LELME2002 - Project in Mechatronics

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Technical folder

TutAnkhaBot

Group 4

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1 Preface

The link to the Onedrive containing the mechanical parts is the following : `https://uclouvain-my.sharepoint.com/personal/sebastien_bosschaert_student_uclouvain_be/_layouts/15/onedrive.aspx?id=%2Fsites%2FO365G%2DProjectInMechatronicsGroup4%5F2021%2FDocuments%20partages&listurl=https%3A%2F%2Fuclouvain%2Esharepoint%2Ecom%2Fsites%2FO365G%2DProjectInMechatronicsGroup4%5F2021%2FDocuments%20partages`

2 Introduction

Théau wrote this section.

Tutankhabot is a robot developed by a group of six students for the 2022 Eurobot competition. The design, building and programming of the robot is done throughout the 2021-2022 academic year in the context of the LELME2002 course at the EPL in Louvain-la-Neuve.

The Eurobot rules precisely describe how to score points and the specifications a robot must meet to take part in the competition. This year's theme is "Age of Bots".

The main actions the robot has to be able to achieve to score points are:

- Move and sort samples around the playing area
- Store the samples in a work shed, in a gallery or at the campsite
- Detect and flip excavation squares
- Switch a statuette with a replica
- Put that statuette in a display cabinet
- Return to a precise point of the playing area at the end of a match
- Estimate the number of points scored

The major and most limiting constraint over the robot design is its size. The perimeter of the robot must be smaller than 1200 mm when not deployed and 1300 mm deployed.

The complete rules can be found at: `https://www.coupederobotique.fr/wp-content/uploads/Eurobot2022_Rules-EN.pdf`

This technical report precisely describes the entire design of Tutankhabot. It includes:

- a general overview with all the parts of the robot
- the dimensions of all the custom mechanisms designed for the robot and their production methods (3D printing, laser cutting,...)
- the motor dimensioning
- the drawings of the parts to machine by the LAFAB
- a global electrical scheme
- a listing of all electrical inputs and outputs
- schematics of the custom designed PCBs

3 Overview of the robot

Clément, François and Sébastien contributed equally to the writing of this section.

In this section, we will review the design of the robot using the 3D model. The robot consists of 4 superimposed plates.

On the bottom floor, there are :

- the driving train
- the orientation and detection system
- a pushing structure

On the first floor, there are :

- the mechanism for the excavation square
- the mechanism for the statuette
- the mechanism for the workshed
- 2 batteries

On the second floor, there are :

- the mechanism for the replica
- 1 Raspberry pi and DE0-Nano FPGA
- 1 Arduino
- 3 PCB

On the top floor, there are :

- 1 lidar
- the emergency pushbutton
- a site for a beacon

4 Mechanical dimensions

Clément, François and Sébastien contributed equally to the writing of this section.

In this section, we will review the different mechanisms that make up our robot, in order to go over the different points that characterize them.

4.1 Structure of the robot

We have three categories of pieces: the bottom plate, the plates for the other levels and the supports. Since the different levels have not the same height, we have different lengths for the supports.

Component	Number	Acquisition process	Comments
Bottom plate	1	Machining	Machined at UCLouvain LAFAB
Intermediate plate	2	Laser cutting	Material: Wood
Plate for batteries	1	Laser cutting	Material: Wood
Upper plate	1	Laser cutting	Material: Plexiglass
Screws for supports level 0	6	External Provider : Misumi	Length : 8mm Type : M3
Supports of level 0	6	External provider: Misumi	Hexagonal brass spacer of 57mm length Male and female thread Screw diameter of M3
Supports of level 1	12	External provider: Misumi	Hexagonal brass spacer of 40mm length Male and female thread Screw diameter of M3 2 screwed together
Supports of level 2	6	External provider: Misumi	Hexagonal brass spacer of 40mm length Male and female thread Screw diameter of M3 2 screwed together
Supports of level 2	6	External provider: Misumi	Hexagonal brass spacer of 40mm length Female and female thread Screw diameter of M3 2 screwed together
Screws for supports level 2	6	External Provider : Misumi	Length : 8mm Type : M3
Supports of batteries	3	External provider: Misumi	Hexagonal brass spacer of 40mm length Male and female thread Screw diameter of M3
Nut for supports batteries	3	External Provider : Misumi	Type : M3
Screws for supports batteries	3	External Provider : Misumi	Length : 8mm Type : M3
Supports of PCBs	4	External provider: Misumi	Hexagonal brass spacer of 40mm length Male and female thread Screw diameter of M3
Nut for supports PCBs	4	External Provider : Misumi	Type : M3
Screws for supports PCBs	4	External Provider : Misumi	Length : 8mm Type : M3
Supports for the PCBs	12	External provider : Misumi	Hexagonal brass spacer of 10mm length Male and female thread Screw diameter of M3

Table 1: Structure of the robot

First, we have the bottom plate of our robot, which will be machined at LAFAB and whose layout is discussed in section 6. Then we have two intermediate plates and the upper plate, which will be realized at the Makilab where we will use the laser cutter.

Finally, to support the different floors, we will use hexagonal brass spacers of different lengths. Indeed we have the following heights for the floors:

- Floor 0-1: 5.7 cm

- Floor 1-2: 8 cm
- Floor 2-Roof: 8 cm

We have 3 types of spacers, all of them are hexagonal brass spacers with a screw diameter of M3 but they differ by length and with the combination of threads. We have two combinations: male-female and female-female. Because on Misumi hexagonal brass spacer 8cm long are more expensive, we take two hexagonal brass spacer of 40mm length with male and female thread that will be screwed together.

4.2 Driving train

Here, we consider everything that has to do with the propulsion of robots. Indeed, we find the main motors, the wheels, the encoders of the motors, the battery that powers them and the emergency stop button that allows to immobilize the robot in case of emergency.

Component	Number	Acquisition process	Comments
Motor	2	Thierry Daras	Geared motor Faulhaber 2642W024 (20W)
Wheels	2	Thierry Daras	Diameter : 59mm Thikness : 10.2mm Reduction ratio : 19:1
Coder	2	Thierry Daras	Model : HEDS-5540A02
Battery	1	Thierry Daras	Model : Solise B12003 12V 3200mAh
Stop emergency button	1	Thierry Daras	/
Screws for the motor	8	External provider: Misumi	Length : 8mm Type : M3
Freebear	2	External provider: Misumi	Model : IS-08SNM Ball transfer
Nut for freebear	2	External Provider : Misumi	Type : M4

Table 2: Driving train

The output shaft of each of the 2 propulsion motors as well as the gearbox are at 90° to the axis of the wheel. The link between those shafts is then performed using a bevel gear at 90°. The wheel is then fixed in rotation on the output shaft of this gear by means of a small pressure screw on a flat on she shaft.

The two motors are each screwed to the bottom plate by means of 4 countersunk screw size M3. Indeed, there are 4 blind holes with M3 thread in the engine blocks, these are about 5mm deep and the bottom plate is 3mm thick, so we need 8mm long screws.

4.3 Orientation and detection system

Here we have all the components that concern orientation and detection as the title of the section suggests. In order to be able to fix the proximity sensors on our robot, we insert them in a suitable structure that will be 3D printed. It will have 2 holes located on the sides to pass M3 screws. The sensors will be fixed on the plate of the first stage, each one with 2 M3 screws and two nuts of corresponding size.

Component	Number	Acquisition process	Comments
Odometer set	2	Thierry Darras	Model of the encoder : AMT103V
Proximity sensors	5	Thierry Darras	HCSRC04
Support of proximity sensor	5	3D Printing	/
Screws (proximity sensors)	10	External provider : Misumi	Minimum length : 10mm Type : M3
Nuts (proximity sensors)	10	External provider : Misumi	Type : M3
Lidar	1	Thierry Darras	/
Supports of the Lidar	4	External provider : Misumi	Hexagonal brass spacer of 10mm length Male and female thread Screw diameter of M3

Table 3: Orientation and detection system

For the lidar, we take additional spacers of 1cm long so that it is slightly higher. It will be fixed to the top plate of the robot with screws that will be fixed in the female thread of the spacers.

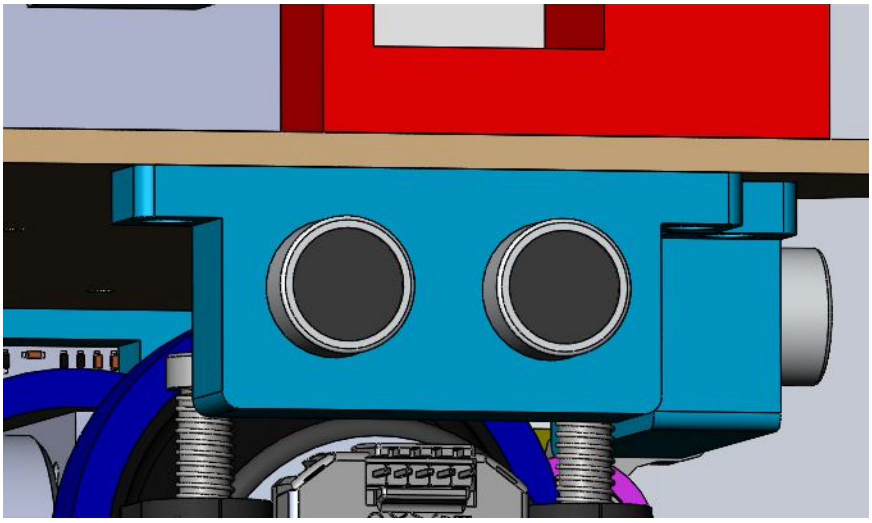


Figure 1: Proximity sensor in its housing

4.4 Pushing structure

In order to push samples below the workshed, we will use a pushing structure. The latter consist of a Servo motor that spins a pushing frame in Plexiglas laser cut through an axis of rotation 3D printed. A support for this mechanism will be 3D printed.

Component	Number	Acquisition process	Comments
Support	1	3D Printing	/
Axis of rotation	2	3D Printing	/
Pushing frame	1	Laser cutting	Material : Plexiglass
Motor	1	External provider : Dfrobot	Servo motor DSS-M15S Provided with adapters
Screws for support	2	External Provider : Misumi	Minimum length : 10mm Type : M3
Hexagonal nuts for the support	2	External Provider : Misumi	Type : M3
Screws for axis of rotation	2	External Provider : Misumi	Minimum length : 10mm Type : M2
Hexagonal nuts for the axis	2	External Provider : Misumi	Type : M2

Table 4: Pushing structure

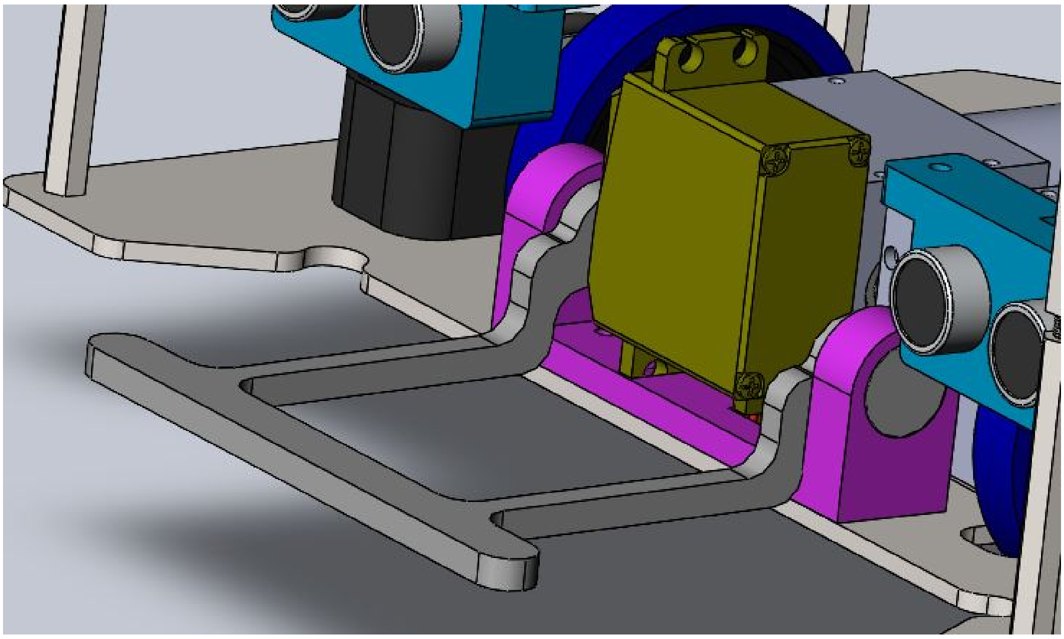


Figure 2: Pushing structure for the samples

4.5 Probes

For the probes, we have designed a structure that will be made in 3D printing. It will be fixed to the floor of the second floor with 2 screws and 2 nuts, all M3 size. These screws are also countersunk. This one receives and allows to fix the servo motor, it also includes a sliding bearing for the shaft. This shaft is equipped with a shoulder and a flat in order to block the structure of the probes in rotation with a pressure screw. The servo motor is fixed to the structure with 2 screws of size M3 and 2 nuts of size M3 also. This avoids the use of 3D threads which are not very strong for this size of thread. We took M3 screws because it is the largest metric size that can pass through the fixings integrated into the chosen model of servo motor.

Component	Number	Acquisition process	Comments
Motor	1	External provider : Dfrobot	Servo motor DSS-M15S Provided with adapters
Structure of the probes	1	3D Printing	/
Screws to fix the motor	2	External provider: Misumi	Minimum length : 10mm Type : M3
Hexagonal nuts for the motor	2	External Provider : Misumi	Type : M3
Screws to fix the structure	2	External provider: Misumi	Minimum length : 10mm Type : M3
Hexagonal nuts for the structure	2	External Provider : Misumi	Type : M3
Additional metallic contactor	2	External provider: Misumi	Material : Copper Thikness : 0.5mm
Shaft	1	External Provider : Misumi	A shoulder on one side, a flat in the middle, at the other end a blind hole with internally toothed gear

Table 5: Probes

The structure of the probes themselves, i.e. the one that will come into contact with the excavation squares, will also be made in 3D printing. In order to ensure electrical contact, the ends of this structure will have a metallic part. These parts made of copper will have in addition to ensure the electrical contact, an additional function to allow a certain flexibility of the contacts in the event of a misalignment of the 2 contacts compared to the square of excavation and this in order to be able to ensure the stable electrical contact and consequently to be able to carry out a measurement of the resistance.

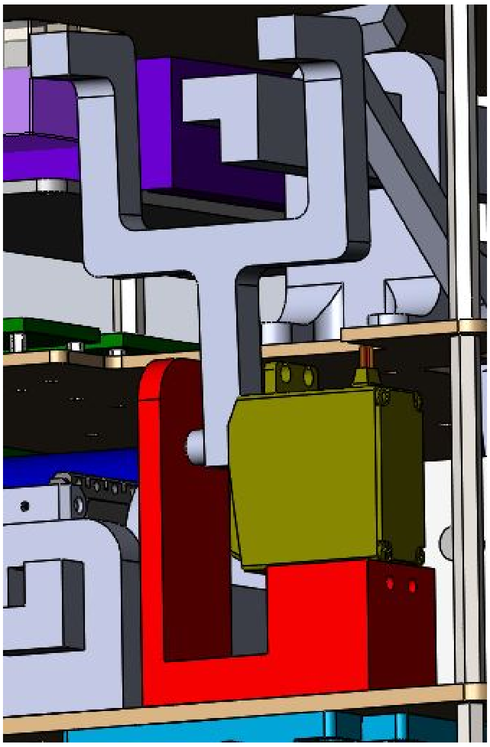


Figure 3: Probes for measuring the excavation squares

4.6 Excavation rack

To be able to flip the right excavation squares, we will use a system of rack and pinion. To do so, a Dynamixel will drive a 3D printed pinion which will move a 3D printed rack toward the excavation square to flip it.The Dynamixel will be fixed to the robot thanks to a 3D printed support. There will also be two 3D printed supports to guide the rack.

