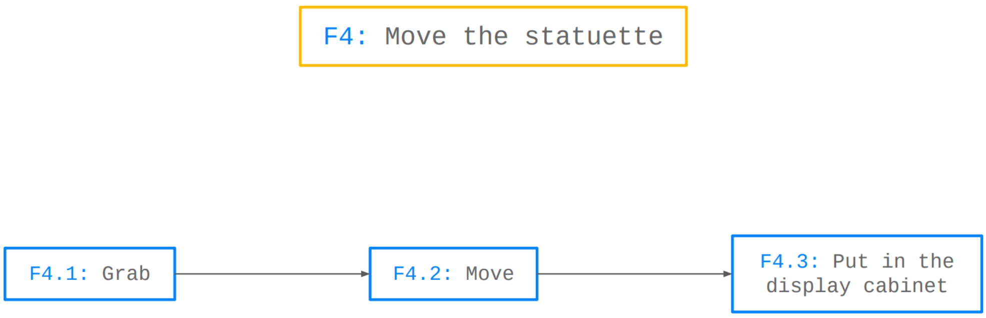


Figure 10: Functional graph of F4

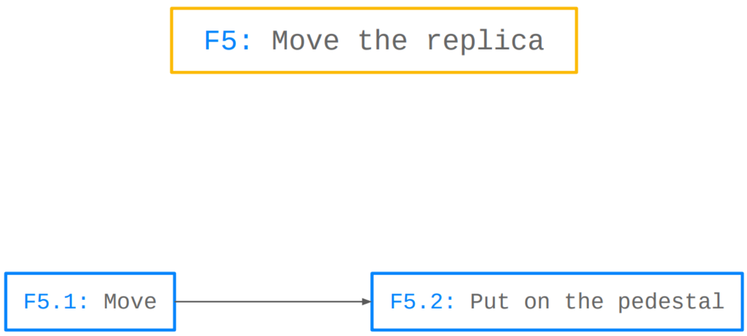


Figure 11: Functional graph of F5

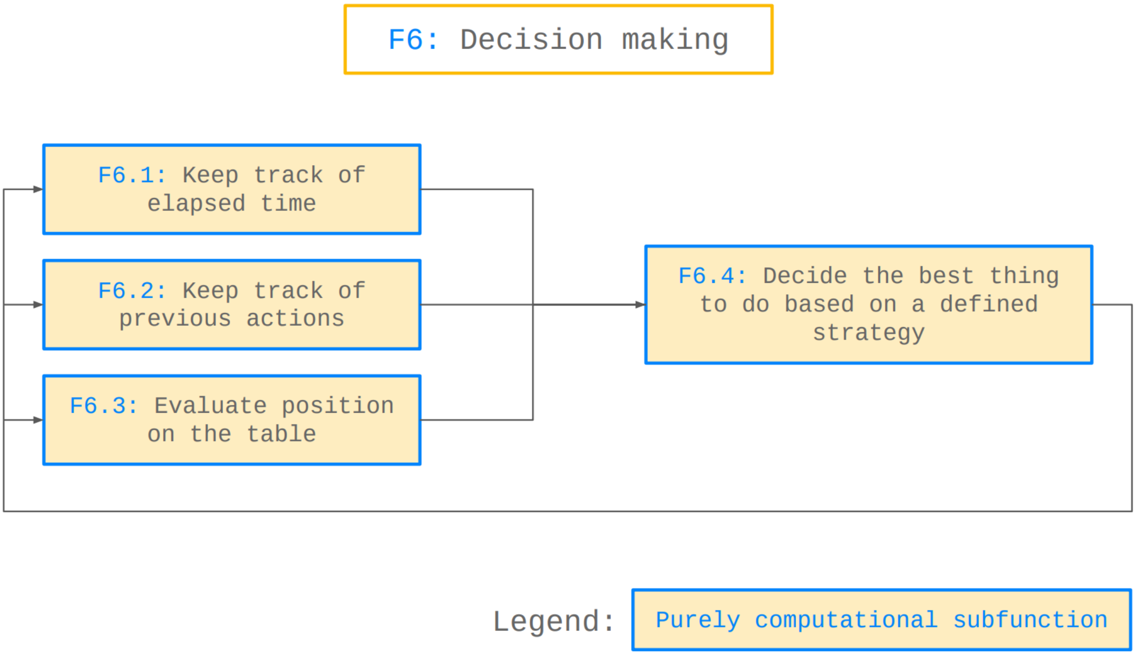


Figure 12: Functional graph of F6

3.2 Morphological graphs

Written by Théau, drawing done by François and drawing updated by Diego

The next step of the designing process was to find multiple ideas for each of the sub-functions. Here are the morphological graphs of every function.

Note that function F6 is purely computational and therefore doesn't have a morphological graph.

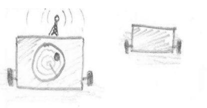
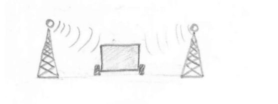
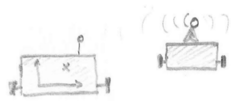
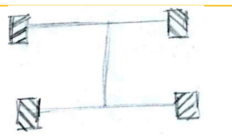
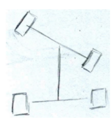
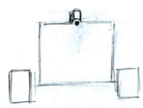
F1.1: Evaluate position and orientation	 Radar / Lidar	 Beacons around the table	 Odometry
F1.2: Detect obstacles nearby	 Proximity sensor	 Beacon on enemy robot	
F1.3: Move (backward, forward, turn)	 4 omniwheels	 4 wheels + car-like movement	 2 driving wheels + ball/caster wheel(s)

