MARS ROVER

A space adventure to Mars and beyond

Phase 1: Vision | Phase 2: Needs | Phase 3: Concept | Phase 4: Structure | Phase 5: Production

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INTRODUCTION

Concept development approach

To do	Completed	**W38** 16.09.-22.09.	**W39** 23.09.-29.09.	**W40** 30.09.-06.10.	**W41** 07.10.-13.10.	**W42** 14.10.-20.10.
Find a group	26.09.2019		26.09.2019			
Vision and Needs	05.10.2019					
Concept design					11.10.2019	17. Okt
Soft-Prototyping for concept design	07.10.2019				07.10.2019	
Concept report						17.10.2019

First we tried to make us familiar with the given task, environment and limitations. We set us goals and a time schedule. In the next step we thought about the needs and demands possible customers might have.

From that point on we derived the main functions. After some research we conducted a brainstorm and collected the advantages and disadvantages of each possible solution. After that our aim was to proof the critical concept through rapid prototyping. With the precious knowledge gained from the rapid prototyping, we evaluated each pro and con on a scale from 0-5(-5 respectively) bearing in mind the needs and demands we derived before. From that we set together our concept.

Phase 1: Vision | Phase 2: Needs | Phase 3: Concept | Phase 4: Structure | Phase 5: Production

THE TEAM

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Nabil Harchaouen, Germany

Adrien Wingert, France

Gabriele Reggianini, Italy

We are a multicultural team of engineering students from all over Europe. Similarly the European Space Agency (ESA) consists of a very diverse group of people. We have different backgrounds, talents and preferences, so everyone can contribute in their own way.

We are the smallest team in this years course, which confronts us with some time challenges. This forces us to keep things simple. At the same time it makes communication in the team easier and everyone has a better overview of the whole project.

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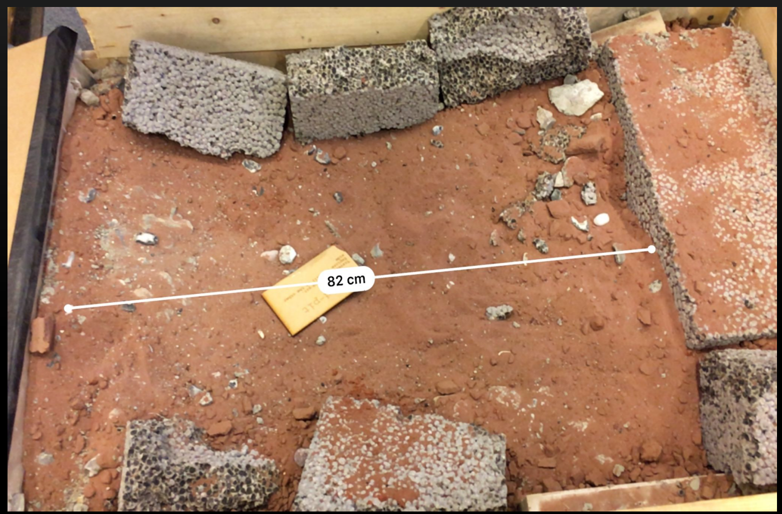
VISION



Mars Desert:
- Sand which can cause problems for the propulsion
- Big rocks which are difficult to maneuver over

Mars forrest:
- Not much space to maneuver
- Dangerous canyon

Mars Hill:
- Very steep
- Low adherence

Mars dump:
- Very uneven surface
- Sharp objects

Vision

Examining the Mars surface in an environmentally friendly way.

Mission

Build a stabile Mars rover of sustainable components

Task frameworks

The rover has to

- maneuver through four different kinds of terrain
- pick up a given object and drop it at a point of interest (POI)
- Fit into a space of 300x200x200mm
- contain a camera
- Be controllable from another room with a video signal
- Handle mars environment

Phase 1: Vision | Phase 2: Needs | Phase 3: Concept | Phase 4: Structure | Phase 5: Production

NEEDS AND DEMANDS

	Demand	Must	Should	Wish
1.	**Functional demand**			
1.1	Speed			X
1.2	Powerful torque	X		
1.3	Self-provider of energy		X	
1.4	Energy Efficient		X	
1.5	Long range		X	
1.6	Stabil structure	X		
1.7	Stabil process	X		
1.8	Going uphill	X		
1.9	Going backwards	X		
1.10	Good maneuverability	X		
2.	**Environmental and economic demands**			
2.1	Light weight			X
2.2	Efficient and environmentally friendly use of material			X
2.3	Can handle Mars and space atmosphere	X		
2.4	Cheap	X		
3	**Operational demands**			
3.1	Easy to repair		X	
3.2	Easy to control	X		
3.3	Reliable operation	X		

Users:

1. Researchers, who want a rover that:
   - Is reliable-> not easy to repair or replace
   - Is user friendly
   - Has long RC-range(can be steered from earth)
   - Has a good use of material
   - Is as cheap as possible
2. Robot operators, that want a rover that:
   - Moves on mars surface without problems
   - Has a good battery duration
   - Doesn’t get trapped