Component	Number	Acquisition process	Comments
Motor	1	Thierry Daras	Model : Dynamixel AX12A
Rack	1	3D Printing	/
Pinion	1	3D Printing	/
Support for the rack	2	3D Printing	/
Support for the Dynamixel	1	3D Printing	/
Adapter for DynamixelAX12A	1	3D Printing	Junction between the Dynamixel and the pinion
Screws to fix the motor on the support	4	External Provider : Misumi	Minimum length : 10mm Type : M2
Hexagonal nuts for the motor	4	External Provider : Misumi	Type : M2
Screws for supports	7	External Provider : Misumi	Minimum length : 14mm Type : M3
Hexagonal nuts for the supports	7	External Provider : Misumi	Type : M3

Table 6: Excavation rack

4.7 Gripper for workshed

As for the probes, we have designed a structure that will be made in 3D printing. It will be fixed to the floor of the second floor with 2 screws and 2 nuts, all M3 size. These screws are also countersunk. This one also receives and allows to fix the servo motor, it also includes a sliding bearing for the shaft. This shaft is equipped with a shoulder and a flat in order to block the structure of the probes in rotation with a pressure screw. The servo motor is fixed to the structure with 4 screws of size M3 and 4 nuts of the corresponding size. We took M3 screws because it is the largest metric size that can pass through the fixings integrated into the chosen model of servo motor. As for the structure of the gripper itself, it will, like the structure of the probes, be 3D printed.

Component	Number	Acquisition process	Comments
Motor	1	External provider : Dfrobot	Servo motor DSS-M15S Provided with adapters
Structure of the gripper	1	3D Printing	/
Screws to fix the motor	4	External provider: Misumi	Minimum length : 10mm Type : M3
Hexagonal nuts for the motor	4	External Provider : Misumi	Type : M3
Screws to fix the structure	2	External provider: Misumi	Minimum length : 10mm Type : M3
Hexagonal nuts for the structure	2	External Provider : Misumi	Type : M3
Shaft	1	External Provider : Misumi	A shoulder on one side, a flat in the middle, on the other side, a coupling plate with 4 holes

Table 7: Gripper for workshed

4.8 Gripper for the statuette

In this section, we find the clamp of the statuette, as well as the motor to control it and various adapters. First, the clamp is composed of several elements (gear, support or elements coming into contact with the statuette) and all these elements will be 3D printed. The whole clamp will be fixed on a vertical parallelepipedic structure so that it is the desired height compared to the ground. The motor will be positioned under the clamp with its output shaft directed upwards. It will be fixed through a support, adapted and printed in 3D, to the plate of the first stage. The motor used is a dynamixel, we have designed a gear wheel that can be fixed with 4 screws in the 4 tapped holes of the dynamixel to transmit the motor torque.

Component	Number	Acquisition process	Comments
Motor	1	Thierry Daras	Model : Dynamixel AX12A
Adapter for DynamixelAX12A	1	3D Printing	Junction between the Dynamixel and the pinion
Support of the motor	1	3D Printing	/
Screws to fix the motor on the support	4	External Provider : Misumi	Minimum length : 10mm Type : M2
Hexagonal nuts for the motor	4	External Provider : Misumi	Type : M2
Screws to fix the support of the motor	2	External Provider : Misumi	Minimum length : 10mm Type : M3
Hexagonal nuts for the support	2	External Provider : Misumi	Type : M3
Gripper elements	1	3D Printing	/
Screws to fix the support of the gripper	3	External Provider : Misumi	Minimum length : 10mm Type : M3
Hexagonal nuts for the support of gripper	3	External Provider : Misumi	Type : M3
Screws to fix the gripper on the support	2	External Provider : Misumi	Minimum length : 13mm Type : M3
Hexagonal nuts to fix the gripper	2	External Provider : Misumi	Type : M3

Table 8: Gripper for the statuette

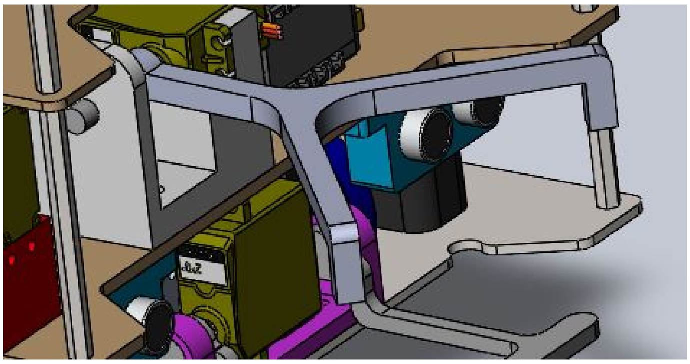


Figure 4: Y-shaped gripper for the samples on the workshed

4.9 Rack for the replica

To be able to drop the replica, we will use a system of rack and pinion. To do so, a Dynamixel will drive a 3D printed pinion which will move a 3D printed rack that will push the replica.The Dynamixel will be fixed to the robot thanks to a 3D printed support. There will also be two 3D printed supports to guide the rack. There is also a 3D printed structure to guide the replica when it is pushed by the rack. We use 2 screws and 2 nuts of size M3 to fix this structure.

Component	Number	Acquisition process	Comments
Motor	1	Thierry Daras	Model : Dynamixel AX12A
Rack	1	3D Printing	/
Pinion	1	3D Printing	/
Support for the rack	2	3D Printing	/
Support for the Dynamixel	1	3D Printing	/
Adapter for DynamixelAX12A	1	3D Printing	Junction between the Dynamixel and the pinion
Screws to fix the motor on the support	4	External Provider : Misumi	Minimum length : 10mm Type : M2
Hexagonal nuts for the motor	4	External Provider : Misumi	Type : M2
Support to guide the replica	1	3D printing	/
Screws for supports	10	External Provider : Misumi	Minimum length : 14mm Type : M3
Hexagonal nuts for the supports	10	External Provider : Misumi	Type : M3

Table 9: Rack for the replica

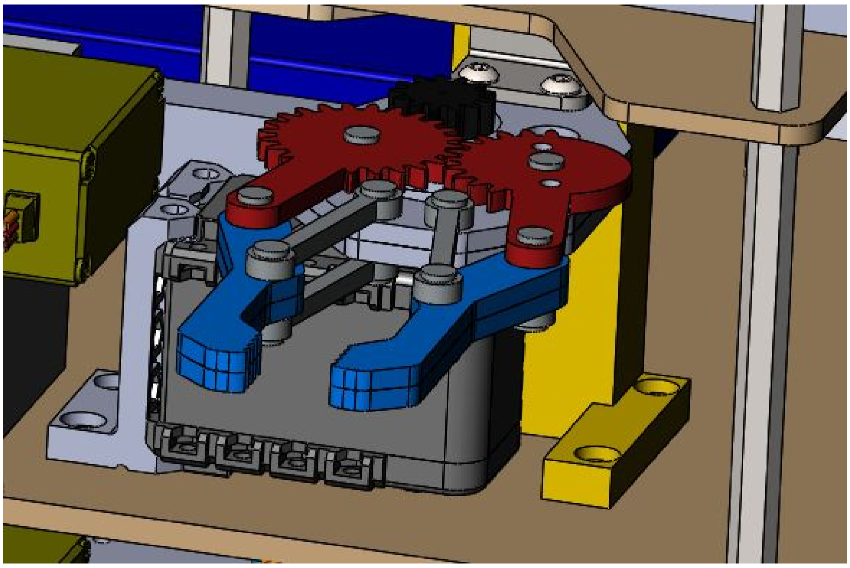


Figure 5: Gripper for the statuette

4.10 Estimation of the global price of mechanical parts

In the Table 10, there is an updated list of components that will be purchased with their number, price and provider. We have also noted the total price, even if it is obviously only an approximation.

Component	Number	Provider	Unit price (€)	Price (€)
Servo motor DSS-M15SProvided with adapters	3	Dfrobot	12.37	37.11
Hexagonal brass spacer of 57mm length Male and female thread Screw diameter of M3	6	Misumi	0.73	36.50 (pack of 50 pieces)
Hexagonal brass spacer of 40mm length Male and female thread Screw diameter of M3 2 screwed together	21	Misumi	0.53	26.50 (pack of 50 pieces)
Hexagonal brass spacer of 40mm length Female and female thread Screw diameter of M3 2 screwed together	6	Misumi	0.20	10 (pack of 50)
Freebear	2	Misumi	18.03	36.06
Nut M4	2	Misumi	1.25	2.5
Hexagonal brass spacer of 10mm length Male and female thread Screw diameter of M3	16	Misumi	0.20	10.00 (pack of 50 pieces)
Screws M3 (15mm)	46	Misumi	0.17	7.82
Screws M3 (8mm)	27	Misumi	0.23	6.21
Hexagonal nut M3	53	Misumi	0.02	20.00 (pack of 1000 pieces)
Screws M2	14	Misumi	0.19	2.66
Hexagonal nut M2	14	Misumi	0.02	20.00 (pack of 1000 pieces)
Additional aluminum contactor (Probes)	1	Misumi	20.06	20.06
Shaft probes	1	Misumi	30	30.00 (estimated price)
Shaft gripper for the workshed	1	Misumi	30	30.00 (estimated price)
Total price				295.42

Table 10: Estimation of global price of mechanical parts

5 Motor dimensioning

Clément, François and Sébastien contributed equally to the writing of this section.

In this section, we will first develop how we find a motor and a gearbox adapted to the requirements of our robot. In a second step, we will do the reverse procedure and will check if the motor and the gearbox that are provided to us are adapted to the requirements of our robot.

5.1 Hypothesis

In order to dimension the motor of our robot, we make some assumptions :

- Number of motorized wheels : $N_w = 2$
- Maximum speed : $v_{max} = 1\ \frac{\text{m}}{\text{s}} \rightarrow \omega_{max} = 238.732$ rpm

- Mass of the robot : $m = 12$ kg
- Radius of the wheels : $r = 40$ mm
- Max acceleration : $a_{max} = 2 \ \frac{\text{m}^2}{\text{s}}$
- Friction torque : Negligible

In order to dimension our motor, we also have to model the speed pattern of our robot. We used a cyclic pattern composed of an acceleration, a constant speed, a brake and a standstill. The typical pattern of our robot during one match of 100 seconds is shown in Figure 6.

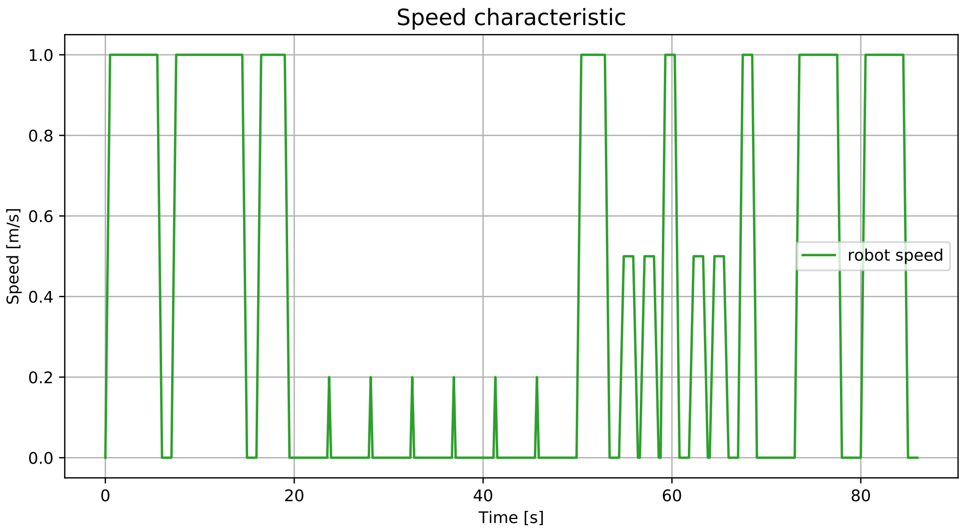


Figure 6: Speed pattern of the robot

5.2 Dimensioning

5.2.1 Preliminary calculations

First, we compute the required torque applied to the wheels of our robot according to the speed pattern we designed previously. The result is available in Figure 7 where the maximum torque is $M_{max} = 480$ mNm.

Then, we compute the RMS determined torque of the entire operating cycle:

$$M_{RMS} = 160.371 \text{ mNm} \tag{1}$$

The maximum power is given by :

$$P_{max} = 12 \text{ W} \tag{2}$$

5.2.2 Gear selection

By inspection of the catalogue of Maxon with our values of M_{max} and M_{RMS}, we will opt for the model GPX19HP. With our value of P_{max}, we need 2 stages. In order to choose the adapted reduction ratio, we computed the maximum ratio that we can take, knowing the maximum speed ω_{max} and the maximum continuous input speed $n_{Gmax} = 10000$ rpm (given in the datasheet of the model and for the number of stages that we want) :

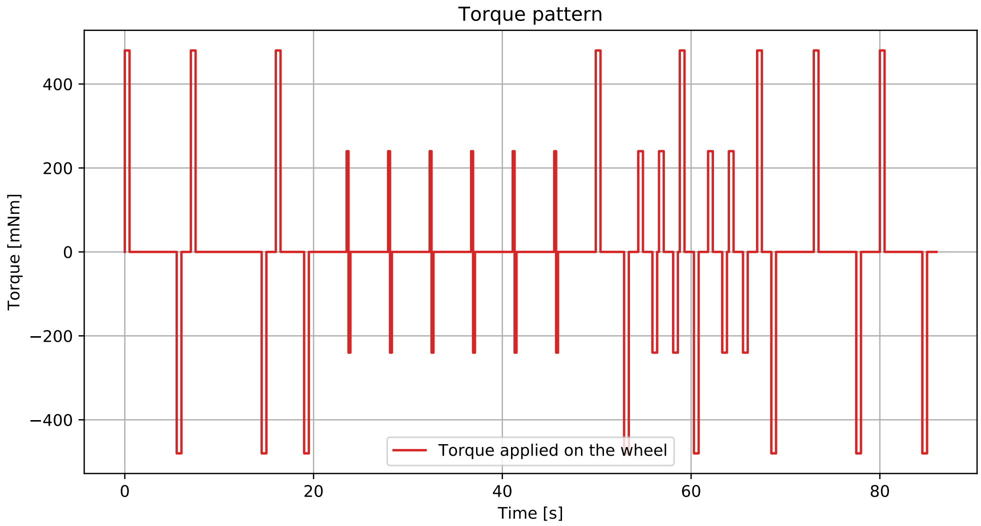


Figure 7: Torque pattern of the robot

$$i_{max} = \frac{n_{Gmax}}{\omega_{max}} = \frac{10000}{238.732} = 41.888 : 1 \tag{3}$$

So, with the possible reduction ratios proposed by the motor, we take the nearest (but smaller) i_{max} which is $i = 35 : 1$.