Figure 13: Morphological graph of F1

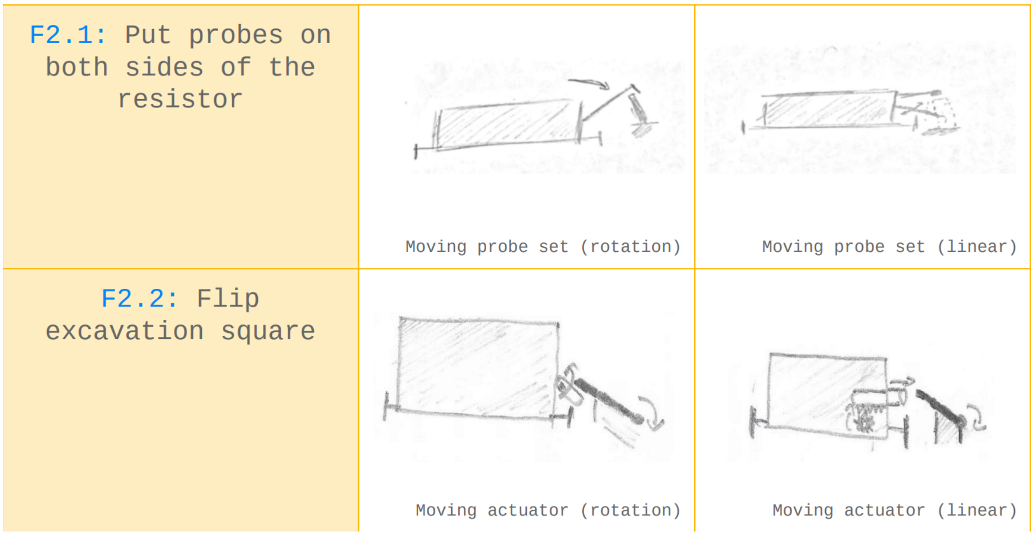


Figure 14: Morphological graph of F2

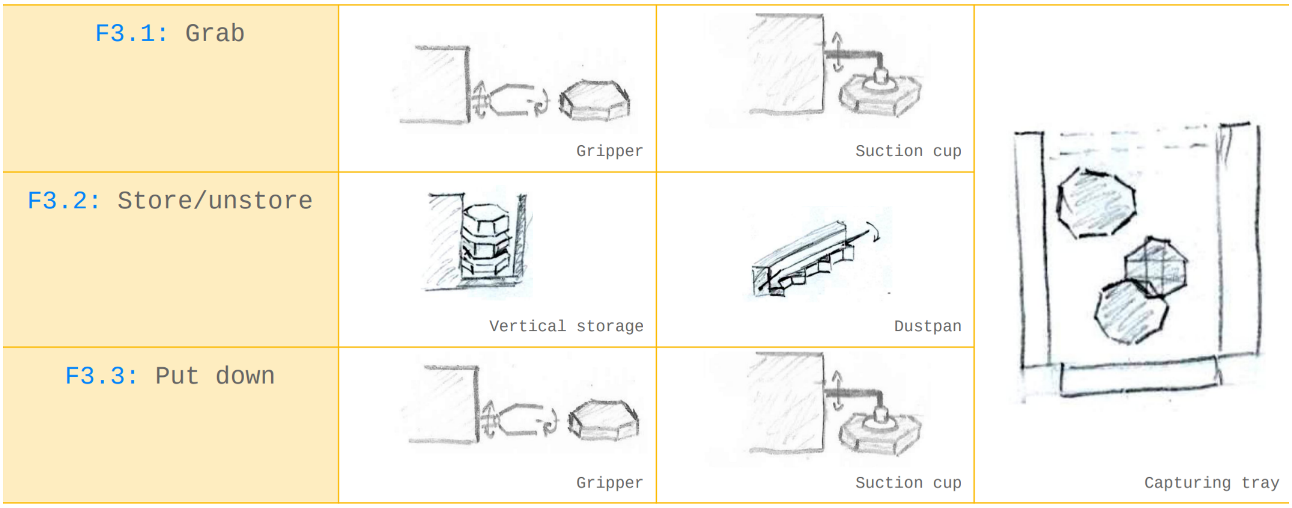


Figure 15: Morphological graph of F3 (excluding F3.4)

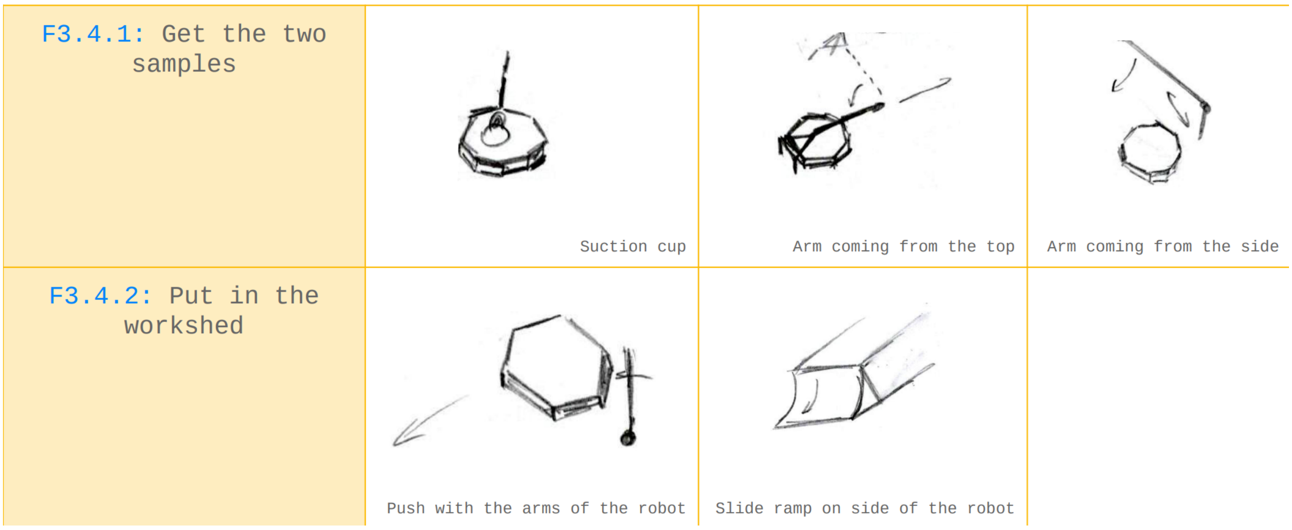


Figure 16: Morphological graph of F3.4

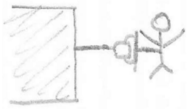
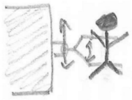
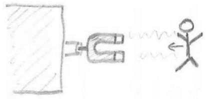
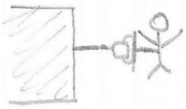
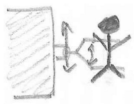
F4.1: Grab	 Succion cup	 Gripper	 Magnet
F4.2: Move	 Store	 Keep in gripper/succion cup	
F4.3: Put in the display cabinet	 Succion cup	 Gripper	

Figure 17: Morphological graph of F4

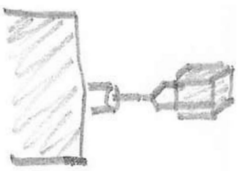
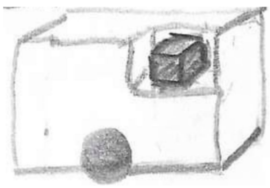
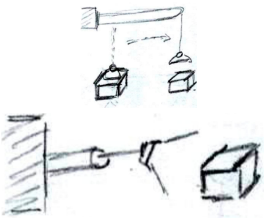
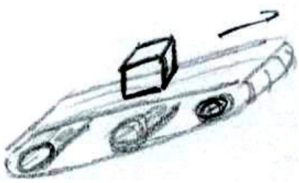
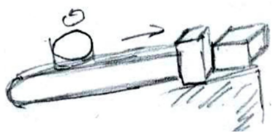
F5.1: Move	 Gripper/Succion	 Store	
F5.2: Put on the pedestal	 Gripper/Succion	 Rolling carpet	 Push

Figure 18: Morphological graph of F5

3.3 Global solutions

Written by Diego

From all those sub-solutions, we formed four sets of global solutions.

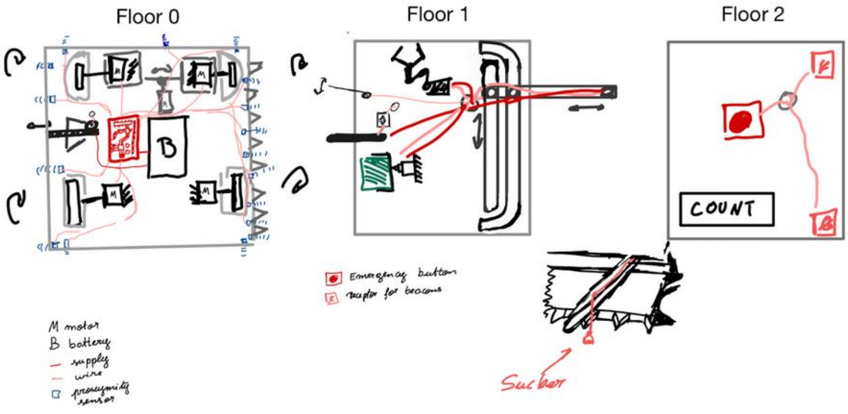


Figure 19: First possible solution

In this first solution, we chose to use a four-wheel motorized system to propel our robot. Two of them are used to direct the robot. On the right part of the robot, there is the storage system, and on the left is the pushing system.

The second floor has four systems, two grips for the replica and the statuette, a sucker system on the left plus the placement and measuring system for the excavation squares.

The second floor is occupied by two sensors to detect beacons and by the emergency button.

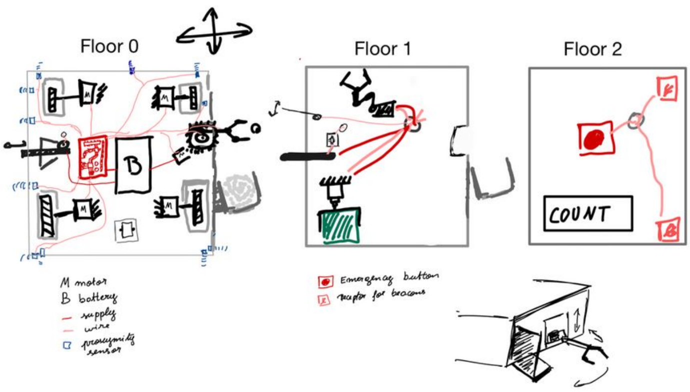


Figure 20: Second possible solution

In this second solution, we change the direction system with four onmidirectionnal wheels. The sucker system is swapped with a gripper and the way we store the samples is modified. Finally, we added a wheel for odometry.