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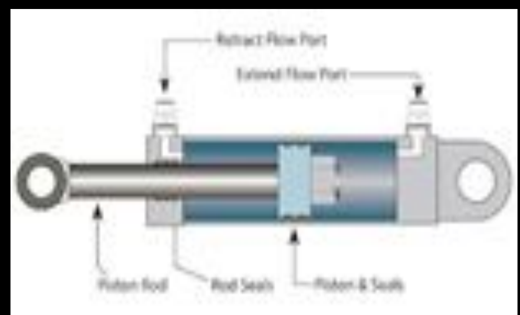
MORPHOLOGICAL MATRIX

Movement	 Continous tracks	 Wheels	 Legs
Grabbing	 Hydraulic/pneumenatic	 Electrical	
Control	 Bluetooth	 Infrared	 Radio frequency

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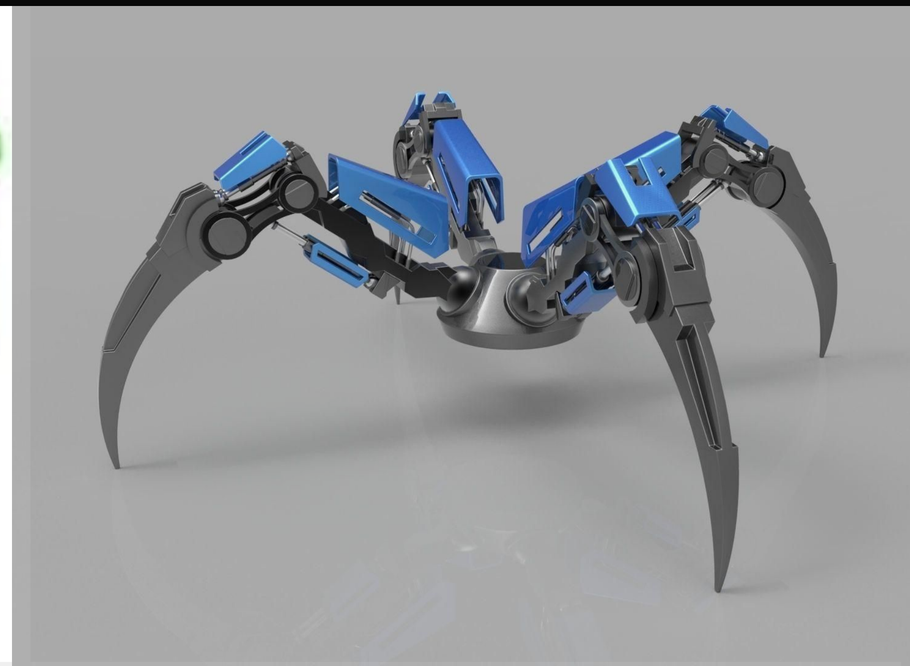
MOVEMENT: The technology

A martian rover has to move without difficulties on every type of terrain to overcome all kinds of obstacles. It also must be agile and able to turn rapidly in order to face the Martian forests.