5.2.3 Motor type selection

In order to choose the motor type, we compute the speed and the torque of the motor shaft by considering the efficiency $\eta = 0.75$ of the GPX19HP gear :

$$\omega_{mot} = i \cdot \omega_{max} = 8355.63 \text{ rpm} \tag{4}$$

$$M_{mot,RMS} = \frac{M_{RMS}}{i \cdot \eta} = 6.109 \text{ mNm} \tag{5}$$

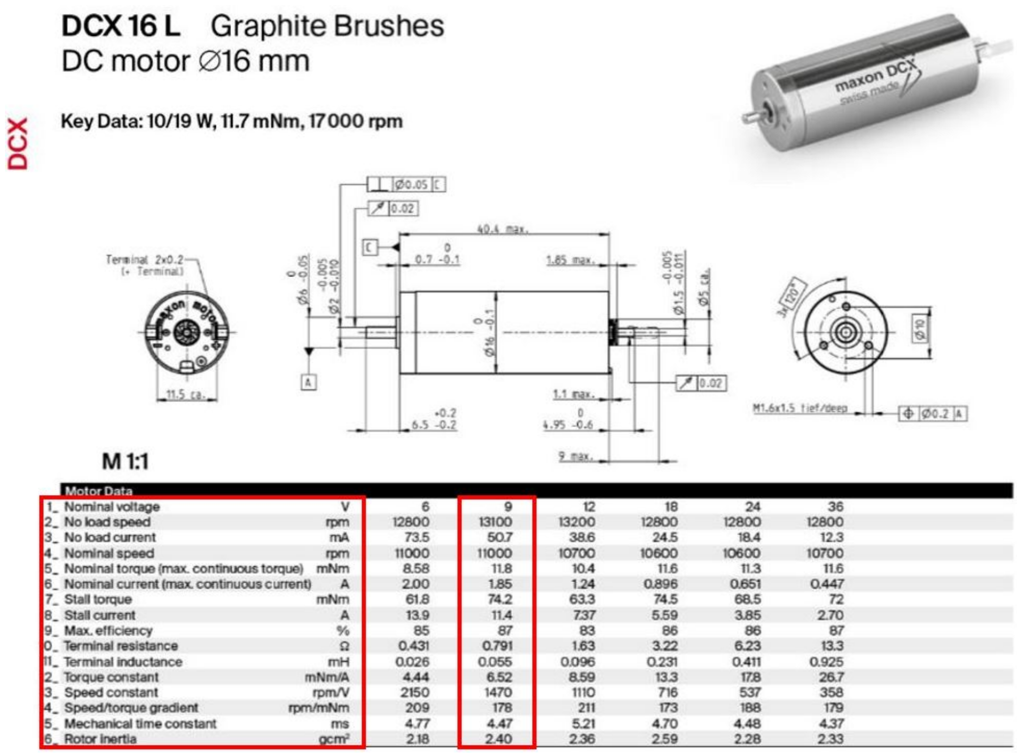
$$M_{mot,max} = \frac{M_{max}}{i \cdot \eta} = 18.28 \text{ mNm} \tag{6}$$

According to the tables of the Maxon catalog, the motor type that fits with these values is the DCX16L. We chose a motor with graphite commutation since it is more adapted to stop-and-go operation. The main characteristics of this motor are available in Figure 8.

5.2.4 Selection of the winding

The DCX16L motor has a mean characteristic gradient of $40.3 \, \frac{\text{rpm}}{\text{mNm}}$. The theoretical speed is calculated as follows:

$$n_{0,theor} = n_{mot} + \frac{\Delta n}{\Delta m} M_{mot,max} = 8355.634 + 211 * 18.28 = 12213.92 \text{ rpm} \tag{7}$$



DCX 16 L Graphite Brushes
DC motor Ø16 mm

DCX

Key Data: 10/19 W, 11.7 mNm, 17000 rpm

M 1:1

Motor Data								
1_	Nominal voltage	V	6	9	12	18	24	36
2_	No load speed	rpm	12800	13100	13200	12800	12800	12800
3_	No load current	mA	73.5	50.7	38.6	24.5	18.4	12.3
4_	Nominal speed	rpm	11000	11000	10700	10600	10600	10700
5_	Nominal torque (max. continuous torque)	mNm	8.58	11.8	10.4	11.6	11.3	11.6
6_	Nominal current (max. continuous current)	A	2.00	1.85	1.24	0.896	0.651	0.447
7_	Stall torque	mNm	61.8	74.2	63.3	74.5	68.5	72
8_	Stall current	A	13.9	11.4	7.37	5.59	3.85	2.70
9_	Max. efficiency	%	85	87	83	86	86	87
0_	Terminal resistance	Ω	0.431	0.791	1.63	3.22	6.23	13.3
11_	Terminal inductance	mH	0.026	0.055	0.096	0.231	0.411	0.925
2_	Torque constant	mNm/A	4.44	6.52	8.59	13.3	17.8	26.7
3_	Speed constant	rpm/V	2150	1470	1110	716	537	358
4_	Speed/torque gradient	rpm/mNm	209	178	211	173	188	179
5_	Mechanical time constant	ms	4.77	4.47	5.21	4.70	4.48	4.37
6_	Rotor inertia	gcm²	2.18	2.40	2.36	2.59	2.28	2.33

Figure 8: main characteristics of the DCX16L

To find the values of the speed constant, we must take the extreme operating point with the maximum speed and torque. This is achieved at no load speed with the maximum voltage (12 V). We take 12 V because our batteries have this voltage output, this way we must not change the voltage to another value. We find the minimum target speed constant of the motor:

$$k_{n,theor} = \frac{n_{0,theor}}{U_{mot}} = \frac{12213.92}{12} = 1017.827 \ \frac{\text{rpm}}{\text{V}} \tag{8}$$

By taking the torque constant of the chosen motor (torque constant $= 8.59 \ \frac{\text{mNm}}{\text{A}}$) and with the no load current taken also in the datasheet of the motor ($i_0 = 38.6$ mA), we can find the peak current corresponding to the maximum torque:

$$I_{max} = \frac{M_{mot,max}}{k_m} + I_0 = \frac{18.28}{8.59} + 38.6 * 1e^{-3} = 2.167 \text{ A} \tag{9}$$

This current is smaller than the nominal current of our power supply (3 A).

Thus, we found a gear and a motor that fulfill the requirements.

5.3 Reverse engineering

In this section, we are going to apply the reversed methodology versus before. Indeed, this time we are going to start from a motor and a gearbox (which are given to us) and we will see if they match the hypothesis that we imposed for our application. The references of the given components are in Table 11.

5.3.1 Motor characteristics

The important characteristics of the motor (from the datasheet) are available in Table 12.

Component	Reference	Brand
Motor	2642W024CXR	Faulhaber
Gear	Planetary gearheads 32A	Faulhaber

Table 11: Components received

Motor characteristic	2642024 CXR	Unit
$M_{mot,max}$	150.5	mNm
Rated torque for continuous operation	26	mNm
Rated speed for continuous operation	4770	rpm
No load speed n_0	5900	rpm
Nominal voltage U_N	24	V
P_{2nom}	23.1	W

Table 12: Falhauber 2642W024CXR

5.3.2 Gear

For the Falhauber 2642W024CXR, we have a list of compatible gears in the datasheet. As said earlier, we have a compatible gearbox for this motor whose characteristics are in Table 13.

Gear characteristic	32A	Unit
Maximum input speed for continuous operation	3000	rpm
Number of gear stages	2	/
Reduction ratio	19:1	/
Continuous torque	2.25	Nm
Intermittent torque	3	Nm
Maximum efficiency	85	%

Table 13: Falhauber Planetary gearheads 32A

5.3.3 Output characteristics of the geared motor

We reuse the equations of subsubsection 5.2.3, with the characteristics of the received gear and motor in order to find the output characteristics of the geared motor.

$$M_{RMS} = M_{mot,RMS} \cdot i \cdot \eta = 26 \cdot 19 \cdot 0.85 = 419.9 \text{ mNm} > 160.371 \text{ mNm} \tag{10}$$

$$M_{max} = M_{mot,max} \cdot i \cdot \eta = 150.5 \cdot 19 \cdot 0.85 = 2.431 \text{ Nm} > 480 \text{ mNm} \tag{11}$$

$$\omega_{max} = \frac{\omega_{mot}}{i} = 251.05 \text{ rpm} > 238.732 \text{ rpm} \tag{12}$$

As we can see, the output parameters of the geared motor are higher than the ones we need for the speed and torque characteristics of our robot.

6 Drawings of the parts to machine by the LAFAB

Clément, François and Sébastien contributed equally to the writing of this section.

The only part that will be machined by the LAFAB is the bottom plate of the robot. A part of the plan is available in Figure 9 but as a reminder, the full documentation about this part is available in the drive.

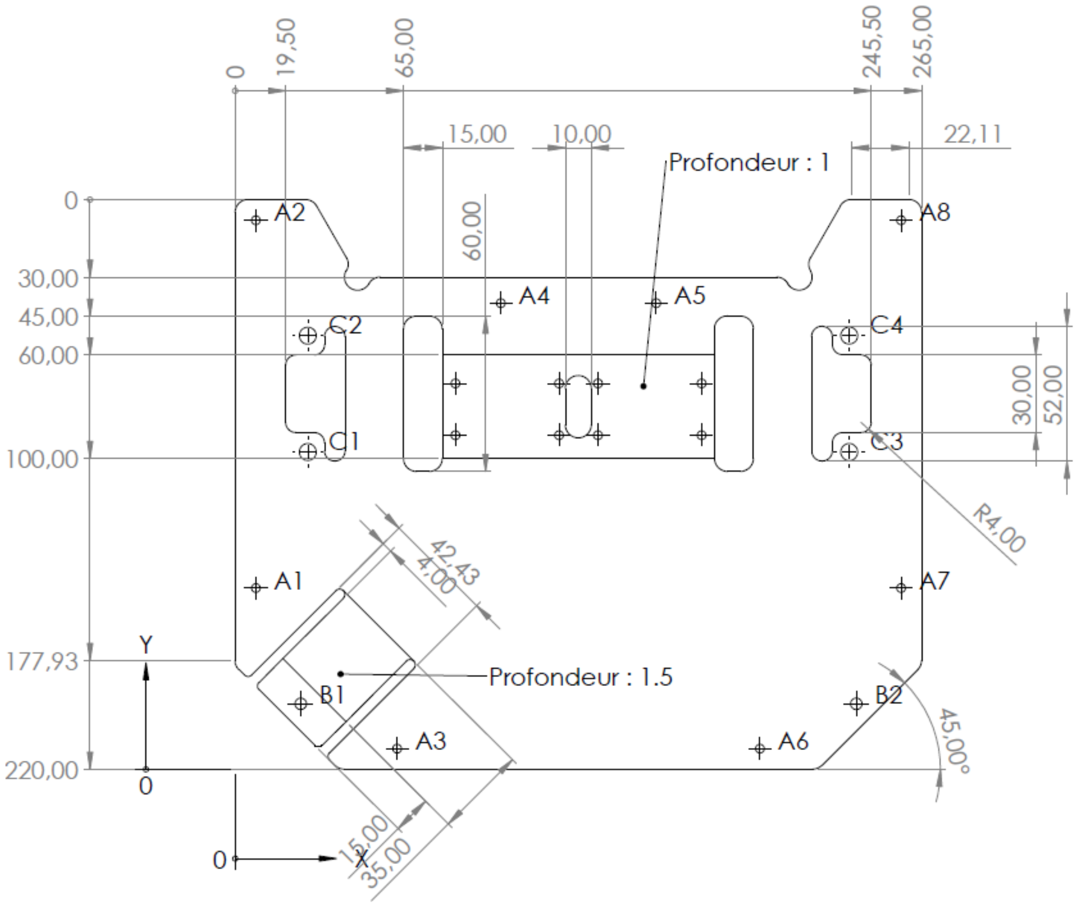


Figure 9: Drawing of the bottom plate of the robot

7 Global electrical scheme and connections between the blocks

Diego and Nicolas both contributed equally to the writing of this section.

The following section explains the global electrical scheme of the robot and the connections between the modules. Specific attention will be put on the connections, as the electrical scheme is nearly the same as in the technical folder.

The global electrical scheme, with all the connections and all the modules, is shown in Figure 10.

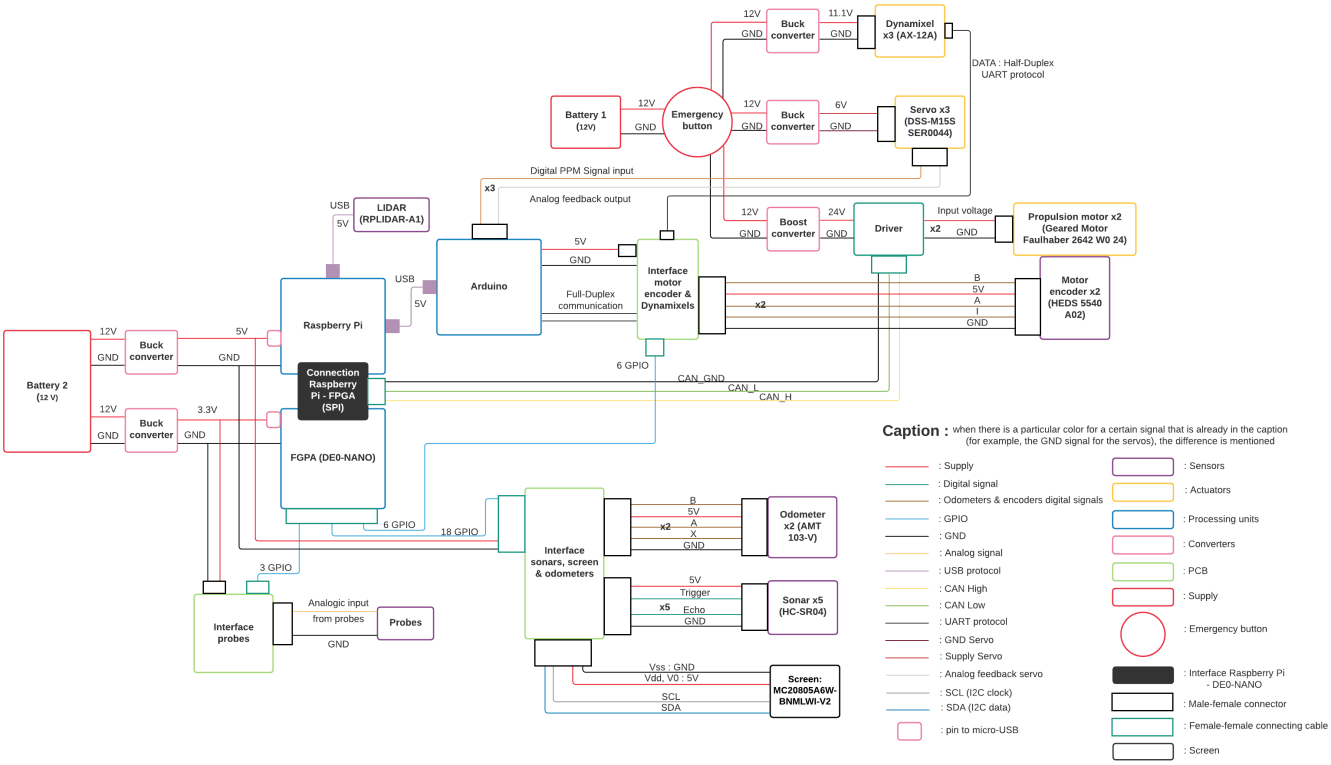


Figure 10: Global electrical scheme, with all connections between the blocks shown

The rest of this section will zoom in on some parts of the global electrical scheme to analyse and explain in more detail the connections between the blocks. For a more detailed description of all the inputs and outputs of the interfaces, refer to section 8.

Figure 11 shows a zoomed in version of the caption used for the global electrical scheme.

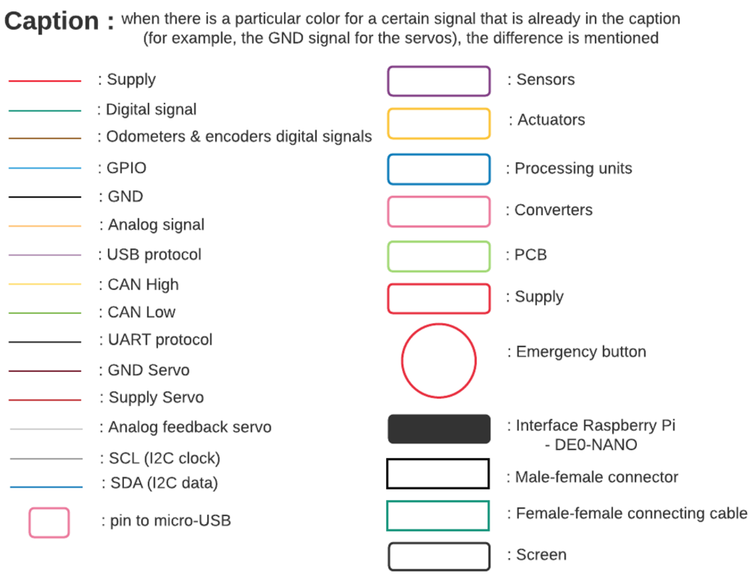


Figure 11: Zoomed in caption for the global electrical scheme

7.1 Note on the connections between the blocks

In order to easily disassemble the different modules, PCBs, motors... in the assembling phase, the connections between the blocks aren't "direct".