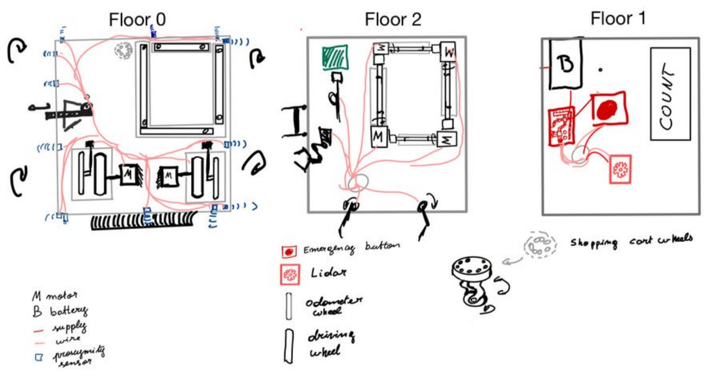


Figure 21: Third possible solution

The third solution uses odometric wheels and a LIDAR to keep track of the robot's position. Operating the samples is done by a retractable bar (samples are sliding on the floor) and two little arms for moving the samples on top of the work shed.

The moving system is composed of two driving wheels and one caster wheel. The odometric wheel are placed right on the side of the driving wheels.

The last difference is the location of the battery. It has been moved to the top for the sake of having more space for other functions.

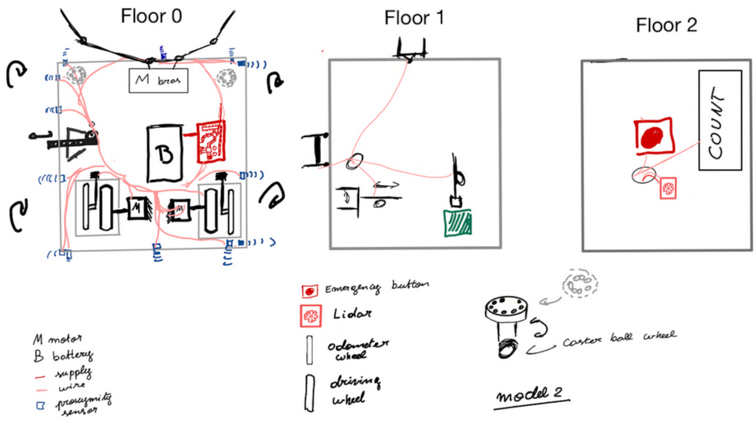


Figure 22: Fourth possible solution

For this fourth solution, we've chosen to manipulate samples with two arms in front of the robot. The samples in the work shed are taken with a kind of dropping rake. The statuette is taken by another kind of grip. And the single caster wheel is replaced by two ball wheels. The rest of the mechanisms are similar to the third solution.

3.4 Global solution choice

Written by Théau

To get our final solution, we compared the four sets of the previous subsection. All the sets were evaluated with seven criteria we think are the most relevant:

- **Precision**: A precise robot allows for consistency.

- **Reliability/Resilience**: A reliable robot is a robot that wins more matches.
- **Simplicity of implementation**: A simple design gives us more time for testing and often is more reliable.
- **Speed**: A faster robot can do more in the same amount of time.
- **Cost**: Our expenses are counted and limited.
- **Footprint**: A smaller footprint is less likely to run into obstacles.
- **Power consumption**: Higher consumption means bigger battery and therefore less space in the robot.

The comparison between the four solutions is shown in figure 23, the details of the comparison are shown in figure 24.

	Set 1	Set 2	Set 3	Set 4
Precision	0	-	++	++
Reliability - Resilience	0	-	+	++
Simplicity of implementation	0	+	0	+
Speed	0	-	++	++
Cost	0	0	+	++
Footprint	0	0	++	+
Power Consumption	0	-	+	+

Figure 23: Relative with interval comparison of the four solutions

Set Comparison

- **Set 1:**
  - Difficult to implement (4 wheels, multi-axis gripper)
  - Costly (4 wheels and motors, beacons)
  - Single orientation method (no redundancy)

- **Set 2:**
  - Easier moving method (omniwheels)
  - Difficult to implement gripper
  - Even more expensive (omniwheels)
  - Still no redundancy for orientation

- **Set 3:**
  - Cheaper and reliable 2-motor movement
  - Difficult to implement gripper
  - Odometric wheels (lot easier with 2 motors) + LIDAR (redundancy)
  - Caster wheel doesn't allow certain types of movements

- **Set 4:**
  - Cheaper and reliable 2-motor movement
  - No multi-axis gripper
  - Odometric wheel + lidar
  - Two ball wheels with suspensions (stable and move freely)

Figure 24: Details of the comparison

You can see that set 4 is the most relevant for Tutankhabot. It is the solution we will use to go further in the designing process.

4 Definitive layout

This section has been written by Clément, François and Sébastien in an equitable manner. They first selected/designed all the mechanisms described in this section together, and then they divided the sections, so that they could work in parallel. They then reviewed and adjusted the work of the others. They also did the mock-up in order to visualize the size of the mechanisms and to adjust all the components together.

4.1 Description and validation of the mechanisms

4.1.1 Evaluate position and orientation (F1.1) : odometry

Odometer wheels system measure the number of revolutions of its wheels. With simple maths, it computes the distance travelled by the wheel. Moreover, if we use a set of two aligned odometer wheels (about $4\ cm$ diameter) and we know the distance between the wheels, we can then determine the complete position of these wheels and consequently the location and orientation of our robot. One important constraint is that the axis of the odometer wheels set must be aligned with the motorized wheels (at least vertically) in order to avoid skating in the odometer wheels, which would involve mistakes in the measurement. This system will also have to be mounted on suspensions to avoid hyperstaticity.

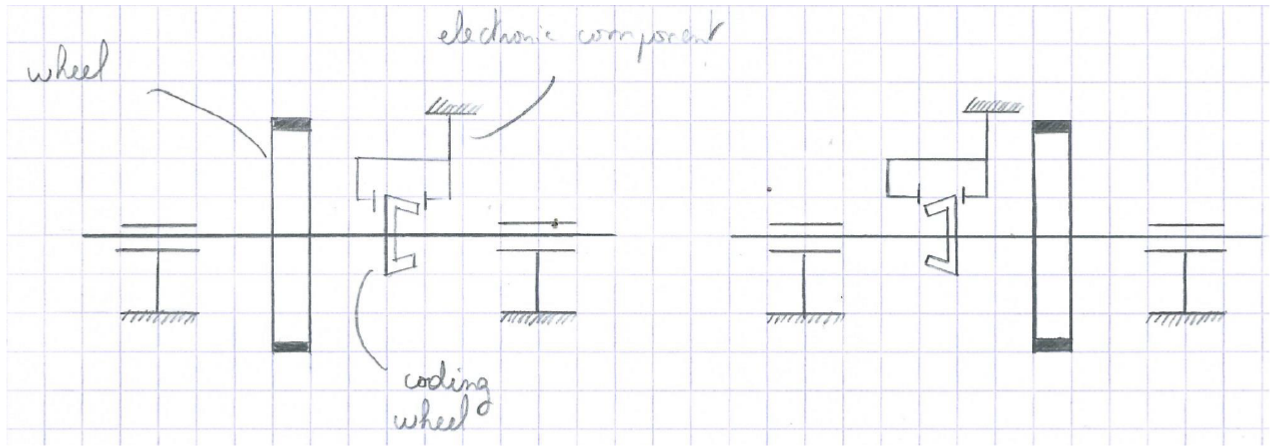


Figure 25: Kinematic schematic of odometer wheels

4.1.2 Detect obstacles nearby (F1.2) : proximity sensors

To be able to detect obstacles, we will use proximity sensors. In order to choose which type of sensor we will use, we made a comparative table.