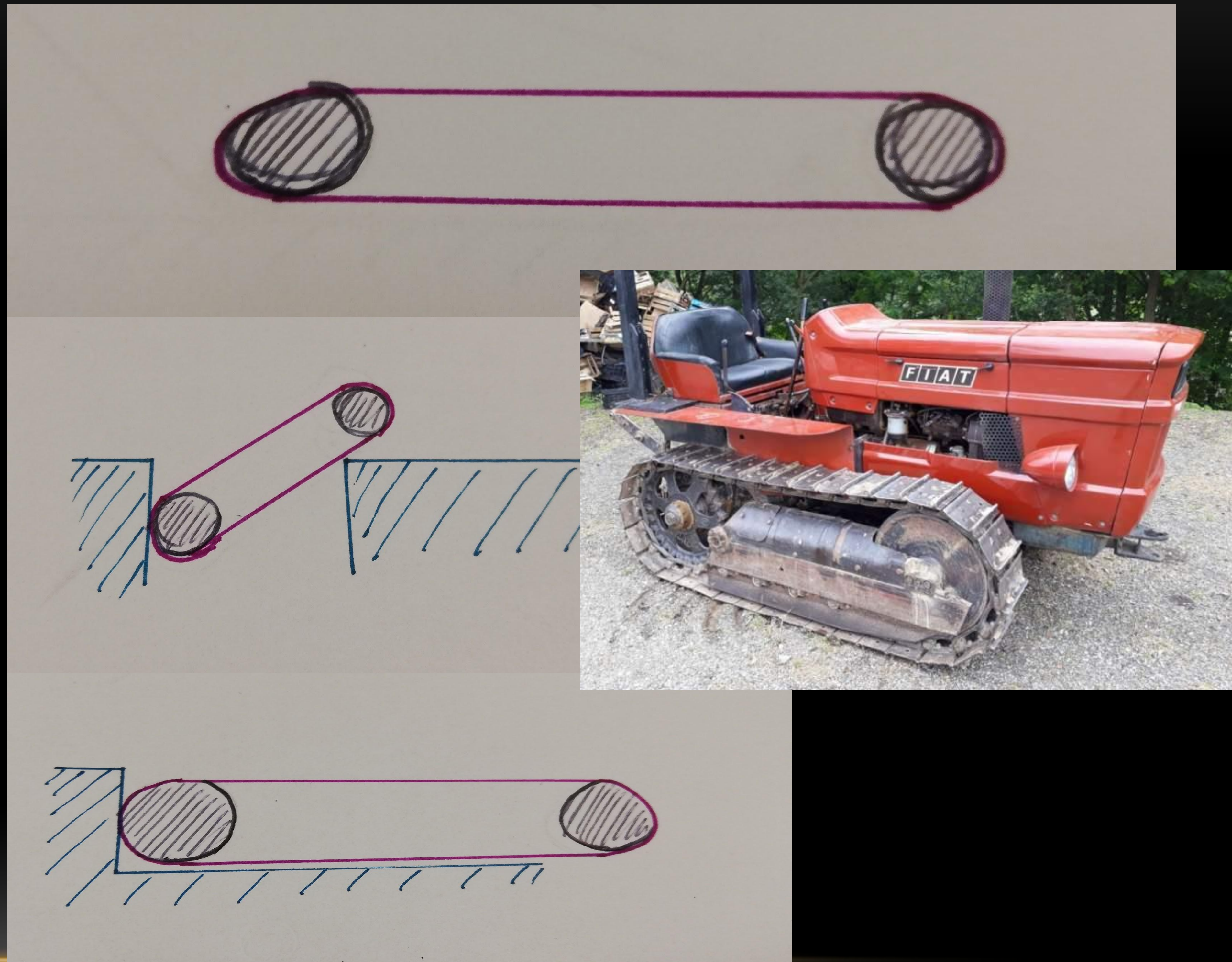


	CONTINUOUS TRACKS	WHEELS	LEGS
PROS	• Easy to turn → **3 PT** • Easy to control → **1 PT** • Good on difficult terrains → **5 PT**	• Easy to control → **2 PT** • Cheap → **1 PT** • Good availability → **4 PT**	• Original → **1 PT** • High distance from ground (can deal with obstacles) → **3 PT**
CONS	• Mechanically complex (to produce) → **-2 PT** • More expensive than wheels → **-1 PT** • Not easy availability → **-1 PT**	• Can get stuck more easily → **-2 PT** • Needs 4x4 propulsion on difficult terrains → **-1 PT** • Could be complex to turn → **-1 PT**	• Complex control → **-2 PT** • Complex to turn → **-1 PT** • Mechanically complex (more than tracks) → **-3 PT**
TOTAL	**5 PT**	**3 PT**	**-2 PT**