On the PCBs, there is only one type of rack that is used in input, with different sizes. This type of rack is illustrated in Figure 12[1].

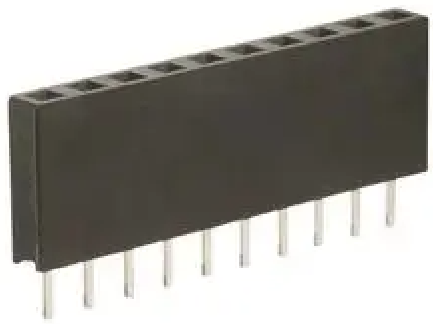


Figure 12: Illustration of the rack used on the PCBs

As a way to easily disassemble the sub-modules during the project, the same racks will be directly connected to the input racks on the PCB. This will allow to plug cables into those racks and move them as blocks afterwards while still being able to disconnect the different parts to move them around the robot. Several sorts of jumper wires (female-female, male-female and male-male) will be used to connect the blocks.

The rest of this section explains the connections and the use of each block.

7.2 Zoom: the sonars, screen & odometers interface

This zoom can be seen in Figure 13.

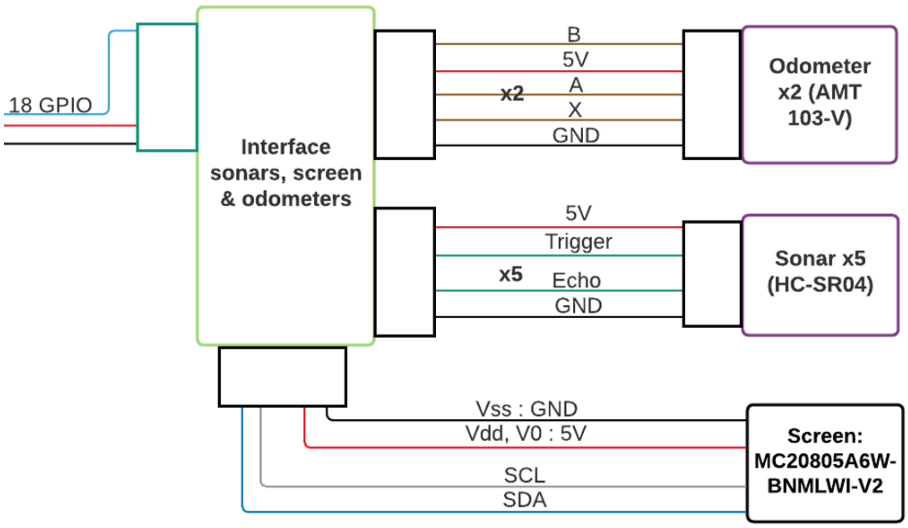


Figure 13: Zoom in on the sonars, screen & odometers interface

[1]Picture from https://be.farnell.com/harwin/m20-7820442/connector-rcpt-4pos-2-54mm-1row/dp/3225922

The sensor interface is used to allow communication between the FPGA and the sensors, by converting the logical levels from 5 V to 3.3 V. Between the sonars and the odometers, the connections are done by using male-female jumper wires : the male end plugs into the female end of the rack on the PCB and the female end of the cable plugs into the male output of the sensors.

The connection to the screen is a little bit different : this screen uses I2C communication and the supply cable needs a 3-way "Y" connector to be able to give 3 inputs at 5 V to the screen. The cables are soldered to the screen component and plugged into the female rack on the PCB.

Between the DE0-NANO and the interface, there are 18 GPIOs that will use a female-female jumper wire to communicate with the FPGA. The supply voltage and GND signals are coming from a buck-converter (see subsection 7.3) that will use a 2-way "Y" connector in order to supply both the Raspberry Pi and the interface with a 5 V input voltage.

7.3 Zoom: interface probes, battery, FPGA, Raspberry Pi and LIDAR

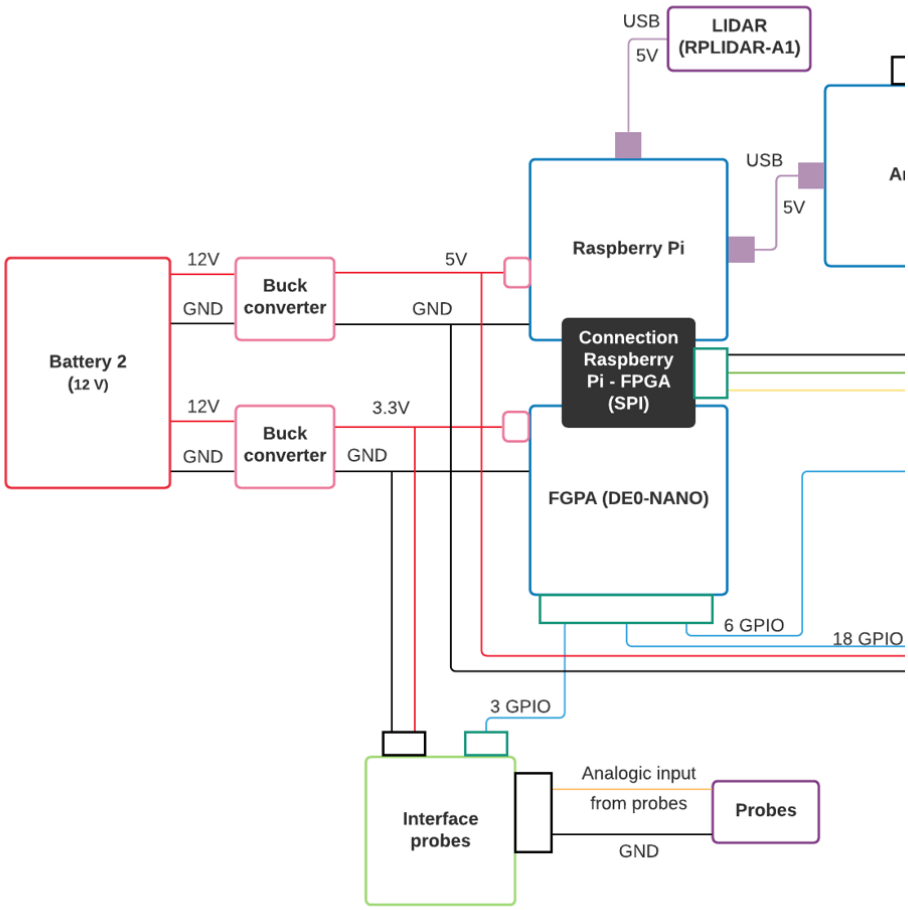


Figure 14: Zoom in on the interface probes, battery, FPGA, Raspberry Pi and LIDAR

The probes' interface is used to convert an analog input coming from the measurement of a resistance to a digital signal that can be used to make a decision based on the value that was measured. The cables coming from the probes will be plugged into the input female rack. There are 3 GPIOs connected to the FPGA via a female-female jumper wire. This interface is supplied by a 3.3 V supply voltage coming from a 2-way "Y" connector that splits the output of a buck-converter in two, towards the FPGA and the interface.

The FPGA and the Raspberry are supplied via a cable illustrated in Figure 15.

Figure 15: Cable used to supply the Raspberry Pi and the FPGA with respectively a supply voltage of 5 and 3.3 V

The LIDAR is supplied by and connected to the Raspberry via a USB cable. As will be shown in the next subsection, the Arduino communicates with the Raspberry Pi and is supplied by it via a USB cable as well.

As visible in Figure 14, there are 6 GPIOs coming from the motor encoder & Dynamixels interface that will be described in subsection 7.4. They communicate with the FPGA via a female-female jumper wire. Finally, the 3 CAN signals coming from the driver driving the propulsion motor (see subsection 7.4) are connected to the interface connecting the Raspberry Pi to the FPGA using a female-female jumper wire.

7.4 Propulsion motor, last interface, actuators and Arduino

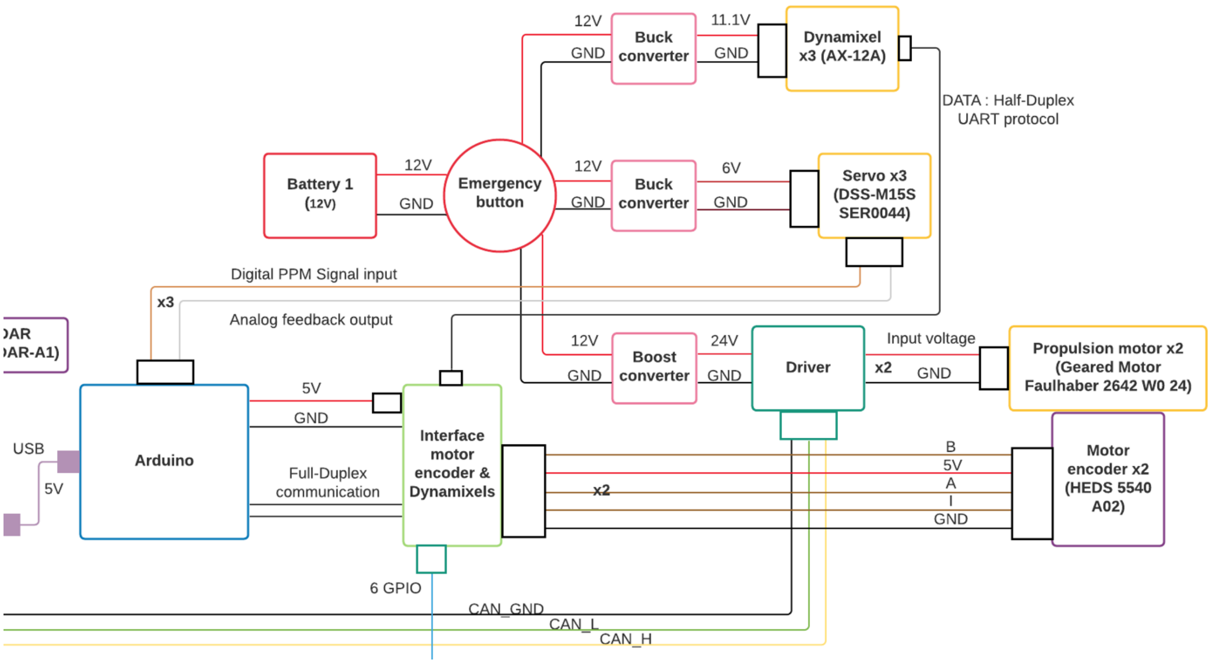


Figure 16: Zoom on the Arduino, the different actuators, the propulsion motors, the encoder and the last interface

As already explained before, the driver (and thus its 3 CAN signals) is connected to the interface between the Raspberry Pi and the FPGA via a female-female jumper wire. The interface for the motor encoder and the Dynamixels has 6 output GPIOs and it connects them to the FPGA via a female-female jumper wire.

The interface is used to allow the communication between the FPGA and the motor encoders as well as allowing a correct communication between the Dynamixels and the Arduino, interfacing a half-duplex UART from the Dynamixels with a full-duplex UART from the Arduino. It is supplied by a 5 V supply voltage signal coming from the Arduino by using a male-female jumper wire: the male end is plugged into the Arduino and the female end is plugged directly on the PCB. The GND signal is simply coming from a male-male jumper wire, one end being plugged into the Arduino and the other into one of the PCB's racks. The same type of connection is used for the Full-Duplex UART communication coming from the Arduino. Finally, the Half-Duplex UART communication coming from the Dynamixels is plugged into the board using a male-female jumper wire, the male end being plugged into an input rack of the PCB and the female end being plugged to the Dynamixels' pins.

The Dynamixels are supplied by a 11.1 V supply voltage via a male-female jumper wire : the male end plugs into the buck and the female end to the first Dynamixel. The same is used for the GND. Between the Dynamixels, female-female jumper wires are used, as the Dynamixels are connected in series to one another.

The servo motors are connected to the Arduino using a male-female jumper wire for the three digital PPM signal input and analog feedback output signals. The male end is plugged into the Arduino and the female end into the Servo. The motors are supplied by a 6 V supply voltage coming from a buck-converter. As the buck has only one output and there is need for 3 supplies, a 3-way "Y" connector is used at the output of the buck, for both the supply and the GND. Male-female jumper wires are used : the male end plugs into the 3-way "Y" connector and the female end plugs into the Servo.

Finally, the propulsion motors are supplied by the driver with a given voltage via a male-female jumper wire, the male end being plugged into a 2-way "Y" connector allowing the one output supply voltage signal of the driver to be split in two, and the female end to the propulsion motor. The same thing goes for the GND. The motor encoders are already connected to the propulsion motors and they communicate with the PCB via a male-female jumper wire : the male end is plugged into a female input of the PCB and the female end is plugged into the pins of the encoder.

8 Inputs and outputs listing

Diego and Nicolas both contributed equally to the writing of this section.

8.1 Sonars, screen and odometers interface

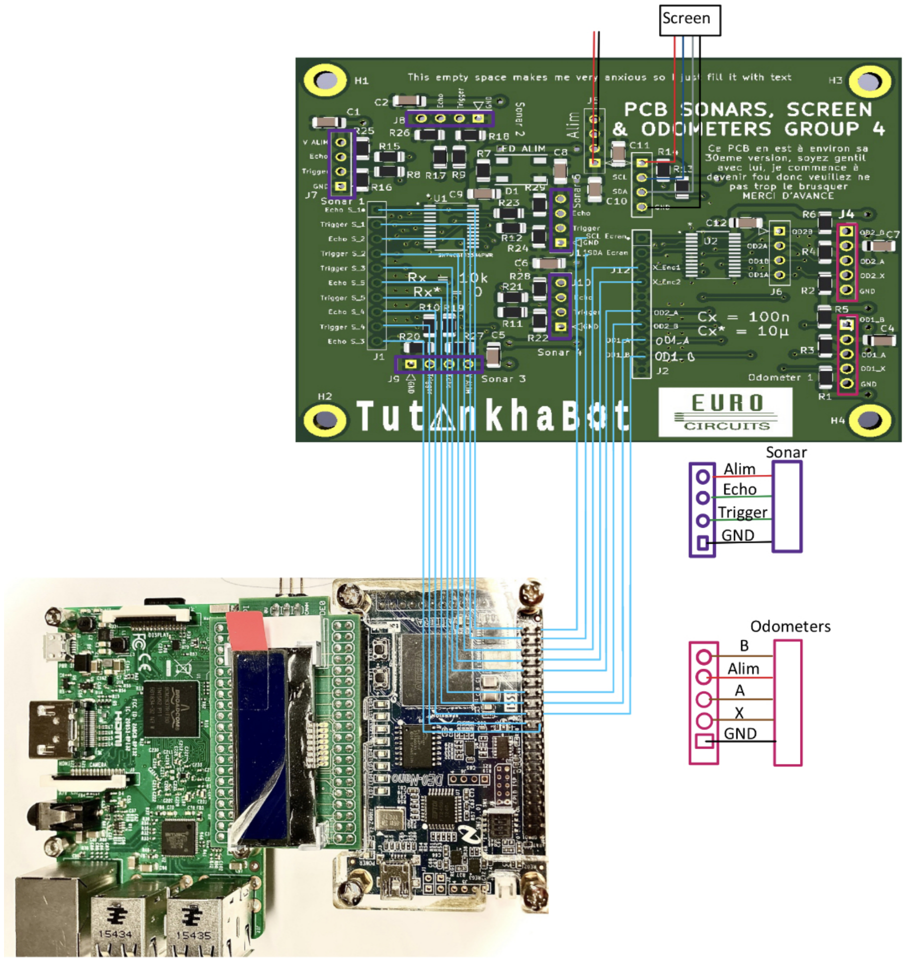


Figure 17: Connections schematic interface of the sonars, screen and odometers

Signal name FPGA	Pin of the interface	Description
GPIO_1N0	Echo_S1	output Echo signal from Sonar number 1
GPIO_1N1	Trigger_S1	input Trigger Signal for Sonar Number 1
GPIO_12	Echo_S2	output Echo signal from Sonar number 2
GPIO_14	Trigger_S2	input Trigger Signal for Sonar Number 2
GPIO_16	Trigger_S3	input Trigger Signal for Sonar Number 3
GPIO_18	Echo_S5	output Echo signal from Sonar number 3
GPIO_110	Trigger_S5	input Trigger Signal for Sonar Number 4
GPIO_112	Echo_S4	output Echo signal from Sonar number 4
GPIO_114	Trigger_S4	input Trigger Signal for Sonar Number 5
GPIO_10	SCL Ecran	Serial clock input for the Screen
GPIO_11	SDA Ecran	serial data line input for the Screen
GPIO_13	X_Enc1	X channel output from the odometer wheel number 1
GPIO_15	X_Enc2	X channel output from the odometer wheel number 2
GPIO_17	OD2_A	A channel output from the odometer wheel number 2
GPIO_19	OD2_B	B channel output from the odometer wheel number 2
GPIO_111	OD1_A	A channel output from the odometer wheel number 1
GPIO_113	OD1_B	B channel output from the odometer wheel number 1
GPIO_115	Echo_S3	output Echo signal from Sonar number 5