Sensor type	Inductive	Optical	Magnetic	Capacitive	Ultrasonic
Detected materials	Metallic object	Every material	Magnetic object	Every material	Every material
Detection range	< 50 $[mm]$	< 100 $[mm]$	< 80 $[mm]$	< 50 $[mm]$	< 15 $[m]$
Cost	Low	Medium	Low	Medium	High for high range but low for low range
Sensitivity	Any	Dust, oil, aspect of object	magnetic field disturbances	Humidity	Air flow and temperature variation

Table 1: Comparison of proximity sensor types

By inspection of this table and by elimination, we will opt for an ultrasonic proximity sensor. Firstly because the robot must be able to detect every type of material (which eliminates inductive and magnetic sensors), but also because we need a sufficient range like $50\ mm$ to be sure to detect obstacles on time (which eliminates the capacitive sensor) and finally because there will be a lot of light during the meetings (which eliminates the optical sensor).

4.1.3 Move (F1.3) : motorized wheels and freebear rollers

In order to move the robot, there will be two motorized wheels (about $8\ cm$ diameter). They will be supplied by two DC motors and two reducers which will be specified in section 5. Since it would not fit in that way and also to gain some space, the DC motor will not be aligned with the wheels. That is why we will have to implement two bevel gears, as you can see in Figure 26.

In order to ensure the stability of the robot, there will be two freebear rollers (about $1\ cm$ diameter) which consist of kind of marbles which can roll in every direction without producing a lot of friction. In this way, it will guarantee the stability of the robot. In order to avoid hyperstaticity, one of the freebear rollers will have to be mounted on a suspension so that the robot remains isostatic.

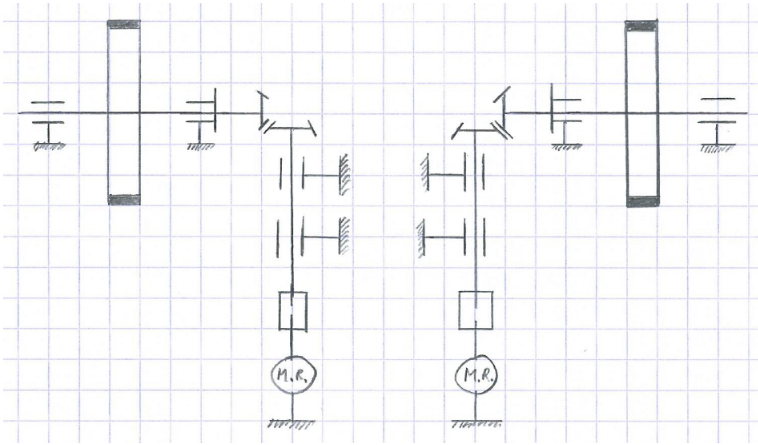


Figure 26: Kinematic schematic of motorized wheels

4.1.4 Put probes on the resistor of the excavation squares (F2.1) : moving probes set

In order to measure the value of the resistor, we have designed probes. In fact, each contact is a rectangular plate $5\ cm$ long and $2\ cm$ high, taking the distance between the centers of each plate, we have a distance of $5\ cm$. The excavation square is a square of $15\ cm$ side, it has an angle of 45° with the plane of the table. To know at which height to put the probes of the robot, we did some calculations, and we arrived at $13.6\ cm$. The robot cannot be against the map border because, if it was the case, it could flip the wrong excavation square by hitting it. By doing some calculations and by taking some security margins, we have a distance of $5\ cm$ between the robot and the border of the map.

By taking all of this into account, we have designed two probes $5\ cm$ apart with an axis of rotation at $13.6\ cm$ higher than the table. They have an "L shape" with the longest distance of about $2.5\ cm$ and the shortest of about $1.4\ cm$. The longest portion will be the one through which the motorized axis passes. To ensure that the electrical contact between the end of the "L" shape and the metallic terminal is sufficient to perform a good resistance measurement, we designed a spring system.

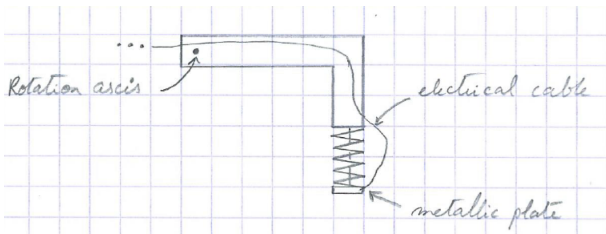


Figure 27: Detailed view of the moving probes set

As we can see in Figure 27, we have a metallic plate attached to a spring which is attached to the end of the "L" probe. A wire provides the electrical connection between the plate and then along each probe to the robot and the electronic measuring device. This allows us to simplify the design of the structure of the probe and since it does not have to take any significant effort, it allows us to print it in 3D. This is an advantage, because the part will have a lighter structure.

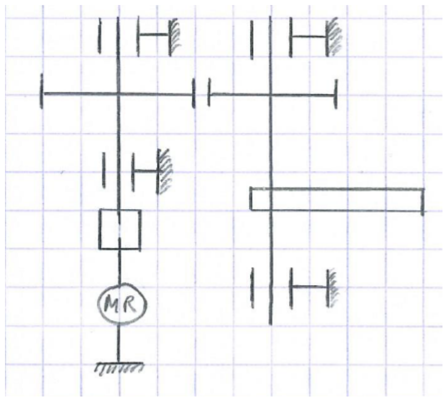


Figure 28: Kinematic schematic of the moving probes set

4.1.5 Flip excavation squares (F2.3) : moving actuator

To complete the mission linked to the excavation squares and after identifying which squares are the good ones, the robot will have to flip them. To do so, there will be a system of rack and pinion powered by a DC motor. The system of rack and pinion will be made using 3D printers in order to fit exactly with the position of the excavation squares. To be able and to be sure to flip the squares the rack will be of $20\ cm$ in length and since the excavation squares are not really heavy (considering MDF with a density of $750\ \frac{kg}{m^3}$, it gives a mass of $0.37\ kg$) , a diameter of $1\ cm$ will be enough. Indeed, if the rack pushes at a height of $9\ cm$ from the rotating point of the excavation square, it must at least produce a force of $2.76\ N$ which can clearly be done by a PLA crack.

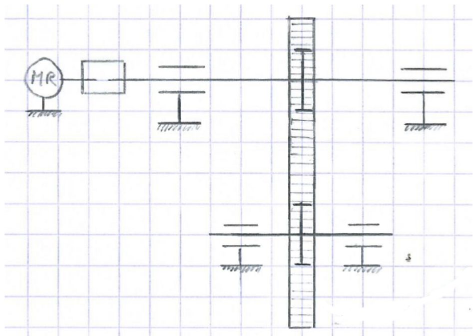


Figure 29: Kinematic schematic of the rack and pinion

4.1.6 Manipulate samples (F3.1, F3.2 and F3.3) : capturing tray

To be able to collect the samples and place them in our camp, we will use capturing trays, which consist of small arms fixed at each front corner of our robot. These arms are able to rotate around their axis in order to move the samples and put them in the center zone in front of the robot. The robot will then push the samples to slide them until they reach the base camp. The length of these arms is of $8\ cm$ and they will be $7\ mm$ above the ground to be able to push the samples.

4.1.7 Independent action (F3.4) : samples in the workshed : arms

In order to grab the samples placed on the workshed (one by one), we have designed an arm in a fork shape but with only two "subarms", as depicted in Figure 32. At the end of each subarm, the structure makes an angle of 90° towards the ground, as we can see in Figure 31. The goal is

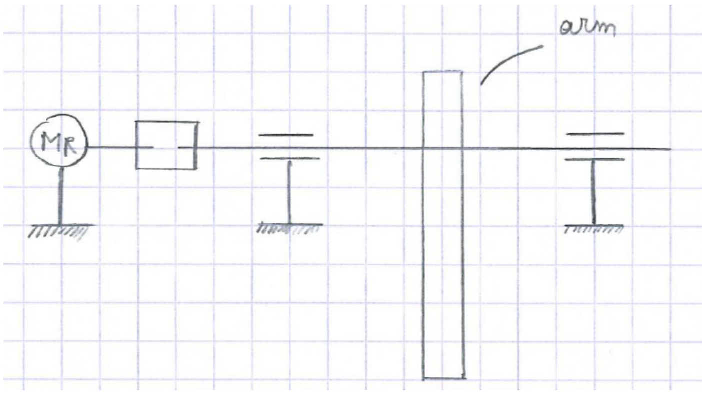


Figure 30: Kinematic schematic of the capturing tray

to put these additions after the diameter of the sample, and then the whole robot reverses to pull the sample and make it drop on the floor of the table. To know at which height to put the axis of the arm, we take the height of the border at $7\ cm$. The robot can be against the workshed because there is nothing it can hit by mistake.