MOVEMENT: The shape of the tracks

2 WHEELS

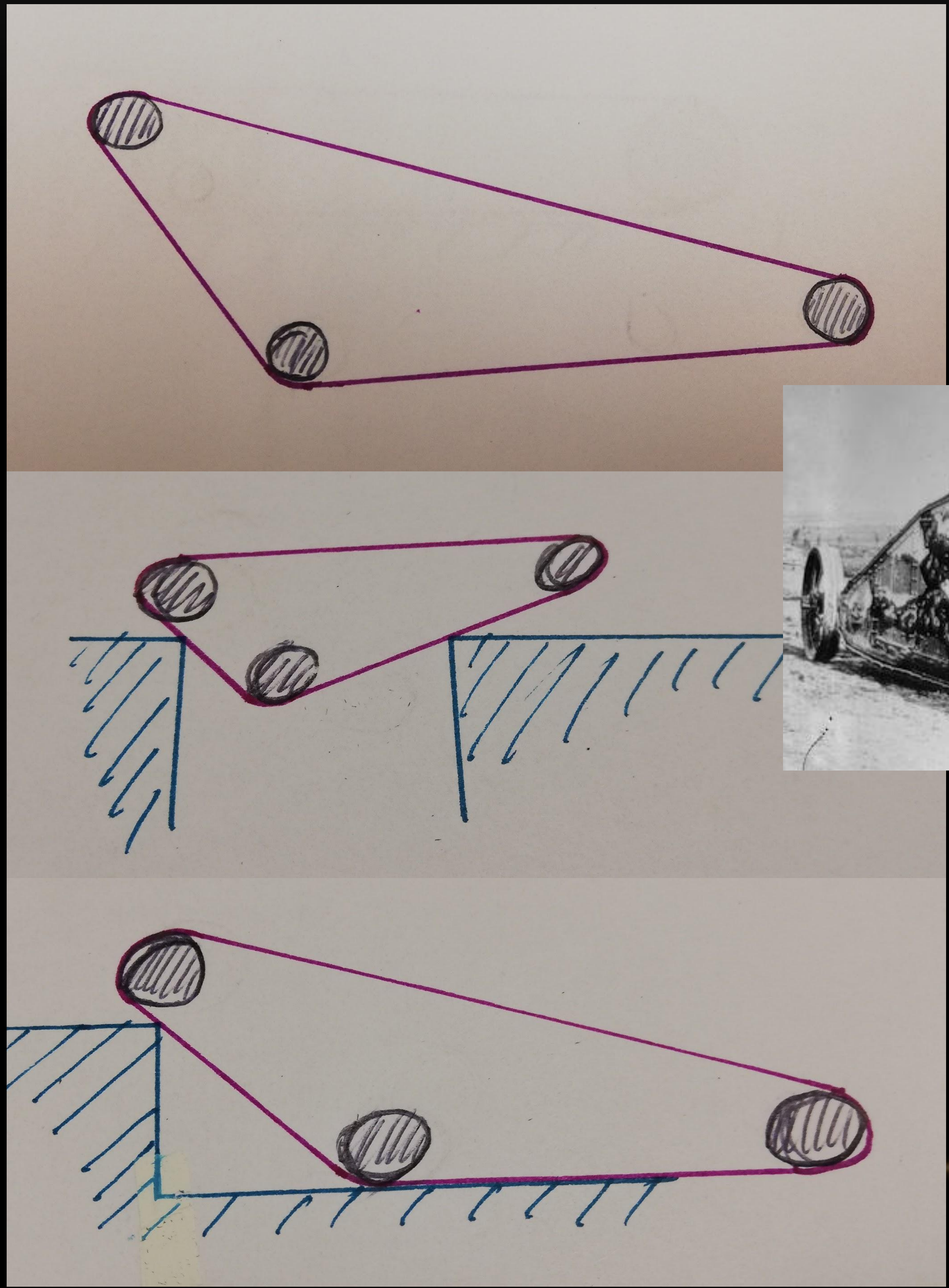
Is the simplest and cheapest way to implement tracks. This shape is widely used in industrial and agricultural fields. It allows good traction on critical terrains such as snow and sand. The center of gravity is low due to the fact that the most heavy components (motors and batteries) are located in the lower part of the robot. However this configuration could have big difficulties on steps (max height equal to wheels radius) or deep canals (if they are too wide the robot will fall)



MOVEMENT: The shape of the tracks

3 WHELLS

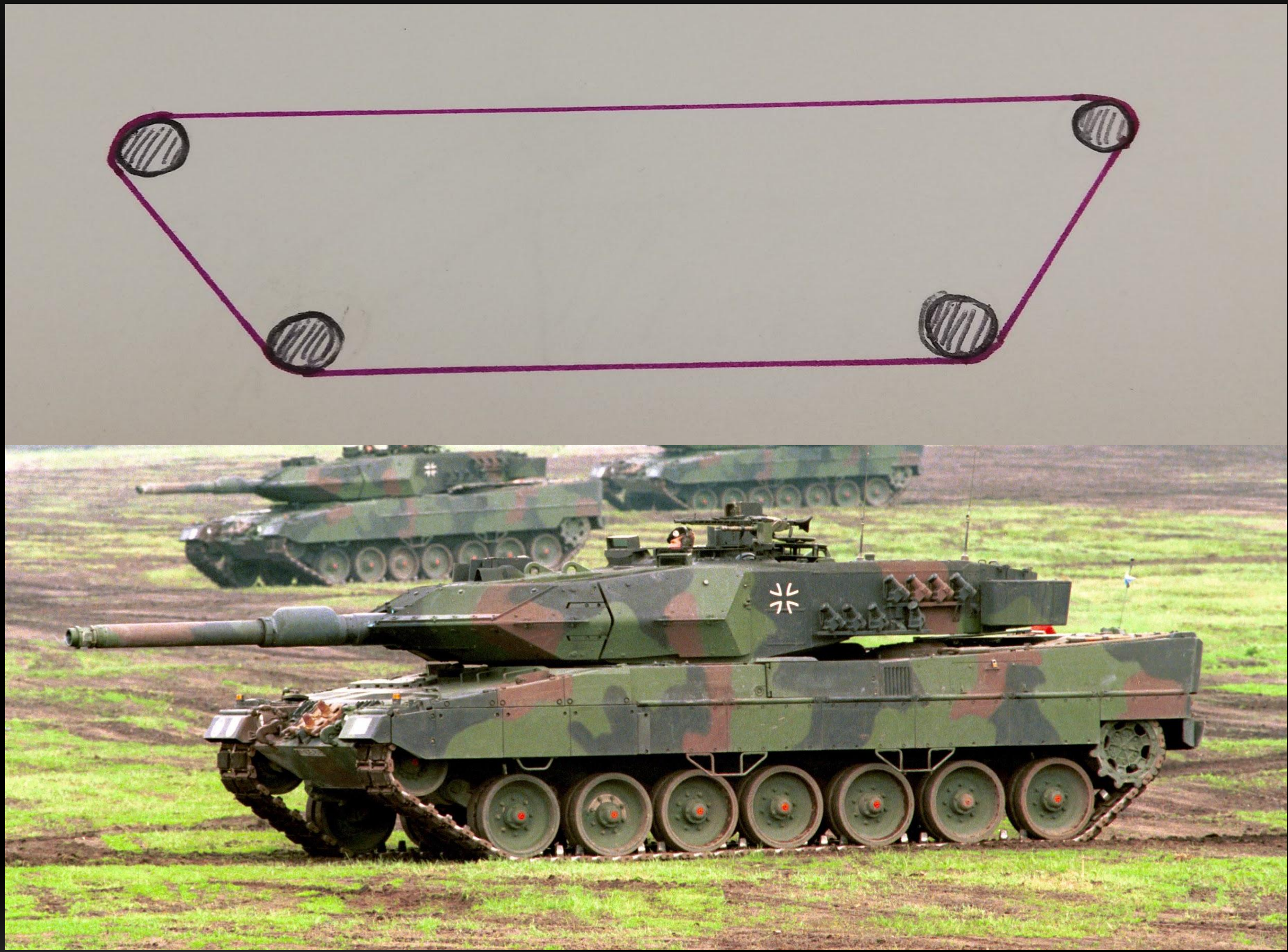
Adding a wheel lifted from the ground in the front side of the robot, it is possible to find a solution on the main problems of the 2 wheels configuration. This solution is inspired by the first tanks (from the years of WW1). This shape combines good traction on difficult terrains with excellent capacity of climbing. However this climbing and fording abilities are applicable only if the robot is going forward. The motors are located in the front wheel, this makes the center of gravity higher but assures a good distribution of the weight inside the rover.