Table 14: Table of GPIO attribution of the interface sonars, screen and odometer

Pin of the interface	Description
ODx_B	B channel input from the odometer wheel number x
Alim	output supply for the odometer wheel number x
ODx_A	A channel input from the odometer wheel number x
ODx_X	X channel input from the odometer wheel number x

Table 15: Odometer connection for odometer number x

Pin of the interface	Description
Alim	output supply for the Sonar number x
Echo	input echo signal from the Sonar number x
Trigger	output trigger signal for the Sonar number x
GND	output ground for the Sonar number x

Table 16: Sonar connection for sonar number x

Pin of the interface	Description
Alim	Supply output for the screen
SDA	Serial Data line output for the screen
SCL	Serial Clock output for the screen
GND	Ground output for the screen

Table 17: Pin attribution for the screen

The Figure 17 shows the connections of the different input-output of the PCB.

The Table 14 details the GPIO attribution of the DE0-NANO for the interface.

The Table 15, 16 and Table 17 explain the connections for respectively the odometer wheels, the sonars and the screen.

8.2 Interface probes

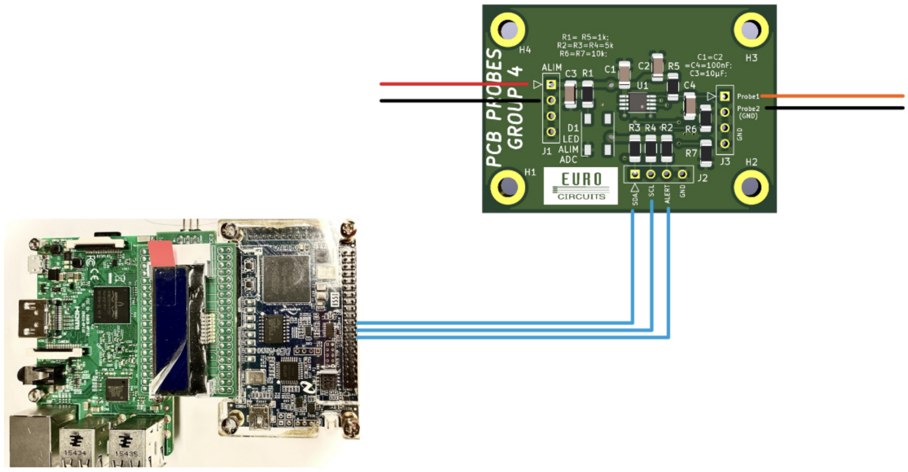


Figure 18: Connections schematic of the interface probes

Signal name FPGA	Pin of the interface	Description
GPIO_123	SDA	Serial Data line output from the ADC
GPIO_121	SCL	Serial Clock input for the ADC
GPIO_119	ALERT	Alert configurable signal for the ADC

Table 18: Connections between DE0-nano and the interface probes

Prob1	input prob at 5 V to evaluate the resistor
Prob2	input prob at 0 V to evaluate the resistor

Table 19: Other pin attributions

The Figure 18 shows the connections of the different input-output of the PCB.

The Table 18 details the GPIO attribution of the DE0-NANO for the interface. And the 19 shows other pin attributions.

8.3 Motor encoders and Dynamixels interface

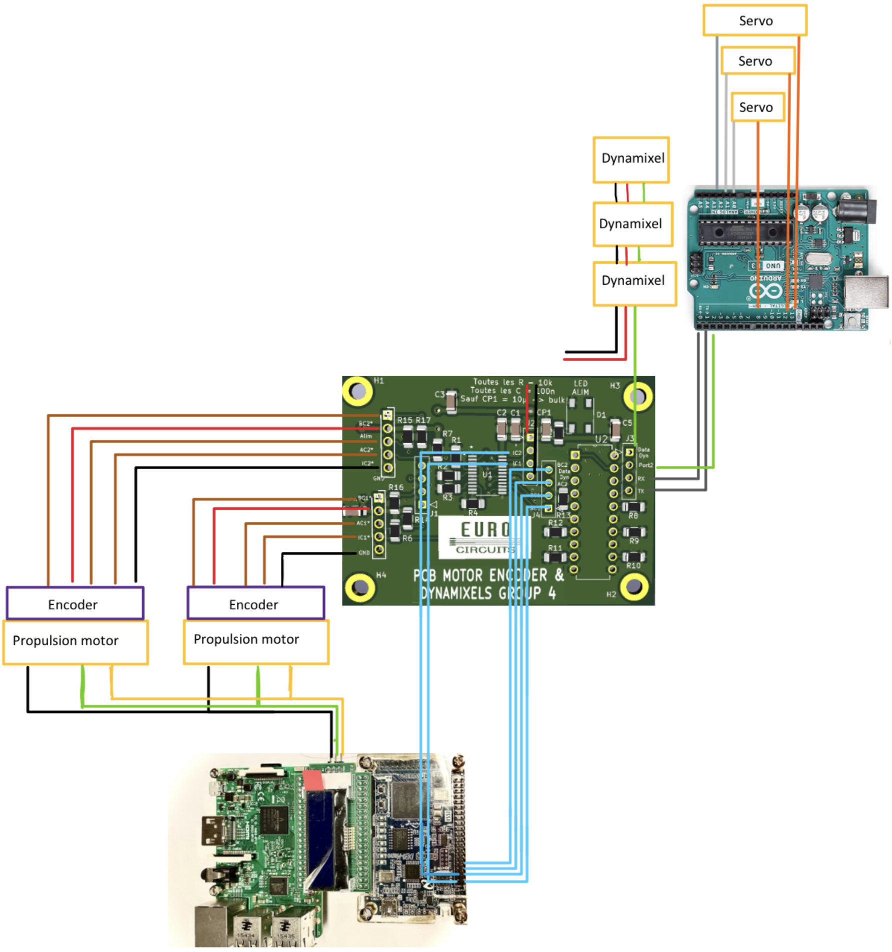


Figure 19: Connections schematic of the interface motor encoder and Dynamixels

Signal name FPGA	Pin of the interface	Description
GPIO_126		unused
GPIO_128		unused
GPIO_130	IC2	I channel output from the encoder number 2
GPIO_132	IC1	I channel output from the encoder number 1
GPIO_127	BC2	X channel output from the encoder number 2
GPIO_129	AC2	A channel output from the encoder number 2
GPIO_131	BC1	B channel output from the encoder number 1
GPIO_133	AC1	A channel output from the encoder number 1

Table 20: Table of GPIO attributions of the interface motor encoders and Dynamixels

Signal name Arduino	Pin of the interface	Description
A0	/	Analog feedback output from a Servo
A1	/	Analog feedback output from a Servo
A2	/	Analog feedback output from a Servo
13	/	Digital PPM signal input for a Servo
12	/	Digital PPM signal input for a Servo
8	/	Digital PPM signal input for a Servo
0	RX	Receiver channel output from the Dynamixels
1	TX	Transmitter channel output for the Dynamixels
2	Port 2	Enable tristate buffer input

Table 21: Table of GPIO attribution of the Arduino board

Pin of the interface	Description
BCx_B	B channel input from the encoder number x
Alim	output supply for the encoder number x
ACx_A	A channel input from the encoder number x
ICx_X	X channel input from the encoder number x

Table 22: Encoder connection for encoder number x

The Figure 19 shows the connections of the different input-output of the PCB.

The Table 20 details the GPIO attribution of the DE0-NANO and the connecting part between the Raspberry Pi and the DE0-NANO for the interface. The Table 21 shows pin attribution on the Arduino. Finally, Table 22 explains the connections for the motor encoders.

8.4 Summary of the connections to the DE0-NANO

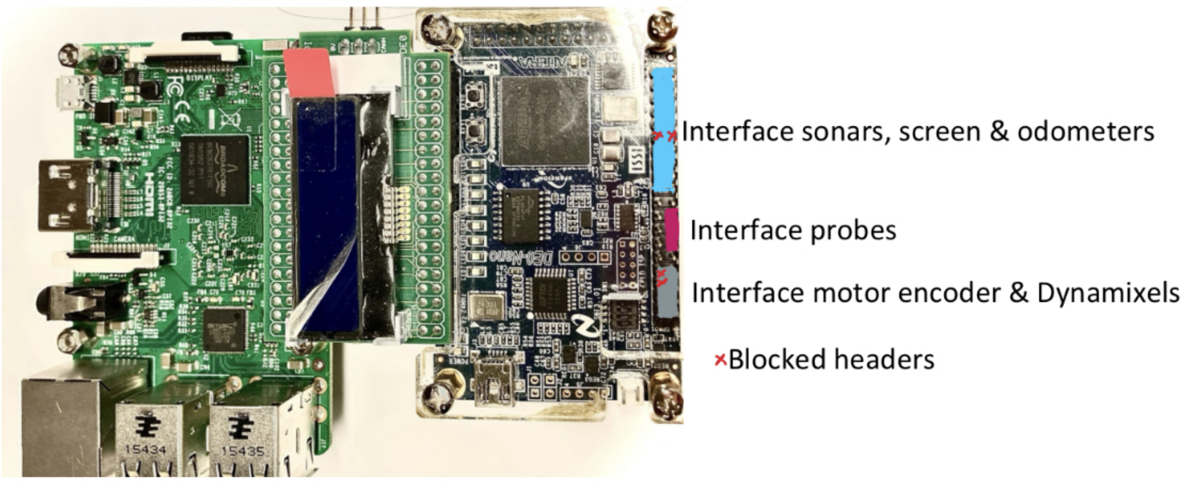


Figure 20: Summary of the DE0-NANO's header used by the interfaces

The Figure 20 shows the pins used on the DE0-NANO. Red crosses show pins that are not used but that are blocked by the connections to the interfaces.

9 KiCAD schematics

Diego and Nicolas both contributed equally to the writing of this section.

In this section are shown the schematics and the resulting PCBs for the three interfaces that have been detailed in section 7.

9.1 Sonars, screen & odometers interface

9.1.1 Schematic

The schematic for this interface is shown in Figure 21.

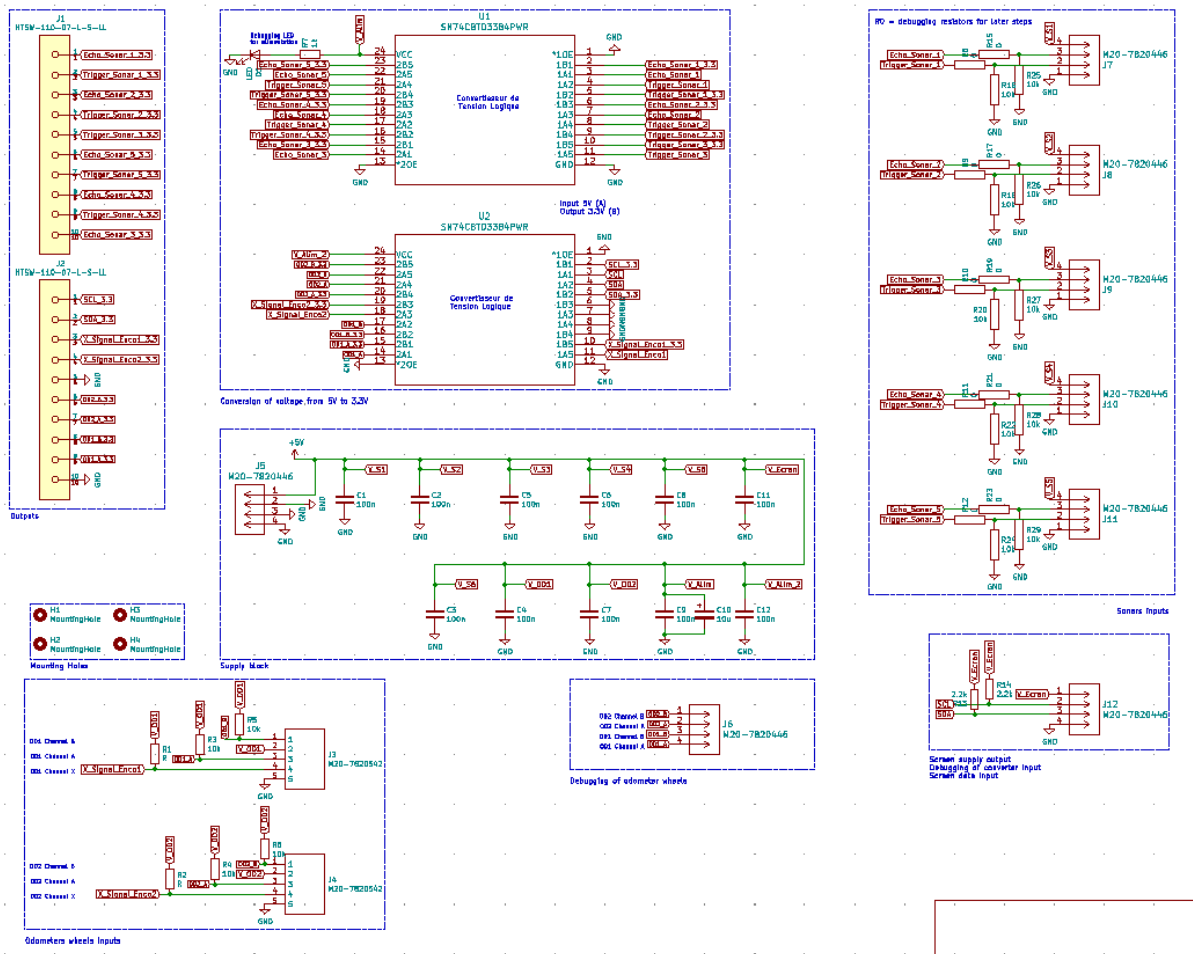


Figure 21: KiCAD schematic of the sonars, screen & odometer interface : zoomed out view

For a clearer reading, this zoomed out version has been cut into 4 parts, from left to right and top to bottom, shown respectively in Figure 22, Figure 23, Figure 24 and Figure 25.