By taking all of this into account, we have designed two subarms $12\ cm$ apart with an axis of rotation at $8.5\ cm$ higher than the table. The "Y" shaped arm is about $10 - 11\ cm$ long, and the shorter length of the additions heading down is about $1.5\ cm$.

Figure 31: Side view of the gripper for the workshed

This allows us to simplify the design of the structure of the arm and since it does not have to make any significant effort, it allows us to print it in 3D. This is again an advantage, because the part will have a lighter structure.

4.1.8 Grab the statuette (F4.1) : gripper

In order to grab the statuette, we designed a gripper which consists of two arms. One of them is fixed, and the other can move horizontally apart from the fixed one. The mechanism to perform this action is shown in Figure 33. In that way, the two arms of the gripper will fit into the notch on the statuette. When we have to grab it first, the robot will place itself in order to put the statuette between the two arms and the mobile arm will get closer to the fixed arm to tighten the statuette. This gripper is at a height of about $14cm$ from the ground (according to the statuette). Its width has a maximum value of $10cm$ and the length of the arms is $10cm$

4.1.9 Move the statuette (F4.2) : keep in the gripper

Once the statuette is grabbed, the robot will keep it in its gripper to transport it to the display cabinet, as it would do if the statuette was not there. The robot will do so until the statuette is

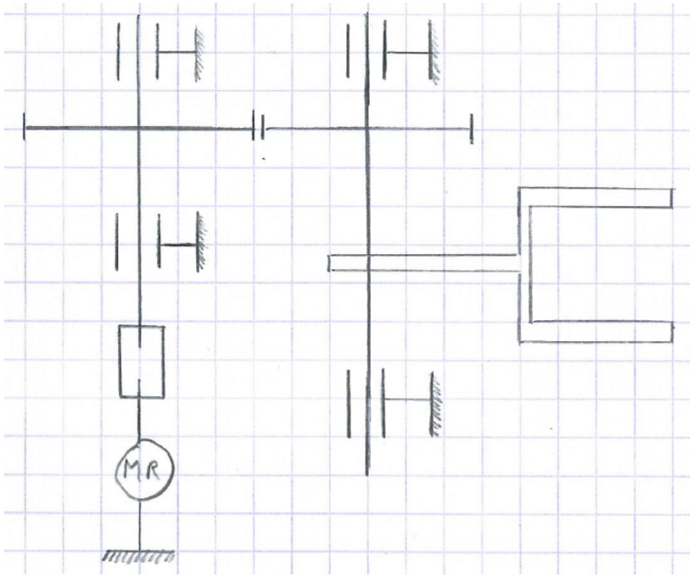


Figure 32: Kinematic schematic of the gripper for the workshed

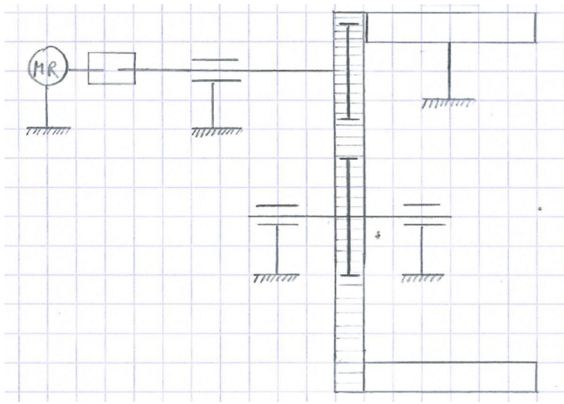


Figure 33: Kinematic schematic of the gripper for the statuette

just above the display cabinet.

4.1.10 Put the statuette in the display cabinet (F4.3) : gripper

Once the statuette is just above the display cabinet, the mobile arm of the gripper can now move away from the fixed one to let the statuette fall on the cabinet.

4.1.11 Move the replica (F5.1) : store

As it is allowed in the rules, the replica will be present in our robot at the beginning of the game. That's why we will create a slot on the left edge of the robot. This slot will not be over the floor so that it doesn't count in the total perimeter. The ground of this slot is also slightly above the level of the pedestal. The dimensions of this slot will be similar to those of the replica. It will look like a cube of $6.5\ cm$ in order to leave some space to avoid it getting stuck.

4.1.12 Put the replica on the pedestal (F5.2) : push

To put the replica on the pedestal, the robot will simply push the replica on it using a translating arm that consists of a rack actuated by a DC motor. This operation will have to be slow so that the replica doesn't slip too far and fall behind the pedestal. The pushing arm will also stop right at the edge of the slot dedicated to the replica in order not to count in the total perimeter. The rack will be $10\ cm$ long.

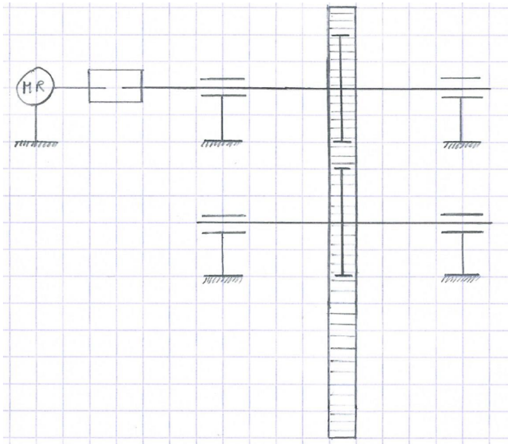


Figure 34: Kinematic schematic of the arm to push the replica

4.2 Evaluation of the quantity and type of the sensors and actuators

In Table 2, we find two types of motor. Indeed, as a preliminary dimensioning, we chose to distinguish first the motors used for the propulsion of the robot itself which are around $25\ W$. We then counted the number of smaller motors used to operate the onboard equipment to perform the tasks on the table. Indeed, this second type of motor is less powerful, around ten times less, than the first type. We need two powerful motors and seven smaller motors, thus a total of nine motors.

Motor type	Number	Localization
DC motor (powerful)	2	Motorized wheels
	Subtotal = 2	
DC motor (small)	1	Probes
	1	Excavation squares
	1	Grip samples on workshed
	2	Capturing arms
	1	Statuette grip
	1	Pushing arms for the replica
	Subtotal = 7	

Table 2: Motors

For the sensors, we have three different types: proximity sensors, LIDAR and ohmmeter, as we can see in Table 3. For the proximity sensors as said in subsubsection 4.1.2, we use ultrasonic proximity sensors. We decided to put 6 sensors around the robot. If we take the baseplate of our robot, we have a rectangle. We would like two proximity sensors on each of the two long sides and only one sensor on the short sides. Then, for the LIDAR, we only need one sensor on top of the robot to use the technology for mapping the environment of the robot. Finally, we need one ohmmeter to analyze the data from the probes to determine the value of the resistor and to decide if we flip the excavation square (subsubsection 4.1.4).

Sensor type	Number	Localization
Proximity sensors	6	Around the robot
LIDAR	1	On top of the robot
Ohmmeter	1	Near the probes
Odometer wheels	2	On the same axis as the wheels

Table 3: Sensors

4.3 Main dimensions of the robot

Figure 35 shows the main dimensions of our robot. The total height (every floor + wheels, etc.) is shown.