MOVEMENT: The shape of the tracks

4 WHEELS

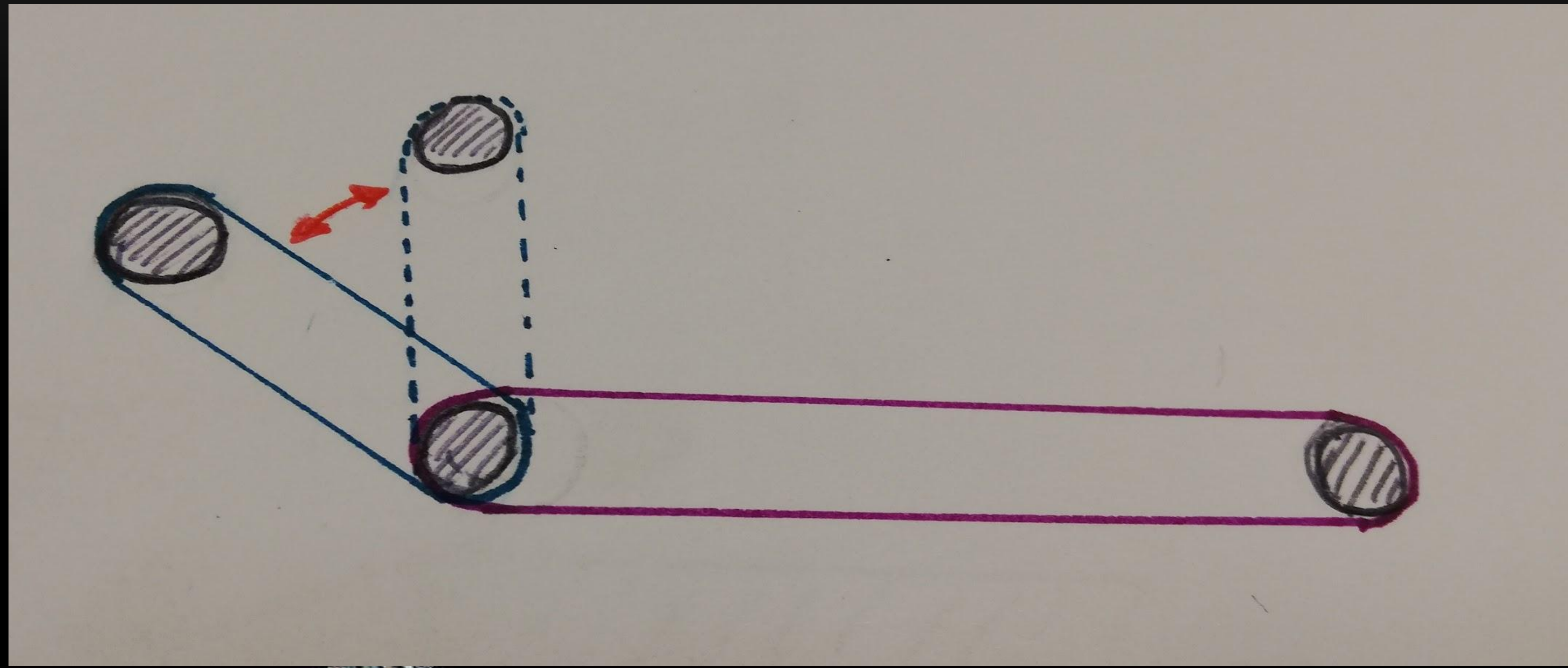
This concept is basically the reproduction of the 3 wheels model in both the front and the back sides of the robot. This avoid the limitations of movement of the previous model. This shape is adopted by all the modern tanks due to its strength and simplicity. This rover can go either forward or backward, with good ability on not getting stuck.