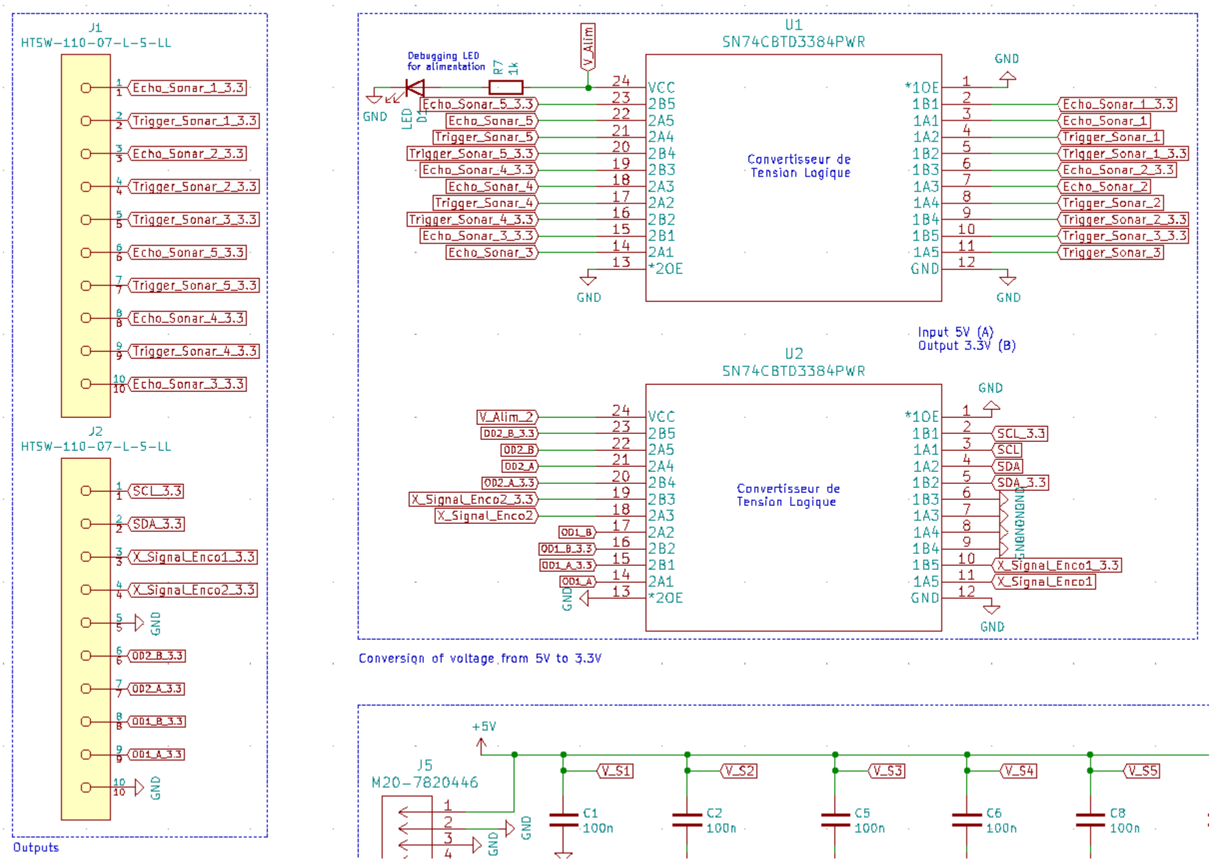


Figure 22: Zoom on the top left part of the KiCAD schematic of the sonars, screen & odometer interface : zoomed in view

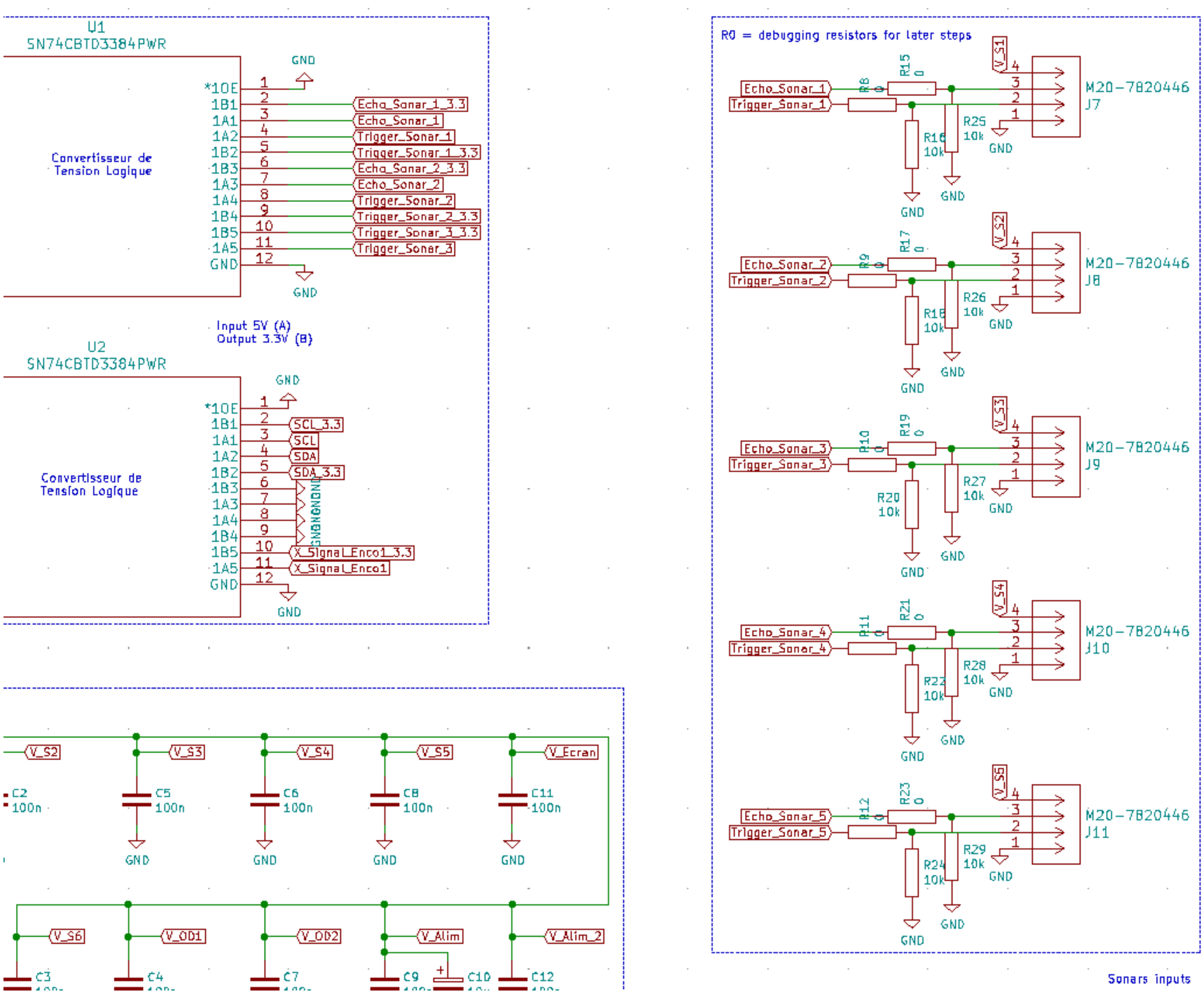


Figure 23: Zoom on the top right part of the KiCAD schematic of the sonars, screen & odometer interface : zoomed in view

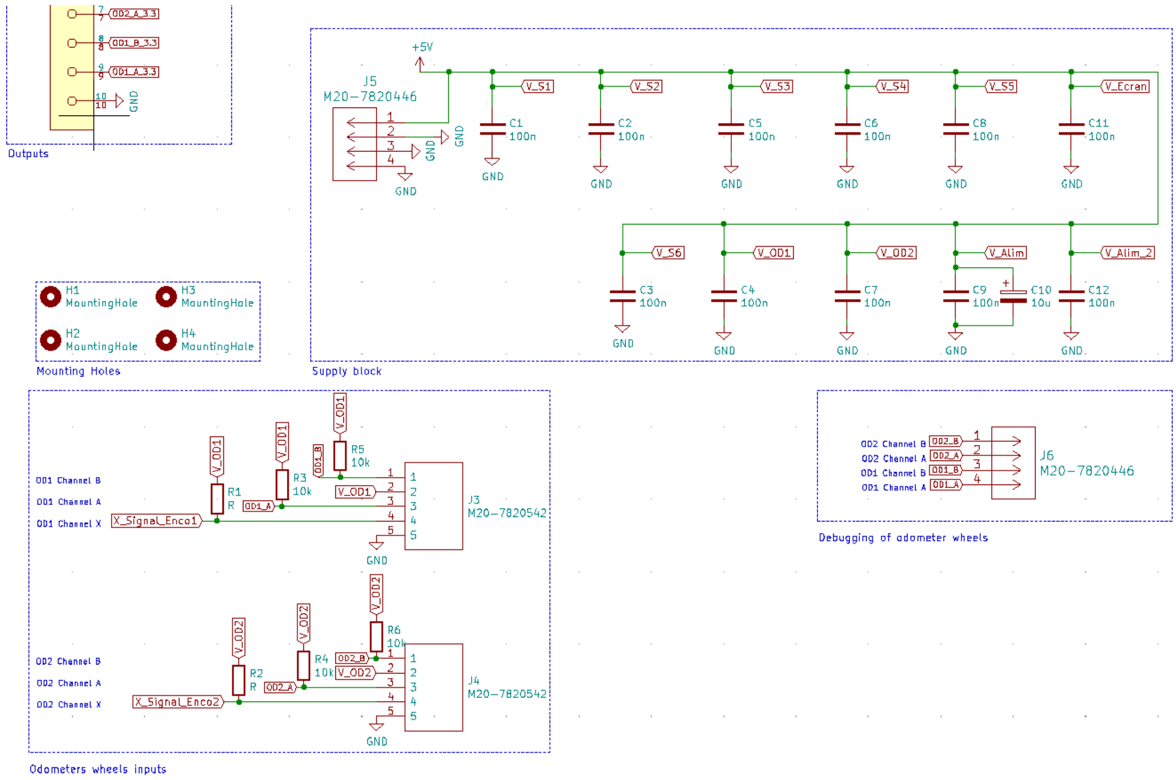


Figure 24: Zoom on the bottom left part of the KiCAD schematic of the sonars, screen & odometer interface : zoomed in view

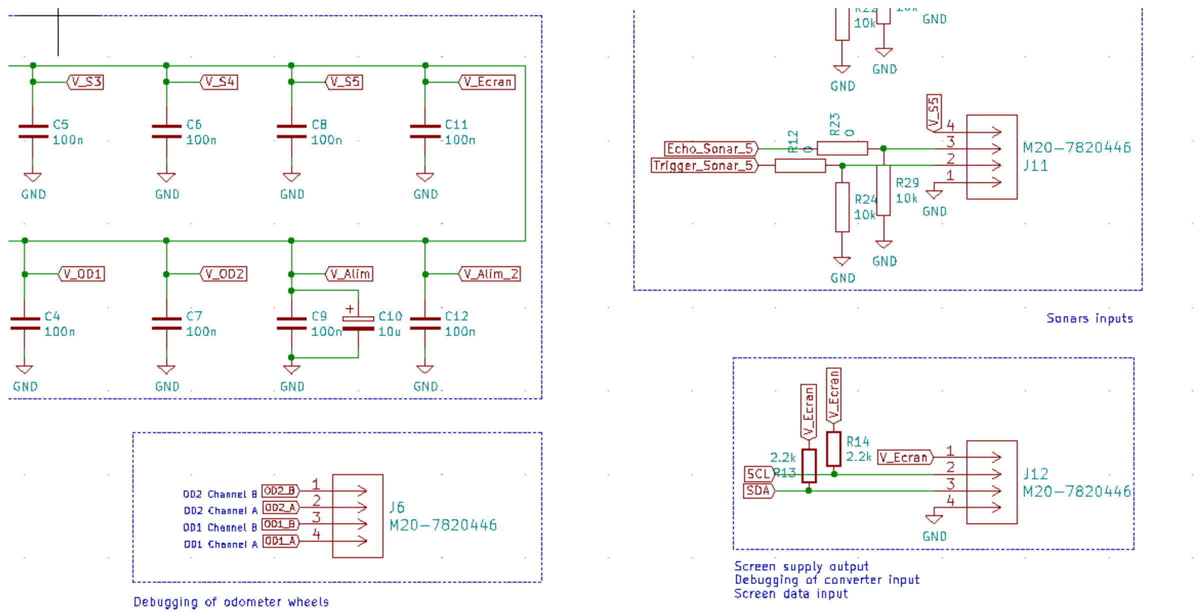


Figure 25: Zoom on the bottom right part of the KiCAD schematic of the sonars, screen & odometer interface : zoomed in view

9.1.2 Routed PCB on KiCAD

In Figure 26 is shown the resulting PCB from the schematic from subsubsection 9.1.1.

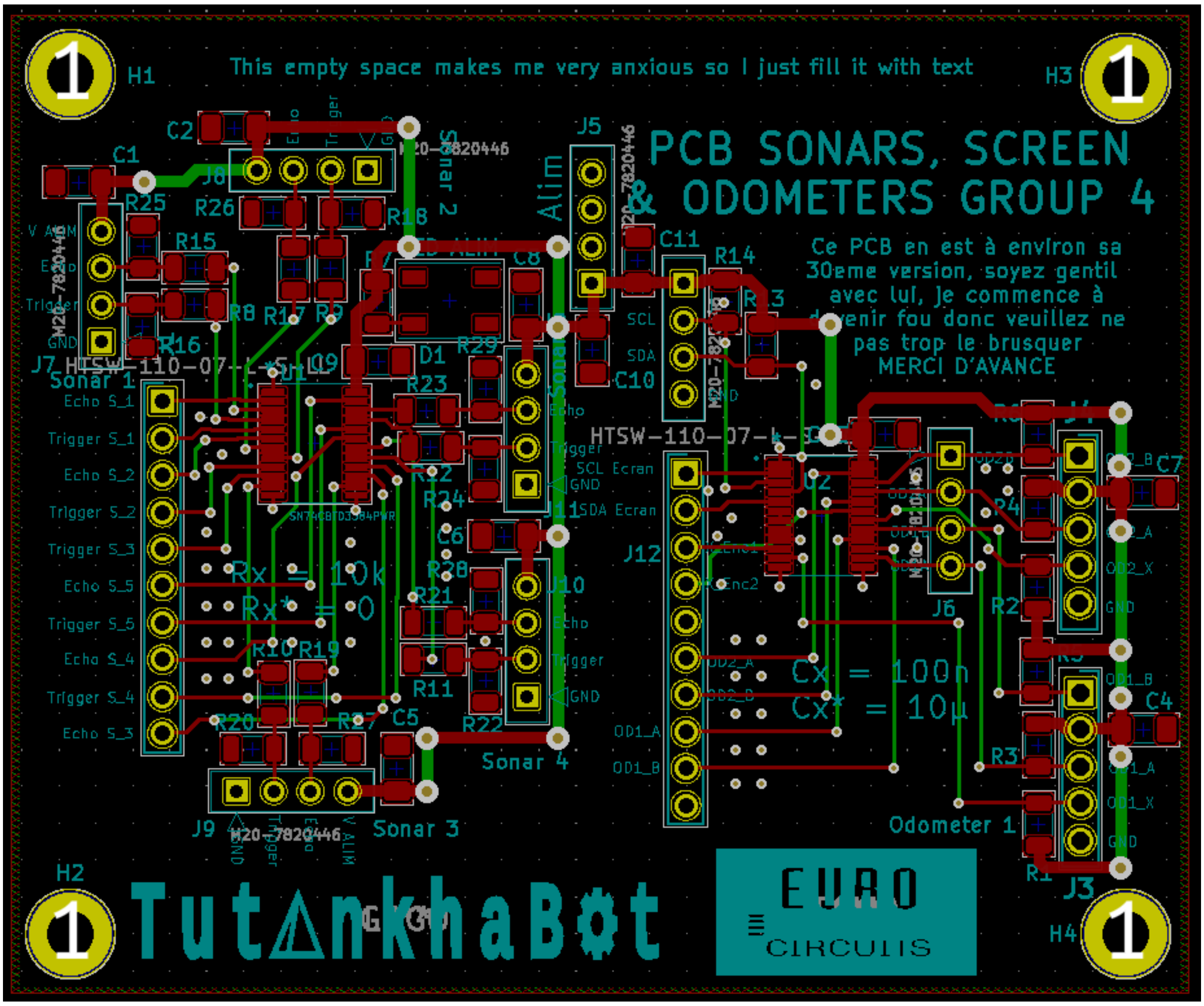


Figure 26: Routed PCB for the sonars, screen & odometers interface

In Figure 27 is shown a 3D view of this PCB.