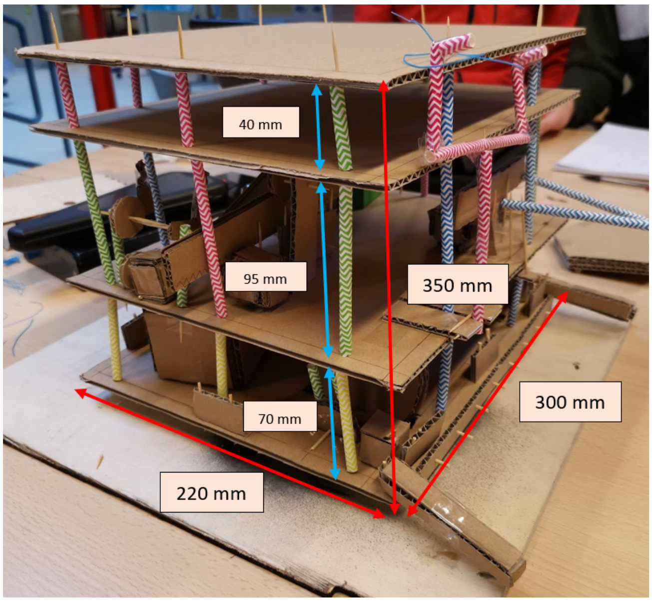


Figure 35: Main dimensions of the robot

5 Dimensioning

Diego and Nicolas contributed equally to this section. They wrote this section in common, working together on some points and in parallel for other tasks. Nicolas looked back over this section to ensure cohesion.

5.1 Preliminary dimensioning of the components

5.1.1 Physical dimensioning

For all the dimensions of the arms, the structure, etc., see previous section.

5.1.2 Driving motors

To find the dimensions, we used this website. This website provides a neat tool to dimension the driving motors with respect to the total mass of the robot, its required speed, etc.

We used the following dimensions:

- Estimated mass per wheel : 7.5 kg.
- Maximum speed of the robot : 1 $\frac{m}{s}$.
- Maximum acceleration : 2 $\frac{m}{s^2}$.
- Radius of the wheel : 0.04 m.
- Number of motors per wheel : 1.
- Maximum tilt : 5°.
- Supply voltage : 24 V.
- Required operating time : 1.667 min (100 s).
- Total efficiency : 45%.

We use a mass of 7.5 kg for the calculation of the motor for one wheel, because we estimate that half the weight of the robot will be supported by each wheel (we thus don't consider the weight taken by the caster ball wheels!)

When we enter those values on the website, we get the following results:

- Angular velocity : 25.00 $\frac{rad}{s}$.
- Torque : 1.9033 Nm.
- Total power : 47.583 W.
- Maximum current : 1.9826 A.
- Required battery : 0.055084 Ah.

To meet those requirements, we decided to use a DC motor whose characteristics are visible using this link. This motor uses a supply voltage of 24 V and has a rotation speed of 6100 $\frac{tr}{min}$ (adjustable with a reducer). The motor is visible in Figure 36.

Figure 36: DC motor chosen

5.1.3 Secondary motors dimensioning

In this section, we evaluate the needs for the secondary motors. We estimate the torques and speeds needed for each function. As we will see throughout the detailed calculations, we will be able to choose only one motor that will suit every function. For this purpose, we use two formulas:

- For the torque : $\overrightarrow{\tau} = \overrightarrow{d} \times \overrightarrow{F}$;

- For the power : $P = \tau\omega$, where ω is the angular speed in $\frac{rad}{s}$, or we use $P = Fv$ (power = force times velocity) ;

For all the 3D printed components, we estimate their mass using ABS as material (a standard plastic used for 3D printing), with density $\rho = 1020 \ \frac{kg}{m^3}$.

→ **F2.1: Put probes on both sides of the resistor :**

From the mechanical dimensioning, we can make the free body diagram shown in Figure 37. We say L = 0.08 m. We quickly establish that, since we estimate $m_{probes} = 50 \ g$ and $m_{arm} = 10 \ g$: $\tau_{max} = w_{probes}.L + w_{arm}.\frac{L}{2} = 0.043164$ Nm. We estimate that the tip of the bar holding the probes has to make a change of 45° from its original position in 0.5 s, which gives us $\omega = 1.571 \ \frac{rad}{s}$. Thus, we get $P = 0.0678 \ W$.

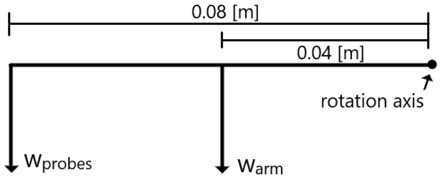


Figure 37: Free body diagram of the situation

→ **F2.2: Flip excavation squares :**

First, we have made some hypotheses :

- the mass of the excavation square is 200 g.
- the application point of the rack's force is at a distance of 50 mm relative to the rotation axis of the excavation square in the direction perpendicular to the floor.

From the hypotheses we can calculate the force $F_g = 0.2$x$9.81 \ N$.

Next with an equilibrium of the moment at the rotation point :

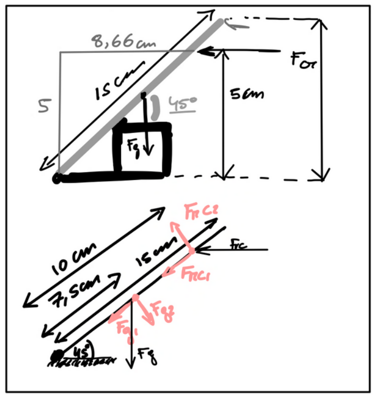


Figure 38: Illustration of the context

$$\sum M = 0$$
$$\Longleftrightarrow 0.1 \times F_{rc2} - 0.075 \times F_{g2} = 0$$
$$\Longleftrightarrow F_{rc2} = 0.75 F_{g2}$$

where :

$$\begin{cases} F_{g2} = \frac{\sqrt{2}F_g}{2} \\ F_{rc2} = \frac{\sqrt{2}F_{rc}}{2} \end{cases}$$

With this we obtained a rack force of 1.47 N. The minimal pushing distance to assure flip is 8.7 cm. We decided to operate this action in less than 0.5 s. This gives a speed of 20 $\frac{cm}{s}$ and a required effective power of 0.3 W.

→ **F3.4.1: Get the two samples :**

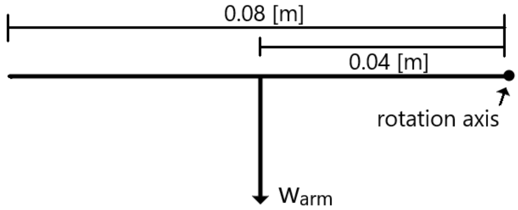


Figure 39: Free body diagram of the situation

We have the same situation as above. We neglect the samples in the calculations, as the motor will be blocked when the whole robot moves backwards. We still have L = 0.08 m. We quickly establish that, since we estimate $m_{arm} = 10\ g$: $\tau_{max} = w_{arm}.\frac{L}{2} = 0.01962\ Nm$. We estimate that the tip of the bar has to make a change of 90° from its original position in 0.5 s, which gives us $\omega = 3.14159\ \frac{rad}{s}$. Thus, we get $P = 0.0616\ W$.

→ **F3.4.2: Put in the workshed :**

Since the rotation axis is parallel to the only force acting on the arm it moves, that is the weight of the arm, and since we neglect the friction between the different parts, the torque required for this application is negligible compared to the other functions, so we just align ourselves with the other functions and consider that the motor we will find to fulfil the requirements of those functions will be also good for this one.

→ **F4.1: Grab the statuette :**
First, the hypotheses :

- the statuette is designed by 3D modeling and has been 3D printed. See Annex B for more information about the statuette geometry.
- we added a security factor of 1.2.
- α = 45°

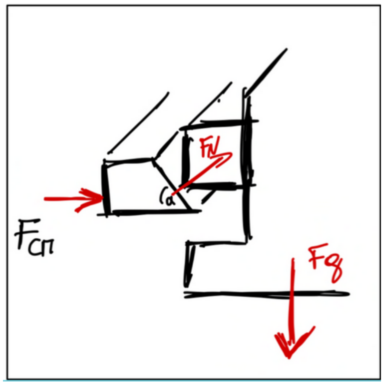


Figure 40: Illustration of the context

By the modeling in SolidWorks we computed a mass of 362 g. With the safety factor, we have a equivalent mass of 434 g.

We rapidly identify the equation system :

$$\begin{cases} F_g = m \times g \\ F_g = -F_N \cos\alpha \\ F_{rc} = F_N \sin\alpha \end{cases}$$

This gives a rack force equal to F_g = 4.26 N. With a distance covered of 4 cm in 0.5 s we have a required effective power of 170.4 mW.