MOVEMENT: The shape of the tracks

ADJUSTABLE INCLINATION

This solution is much more complex than the previous ones. Basically is a 2 wheels shape with an adjustable arm in the front side. This is also equipped with tracks moved by the same motors of the standard tracks. A servo motor assures the movement of the arm. This system allow to combine the advantages of the 2 wheels shape with the capacities of the 3 wheels shape. Adjusting the inclination of the front arm it is possible to change from a shape to the other. However this configuration leads to an increase of costs and system complexity, increasing also the risk of failures (what is not there cannot be broken)



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MOVEMENT: The shape of the tracks

	2 WHEELS	3 WHEELS	4 WHEELS	ADJUSTABLE
Flat	5	4	4	5
Sand	5	4	4	5
Steps	1	4	3	5
Agility	4	4	4	4
Forward	1	5	4	5
Backward	1	2	5	2
Climbing	3	4	4	5
Fording	1	4	3	5
Simplicity	5	4	3	0
Cost	5	4	3	0
TOTAL	**31**	**39**	**37**	**37**

The 3 wheels shape is the best one for our needs. We need good climbing abilities, but it is not necessary to have them both going forward and backward. With this shape we have a good area of contact between the tracks and the ground and we have a big free space in the back of the rover for locating batteries and grabber.

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MOVEMENT: The type of tracks

	PLASTIC CHAIN	CONTINUOUS RUBBER
PROS	• Design available (for 3D print) → **4 PT** • Easy to change length → **3 PT** • Easy to change pads → **2 PT**	• Easy to soft-prototype → **4 PT** • No sand issues → **1 PT** • No repair/assembly/disassembly necessary → **2 PT** • Only one part → **1 PT**
CONS	• Susceptible to sand? → **-1 PT** • Slower to soft-prototype → **-2 PT** • Many parts → **-2 PT**	• Needs to design ourselves → **-1 PT** • No modification once it's printed → **-2 PT**
TOTAL	**4 PT**	**5 PT**

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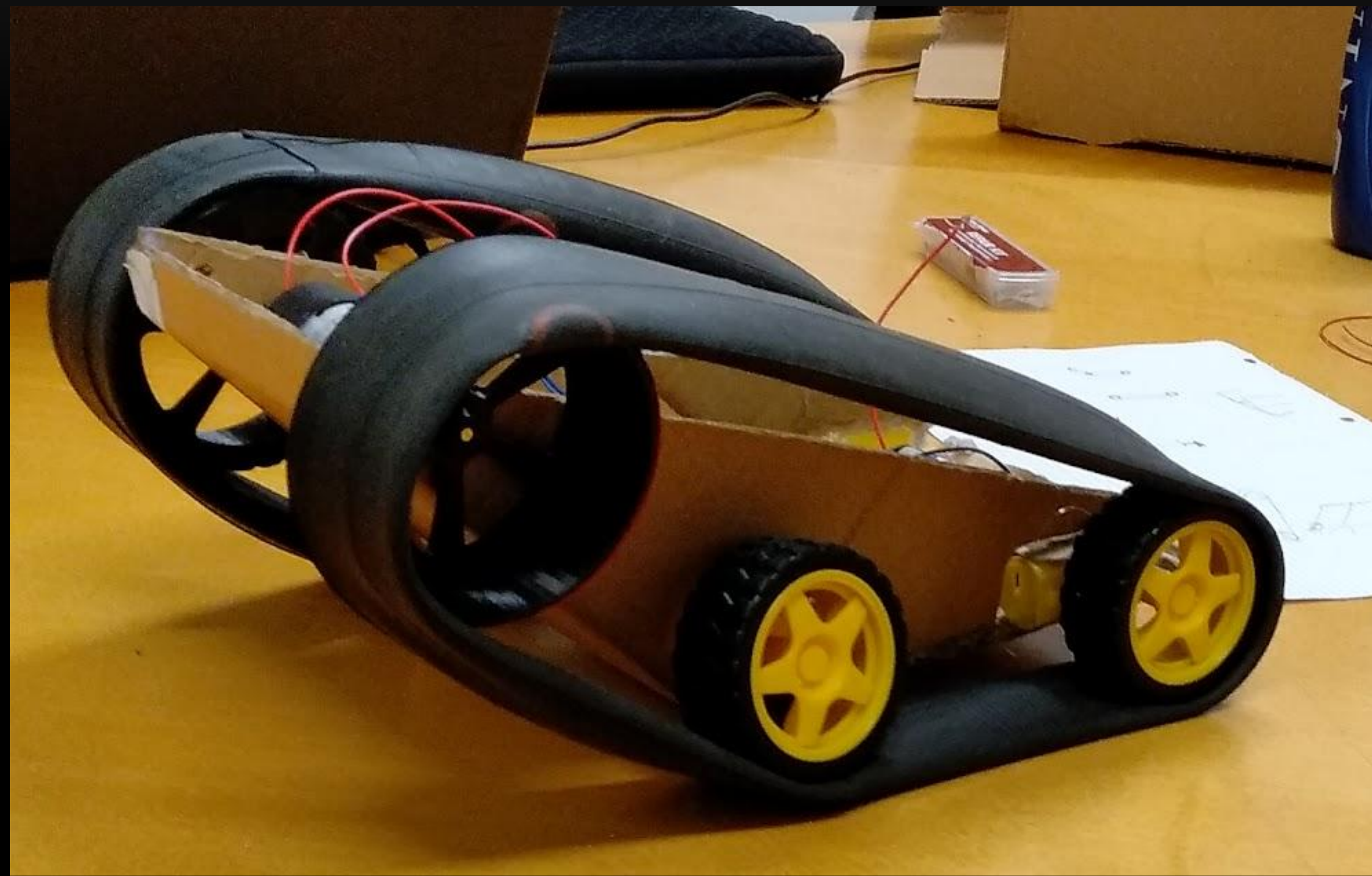
MOVEMENT: Soft-prototype