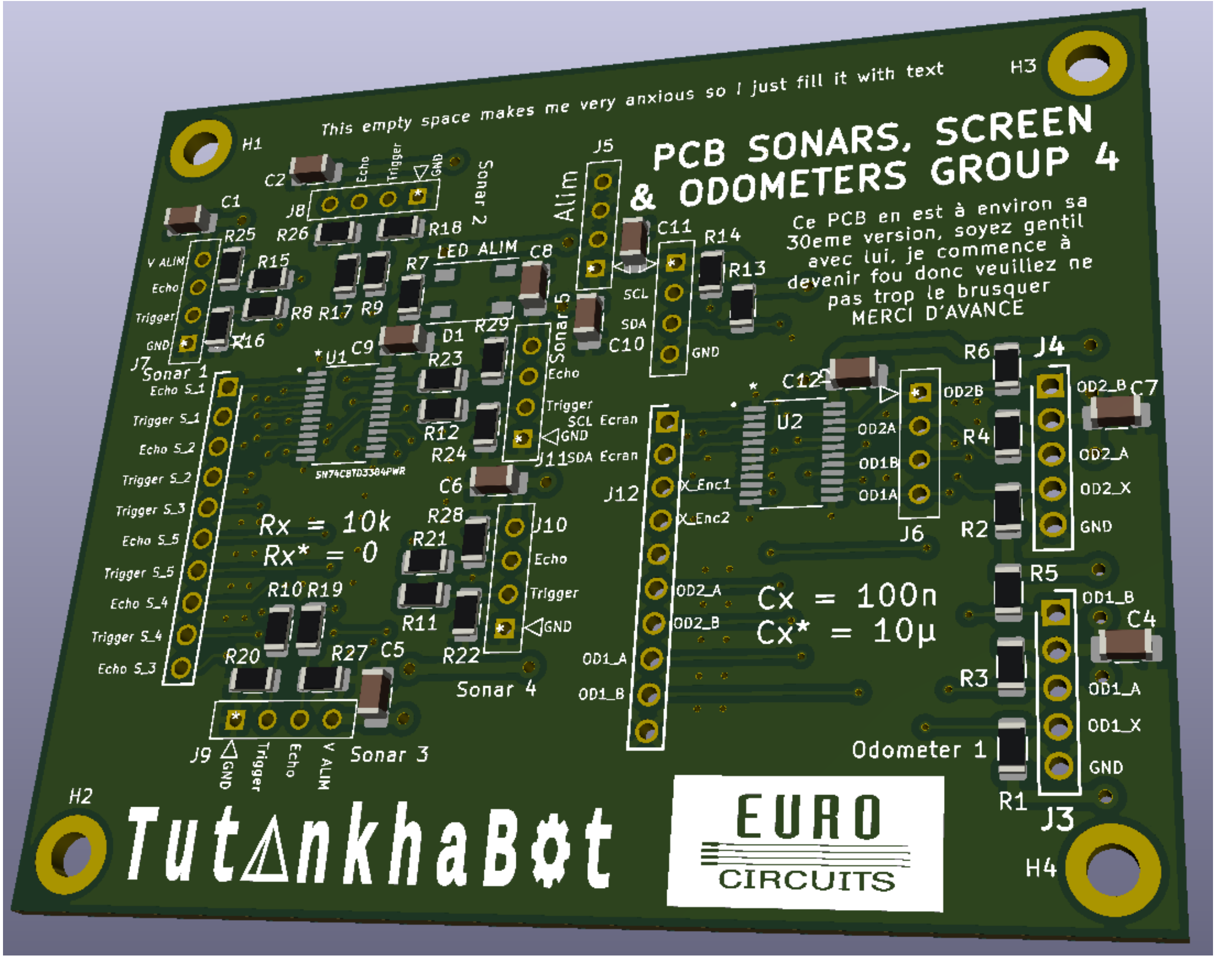


Figure 27: 3D view of the routed PCB for the sonars, screen & odometers interface

9.2 Interface probes

9.2.1 Schematic

The schematic for this interface is shown in Figure 28.

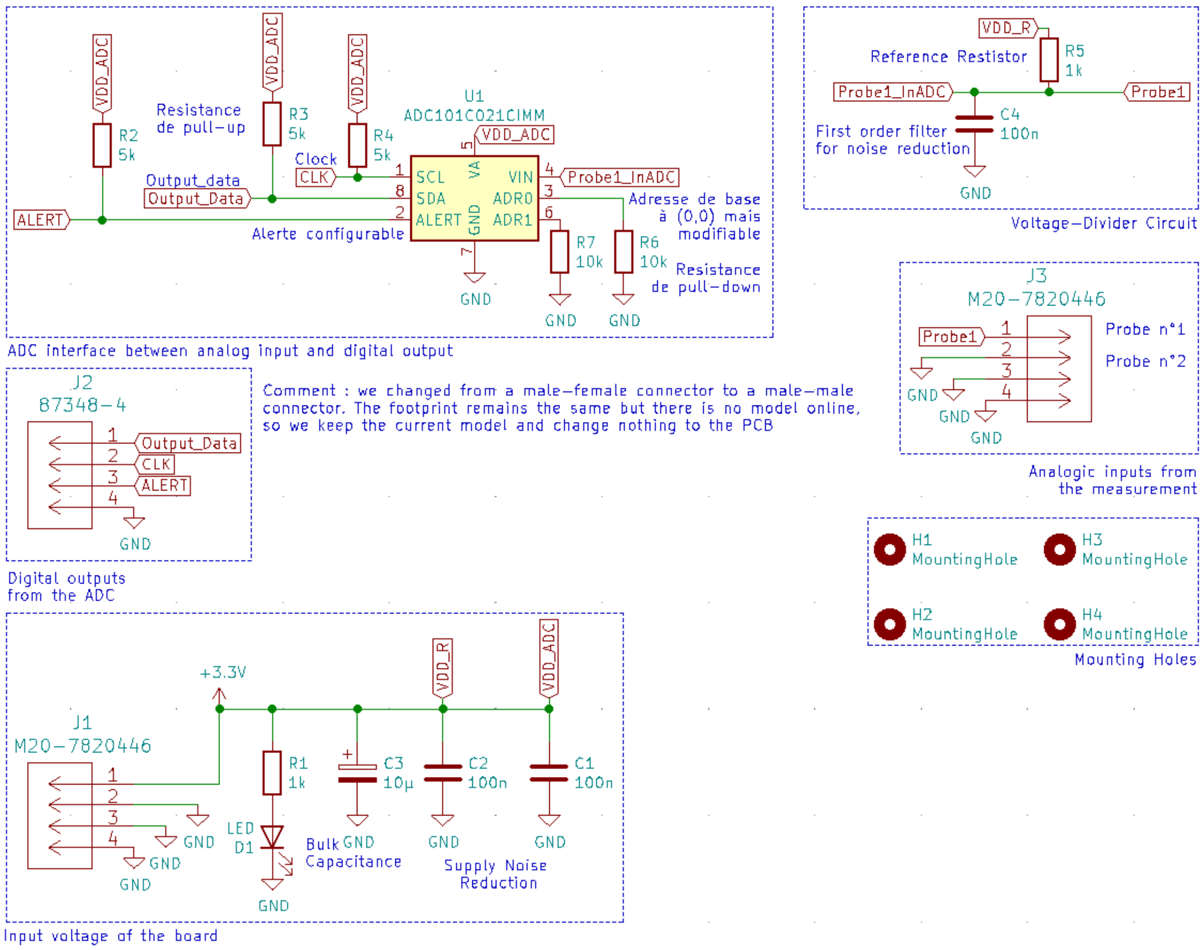


Figure 28: KiCAD schematic of the interface probes

9.2.2 Routed PCB on KiCAD

In Figure 29 is shown the resulting PCB from the schematic from subsubsection 9.2.1.

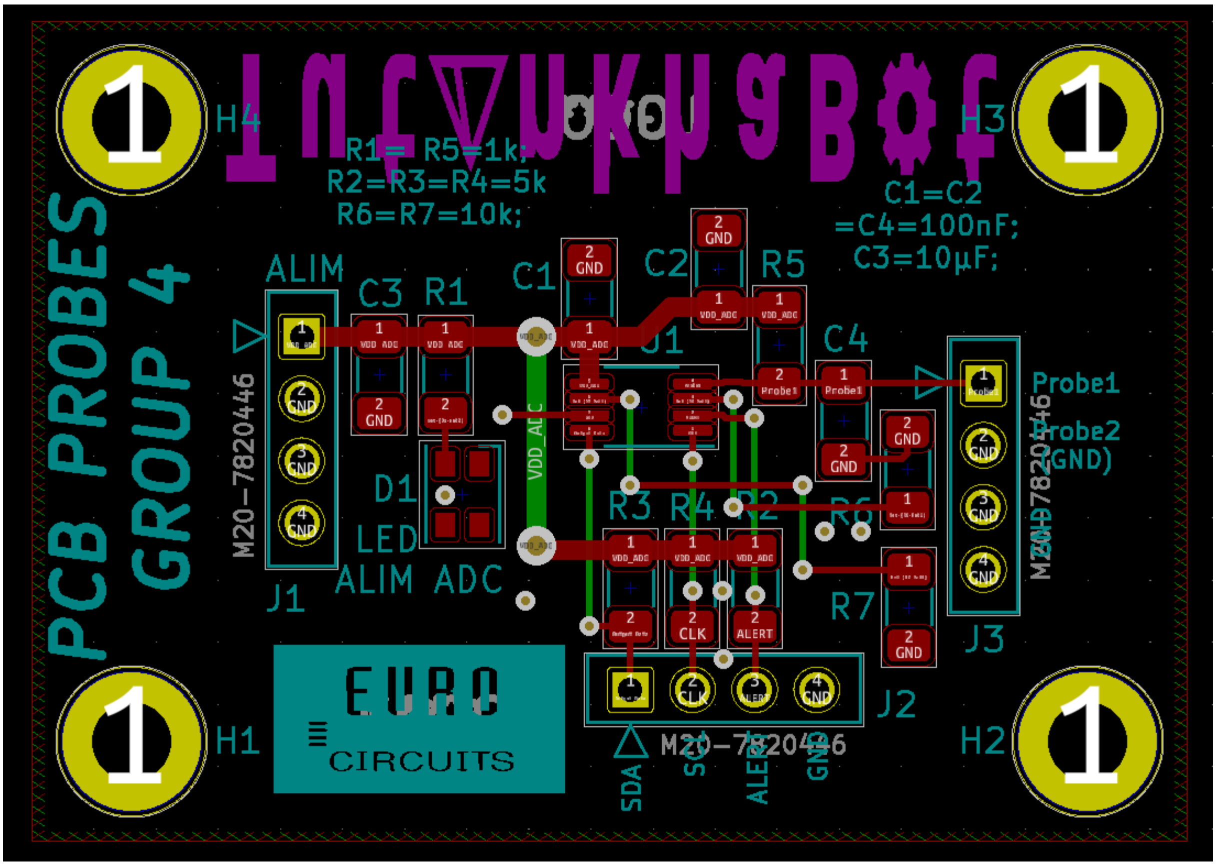


Figure 29: Routed PCB for the interface probes

In Figure 35 is shown a 3D view of this PCB. The group's logo in beneath the board.

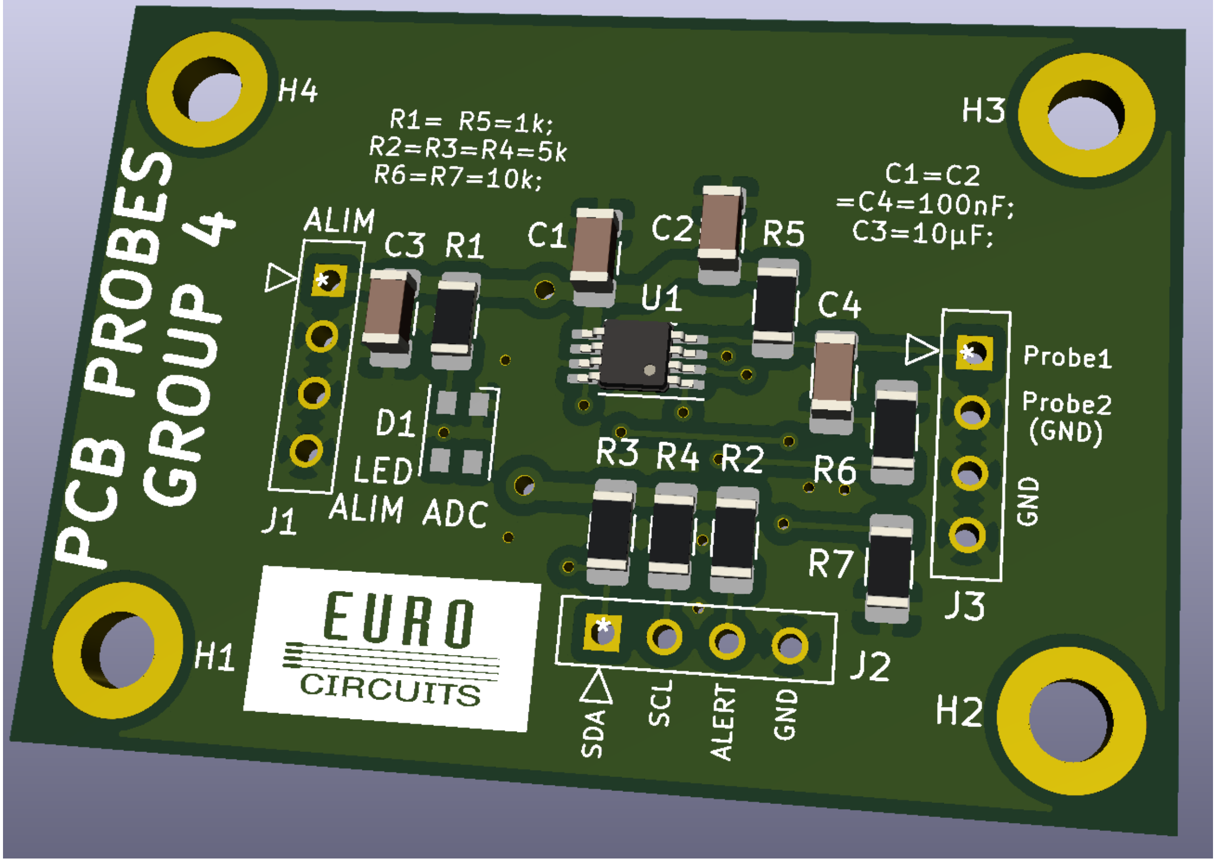


Figure 30: 3D view of the routed PCB for the interface probe

9.3 Motor encoders and Dynamixels interface

9.3.1 Schematic

The schematic for this interface is shown in Figure 31.