→ **F5.2: Put the replica on the pedestal :**

- The replica is supposed to be composed of plywood. So its density is 500 $\frac{g}{m^3}$.
- The table is supposed to be composed of plywood so coefficient of friction $\mu_{s:wood-wood} = 0.5$
- Safety factor = 1.2.

With the data we can compute :

$$\begin{cases} m = 0.06^3 \times \rho = 110\ g \\ m_{eq} = 1.2 \times m = 132\ g \\ F_r = -\mu \times F_g \end{cases}$$

By an equilibrium of forces in the axial direction of the rack :

$$F_{rc} = F_r$$

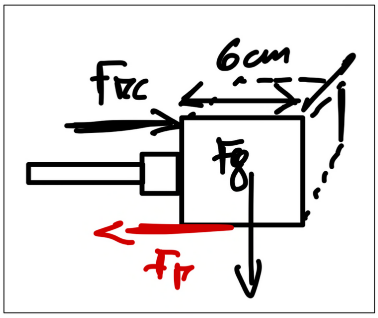


Figure 41: Illustration of the context

With a distance covered of 6 cm in 1 s, we have an effective power of 39 mW.

Considering all the calculations stated above and to get a "generic" motor working for all functions, we decide to use a "X-Train 263 H0" electrical motor (see this link and Figure 42). It is powered with a tension between 4 to 14 V and with a maximum current of 0.30 A. It offers an effective power of 1.3 W, which is sufficient for each function described in this section.

Figure 42: X-Train 263 H0

5.2 Evaluation of the electronics

We summarize in Table 4 the estimated necessary electronics for our robot to locate itself and move.

Name (and link)	Quantity	Communication protocol	Voltage [V]	Power used $[mW]$
Odometer wheels	2	Unknown	4.5-5.5	around 285
Proximity sensors	6	SPI	5	75
Screen	1	Unknown	5	84
LIDAR	1	UART	5	7500
Driving motors	2	-	24	65000
Driving motor's driver	1	CANopen	12-24	unknown
Little motors	7	-	12	2766
Ohmmeter Annex C	1	not decided	5	17
Emergency button Annex D	1	-	supply voltage	around 0

Table 4: Summary table of the required electronics

With this table, we can have an idea of the required battery capacity. We have permanently active components: the six proximity sensors, the two odometer wheels, the LIDAR and the display screen. We can consider the driving motors as permanently active too. We decide to neglect the impact of the Ohmmeter because of its small value of power used and short operating time. Finally, we consider that, globally, only one secondary motor is used at the same time. To have an upper bound approximation, we considered that all the secondary motors could be approached as a single secondary motor continuously activated.

Considering all these approximations, we can estimate that we have a continuous power consumption of 141.085 W, or 141085 mW. When translating this into energy (expressed in Wh), since our device should work during 100 s, which is equal to 0.027778 hours, we get a total energy of 3919.028 mWh. Knowing this, we will look for a battery delivering this energy that has a 12 V and 5 A output.

Our robot also needs a brain, also known as a micro-processor, which will perform Arithmetic Logical Unit (ALU) operations and communicates with the other devices connected with it. We will use a Raspberry Pi 3, as this is the device that we're studying in the LELEC2531 course. It uses I2C, SPI and UART as communication protocols with the other applications. For the control of our robot, we're going to use micro-controllers. We could choose between an Arduino (which uses the same communication protocols as the Raspberry), or a PIC32 micro-controller (which uses a CAN communication protocol) for example. Further investigations may lead to other solutions.

We estimate that we will have to use PCBs for cable management and supply voltage, as the battery delivers a certain voltage and the actuators and sensors need different supply voltages to work effectively.

6 Organisation

In this section, Nicolas wrote the text and created the Gantt Chart. He is in charge of keeping it up to date.

For our team's organisation, we use several ways of communication. We use Teams as our primary source of communication : there, we have our drive, our documents and main topics. It is the center of our project's organisation. We also use Trello when we have a task to divide between the members, so we know who does what and when. Next, we use Messenger for quick notes and fast communication between members. And finally, for the global planning, we use TeamGantt to create a neat Gantt Chart, which you can see in Figure 43.

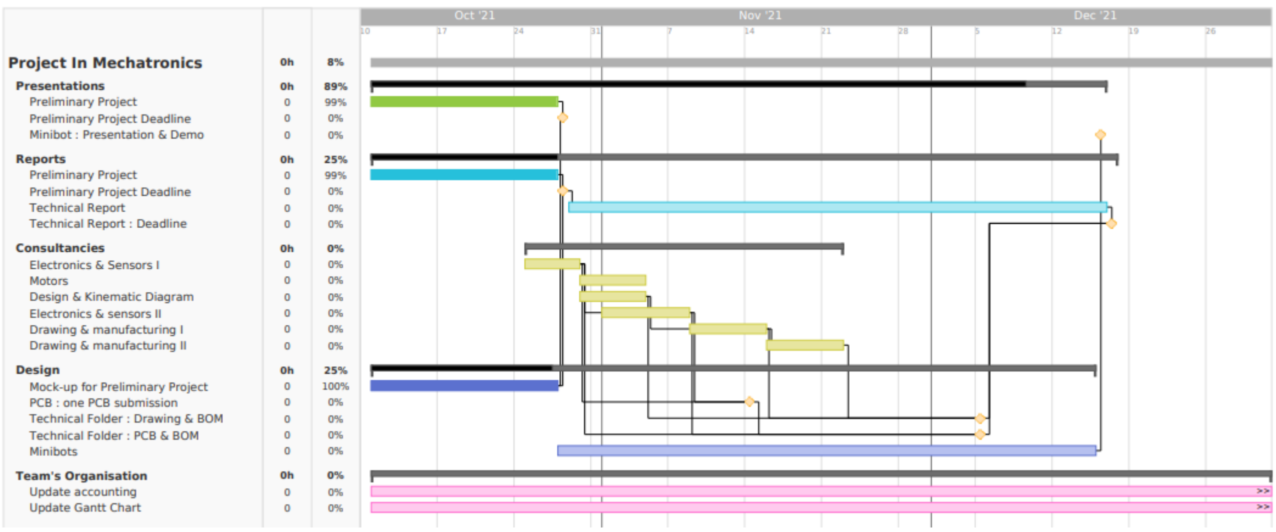


Figure 43: Gantt Chart up to the end of the semester

This Gantt chart will serve as our planning for the end of the semester.

7 Conclusion

Nicolas wrote the conclusion

At this stage, we have a good idea of what our robot will look like. We also have a clearer vision of the different dimensions and we realised that we have to make changes to respect the rules of the Eurobot contest.

We will keep updating the project iteratively and improve it as it moves on and we look forward to the Minibot to work a little bit more on the implementation part of the project.

Appendices

A Strategy Details

This appendix has been written by Diego updated by Théau

Missions	Strategy 1 (reserved for us)	Strategy 1 bis	Strategy 2 (for both teams)	Strategy 3 (optimize difficulty over rentability)
Excavation square	15	15	15	25
Research	6	6	0	6
Analysis	6 x 3 = 18	3 x 1 = 3	9 x 1 + 6 x 3 = 27	0
Base camp	0	3 x 1 = 3	9 x 1 = 9	6x1
Gallery	6 x 3 = 18	0	6 x 3 = 18	0
Work shed	0	3 x 5 = 15	3 x 5 = 15	2x5 = 10
Statuette and replica	2 + 5 + 10 + 15 = 32	32	0	32
Display Cabinet	2 + 5 = 7	7	0	7
Return to the camp	20	20	20	20
Estimate the performance	34.8	30.3	31.2	31.8
Total	**150.8**	**131.3**	**135.2**	**137.8**

Figure 44: Presentation of the different strategies

In Figure 44 we can observe the number of points available for different types of strategies.

The Strategies 1 and 1 bis are based on the idea of only orienting our efforts in actions without competitions. This removes the risk of not being able to perform a task because it was done before us.