BODY: Paper-made, triangular shape, frontal inclination of 45°
MOTORS: Standard 24V DC motors (HL149.24.21)
TRACKS: Rubber-made, without teeth for soft-prototyping



OBSERVATIONS:

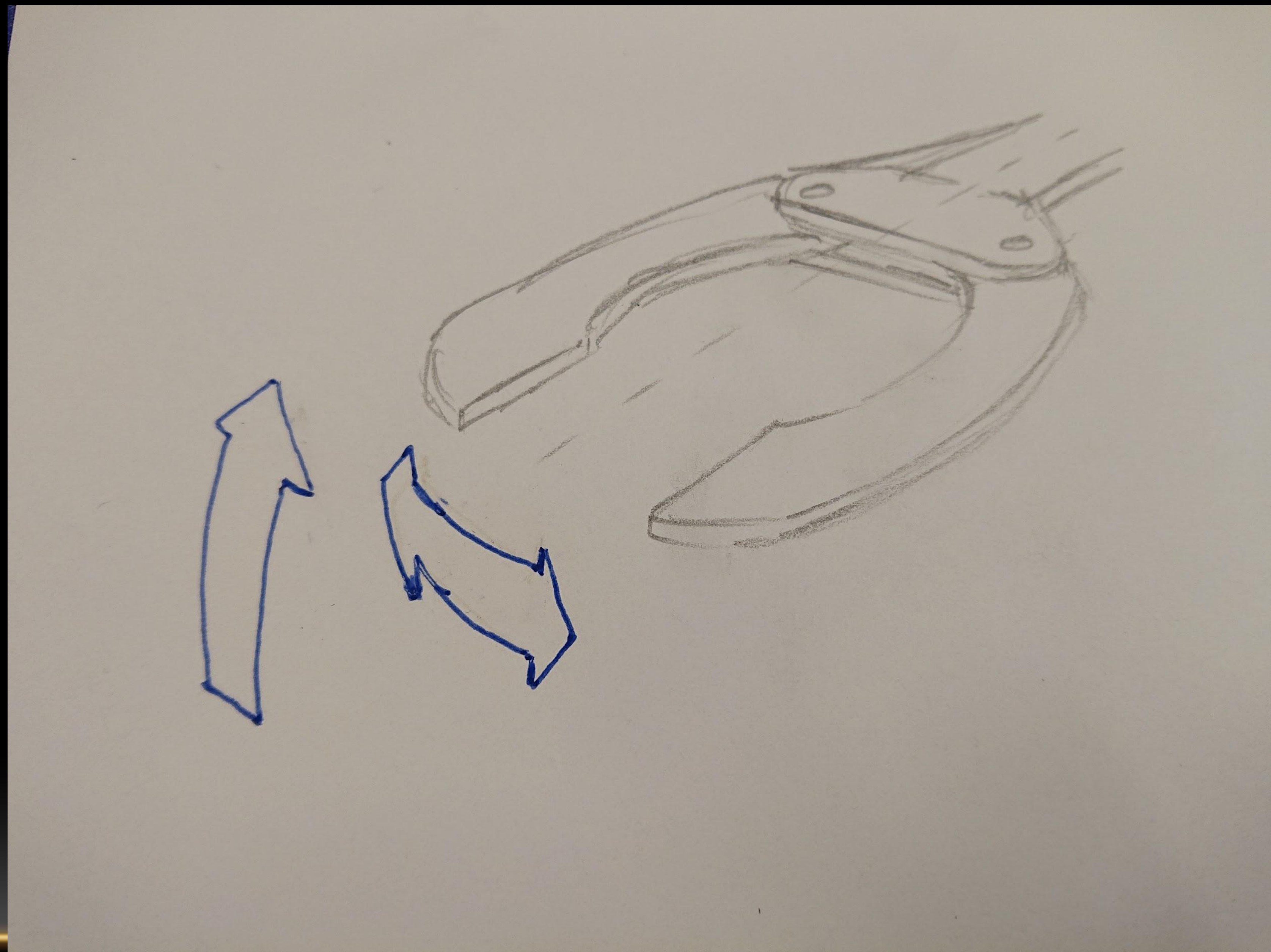
- General shape of tracks and frame is good
- Ground clearance must be larger
- Weight balance must be kept in mind
- Better with smaller wheels on engines and bigger wheels on ground
- Must try to implement LiPo-batteries to provide more current for the engines
- Pay attention for friction in tracks and gears, we could need more powerful motors
- A very rigid frame is needed due to the tension of the rubber tracks