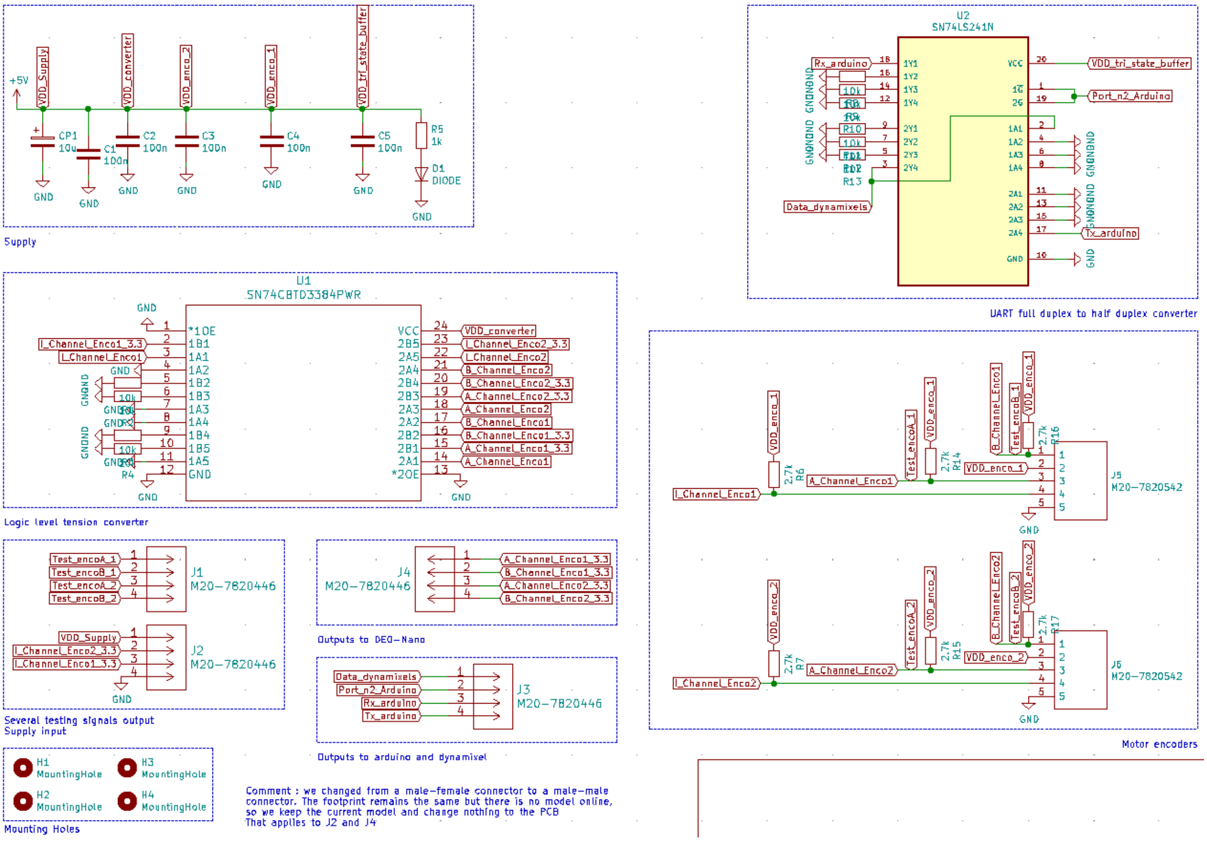


Figure 31: KiCAD schematic of the motor encoders and Dynamixels : zoomed out view

For a clearer reading, this zoomed out version has been cut into 2 parts, one top and one bottom part, shown respectively in Figure 32 and Figure 33.

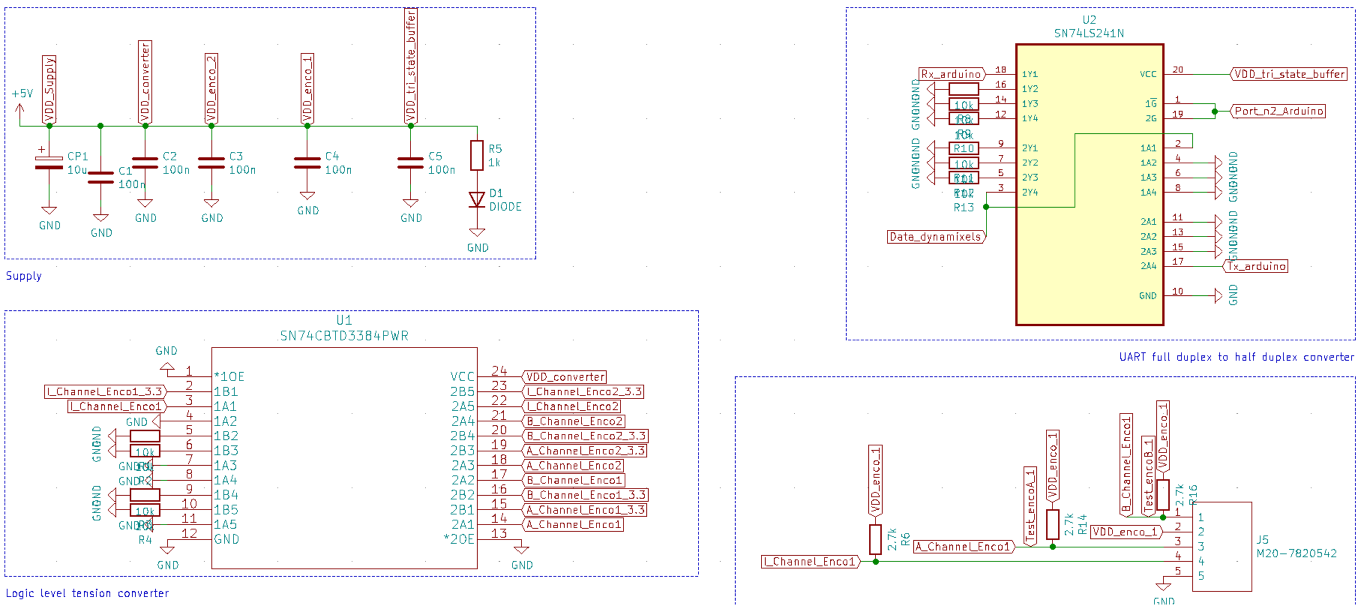


Figure 32: Zoom on the top part of the KiCAD schematic of the motor encoders and Dynamixels : zoomed in view

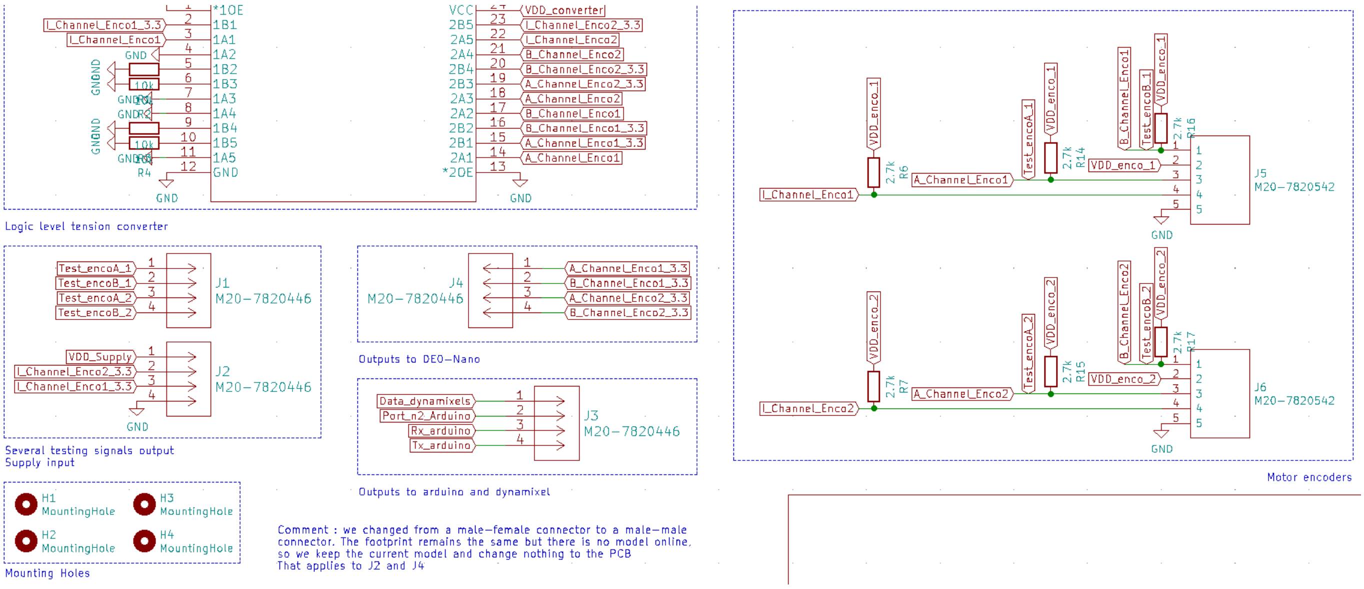


Figure 33: Zoom on the bottom part of the KiCAD schematic of the motor encoders and Dynamixels : zoomed in view

9.3.2 Routed PCB on KiCAD

In Figure 34 is shown the resulting PCB from the schematic from subsubsection 9.3.1.

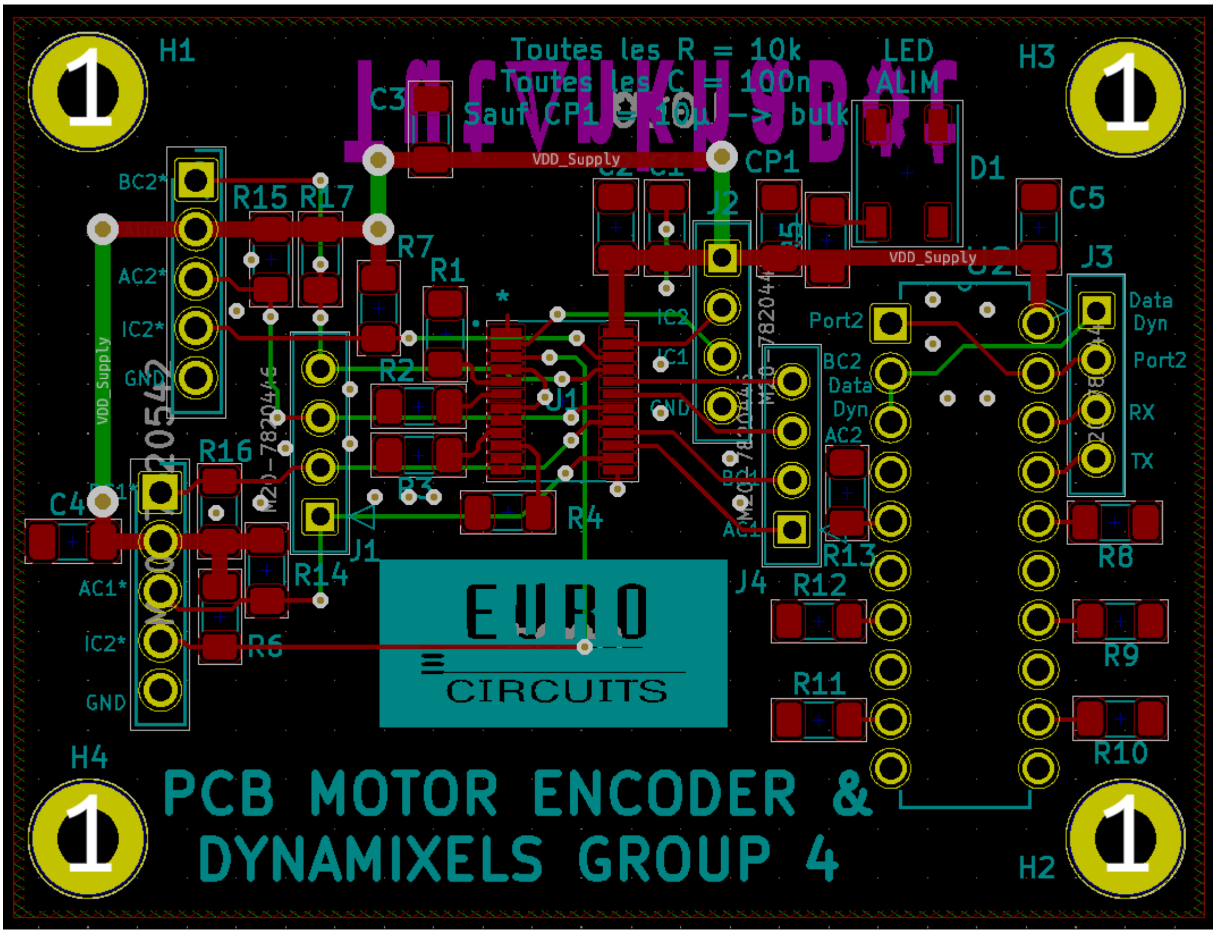


Figure 34: Routed PCB for the motor encoders and Dynamixels interface

In Figure 35 is shown a 3D view of this PCB. The group's logo in beneath the board.

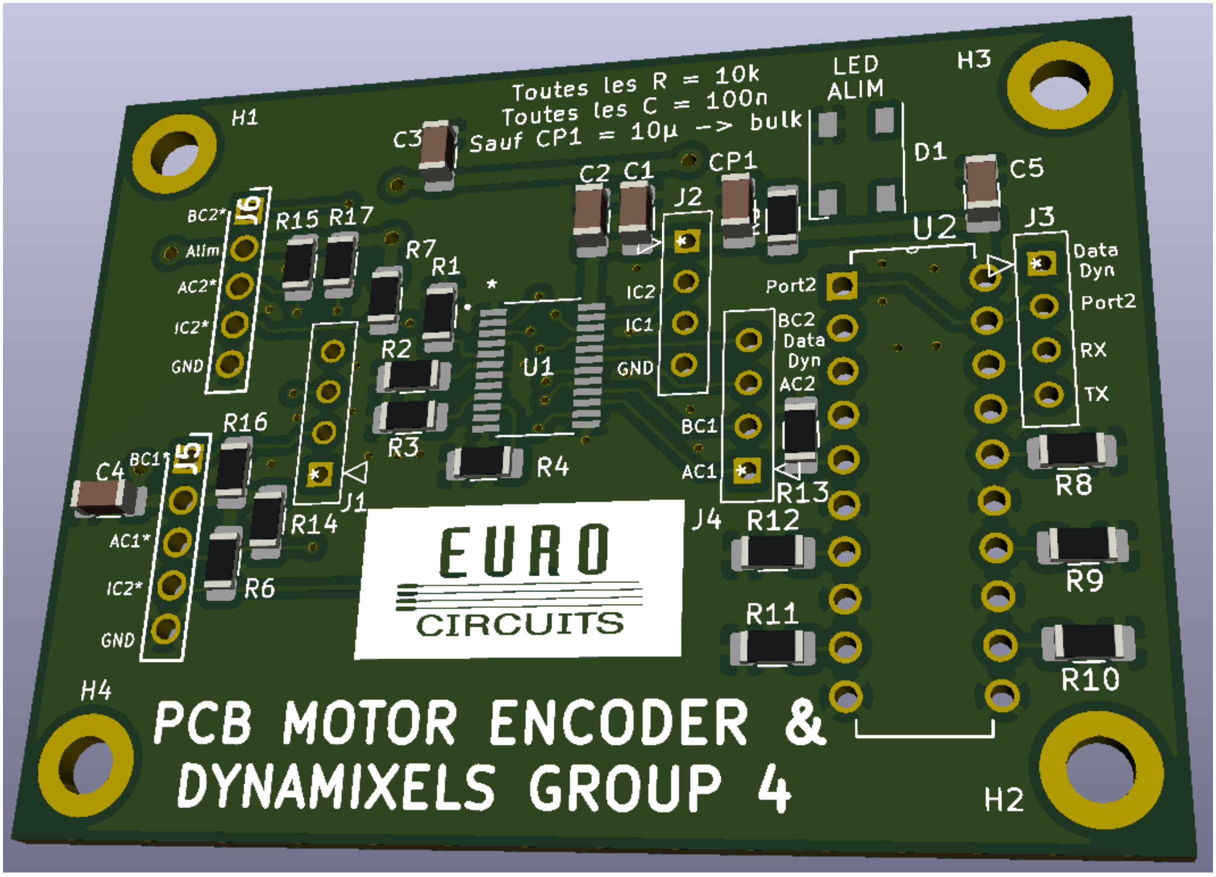


Figure 35: 3D view of the routed PCB for the motor encoders and Dynamixels interface