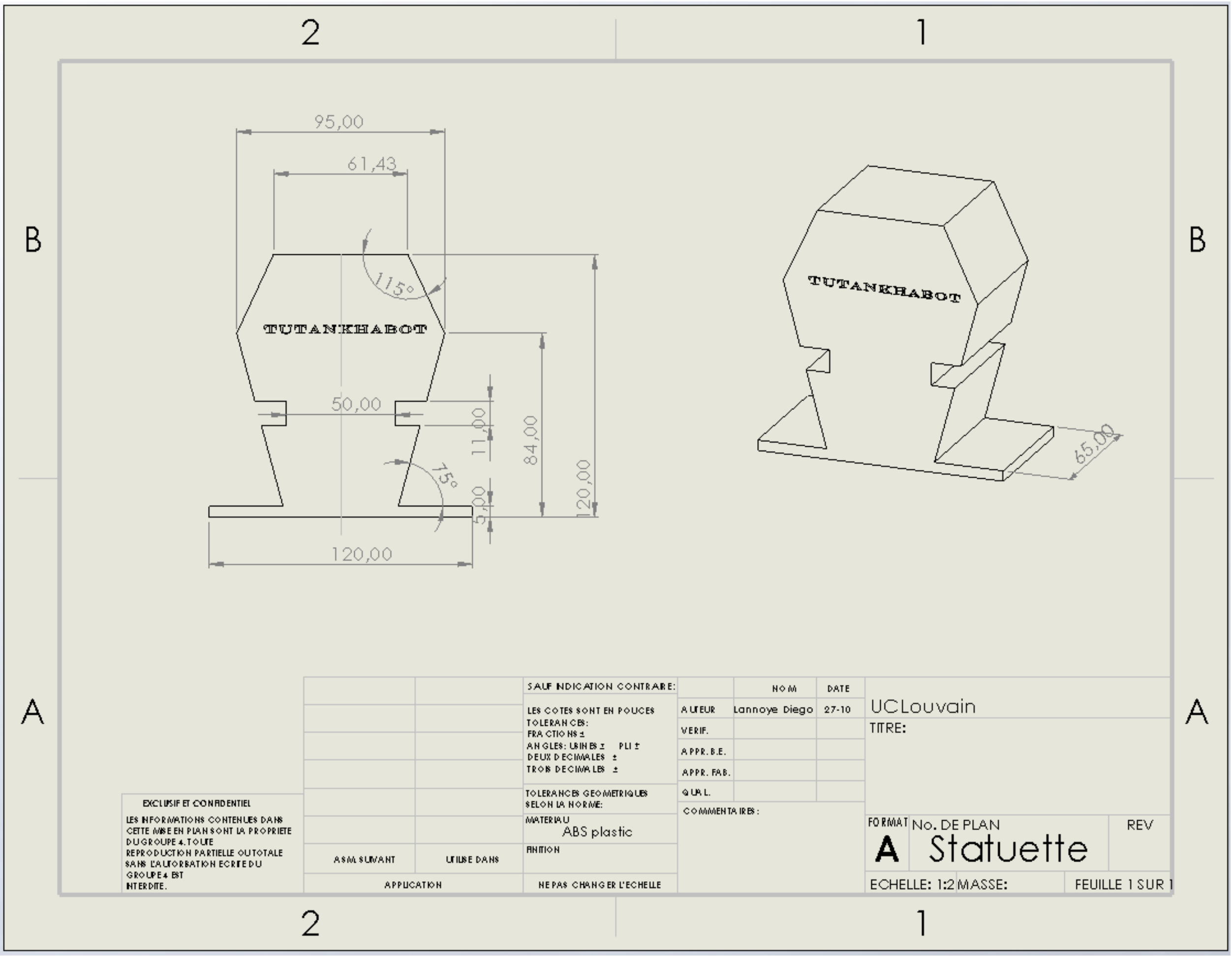
The Strategy 2 is based on the opposite idea of the Strategies 1 and 1 bis. Here we program a robot specialised in doing the common tasks.

The last Strategy is the one described in the section 2. We decided to choose this strategy despite the fact that it doesn't get the biggest score because we think it is a safer choice with the time available and our still little experience in the domain.

We can see that strategy 3 and the strategy described in the section 2 are not exactly the same, it's because the work shed was added.

B Plans for the statuette

This appendix has been written by Diego



C Ohmmeter implementation

This appendix has been written by Diego

The objective of the ohmmeter is to convert a resistance value into a voltage value. This section compares the three possible solutions for this electrical function.

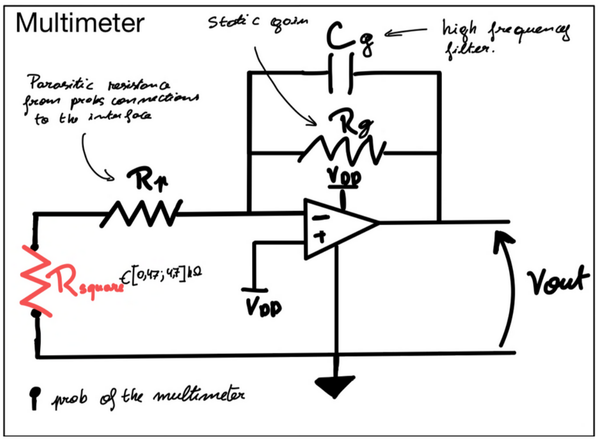


Figure 45: First possible implementation

the tAnnex/Multimeter$_2.PNG$

Figure 46: Second possible implementation

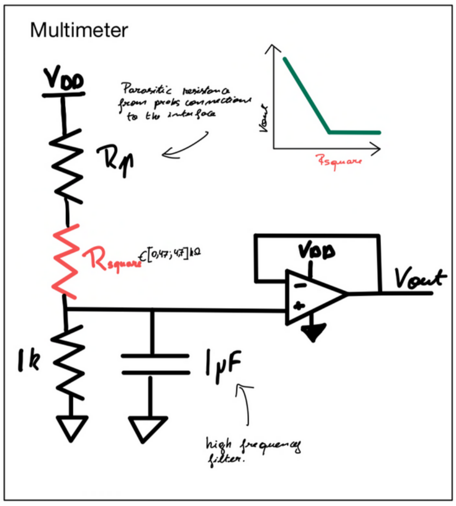


Figure 47: Third possible implementation

The first possible solution is a classical kind of interface. It has the possibility to have adjustable a static gain and low-pass filter. But the ineligible non-idealities of the op-amp make it a non-ideal choice and the simulation on LTspice doesn't give good performance.

The second and third possible solutions are only differentiated by the presence of a op-amp in voltage follower mounting. This addition reduces the linearity of the transfer function at high resistance (low voltage) but removes all parasitism of the following part of the circuit, where the loss of linearity only influences the differentiation between the no contact and the 4.7kΩ resistance. And we think that this can be compensated more easily. We decided to use the third solution.

The power used is the power consumed by the resistive divider. The critical consumption point is when R_{square} is equal to 470 Ω and $R_p = 0$. P = $\frac{V_{DD}^2}{R_p + R_{square} + 1k} = 17\ mW$.

D Emergency Button

This appendix has been written by Nicolas.

We established the design visible on Figure 48 during the practical session on emergency buttons.

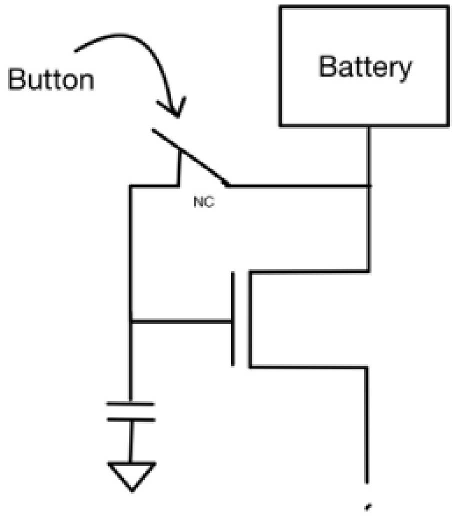


Figure 48: Emergency button functioning schematic

The battery is connected to the rest of the circuit by a nMOS transistor. The transistor's grid is connected to the battery output by the button which is normally closed. So, in normal conditions, the nMOS is allowing the battery to feed the circuit.

When the button is pressed, it disconnects the grid from the power source, which results in a "0" on the grid (as the capacitance will discharge) and the nMOS transistor will thus be blocked, resulting in no supply to the circuit.