GRABBER

FUNCTIONALITY

The grabber must be able to:

- Hold on to an object that weighs approx. 200 g
- Lift the object
- Move out of the way to avoid restricting mobility
- Be durable enough to withstand a low drop



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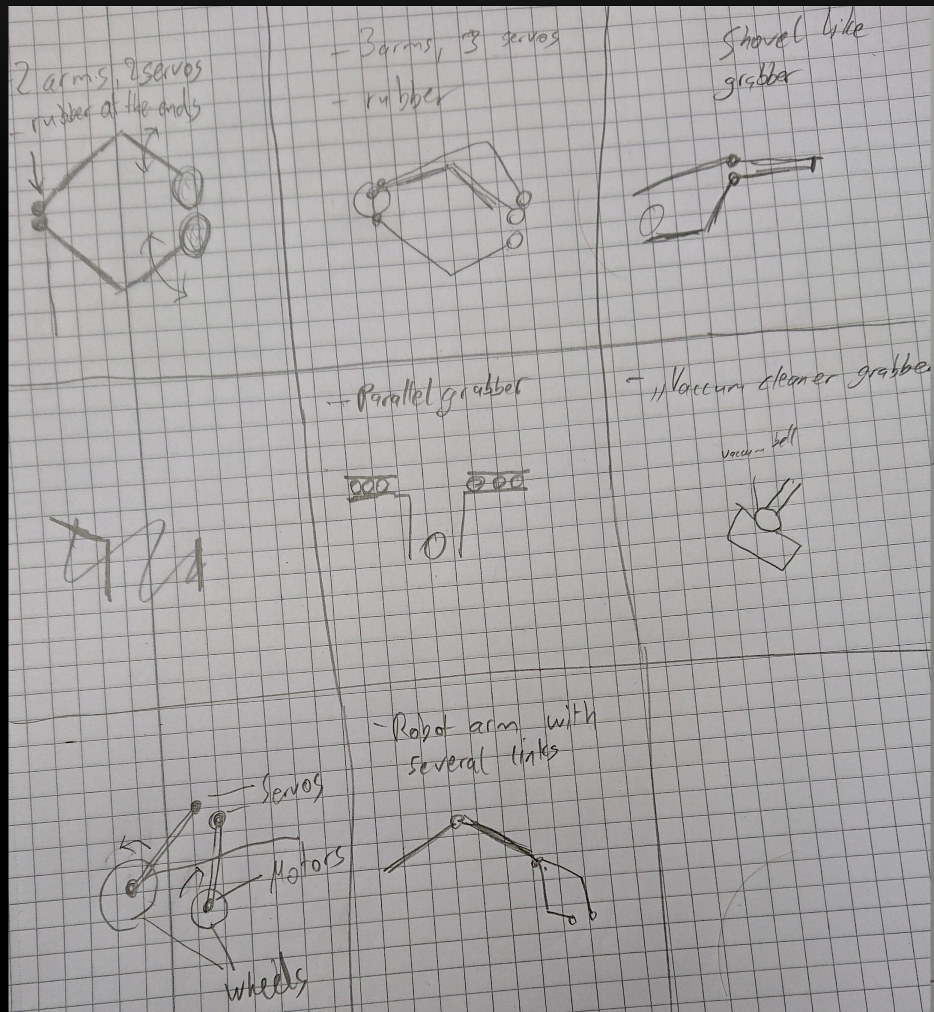
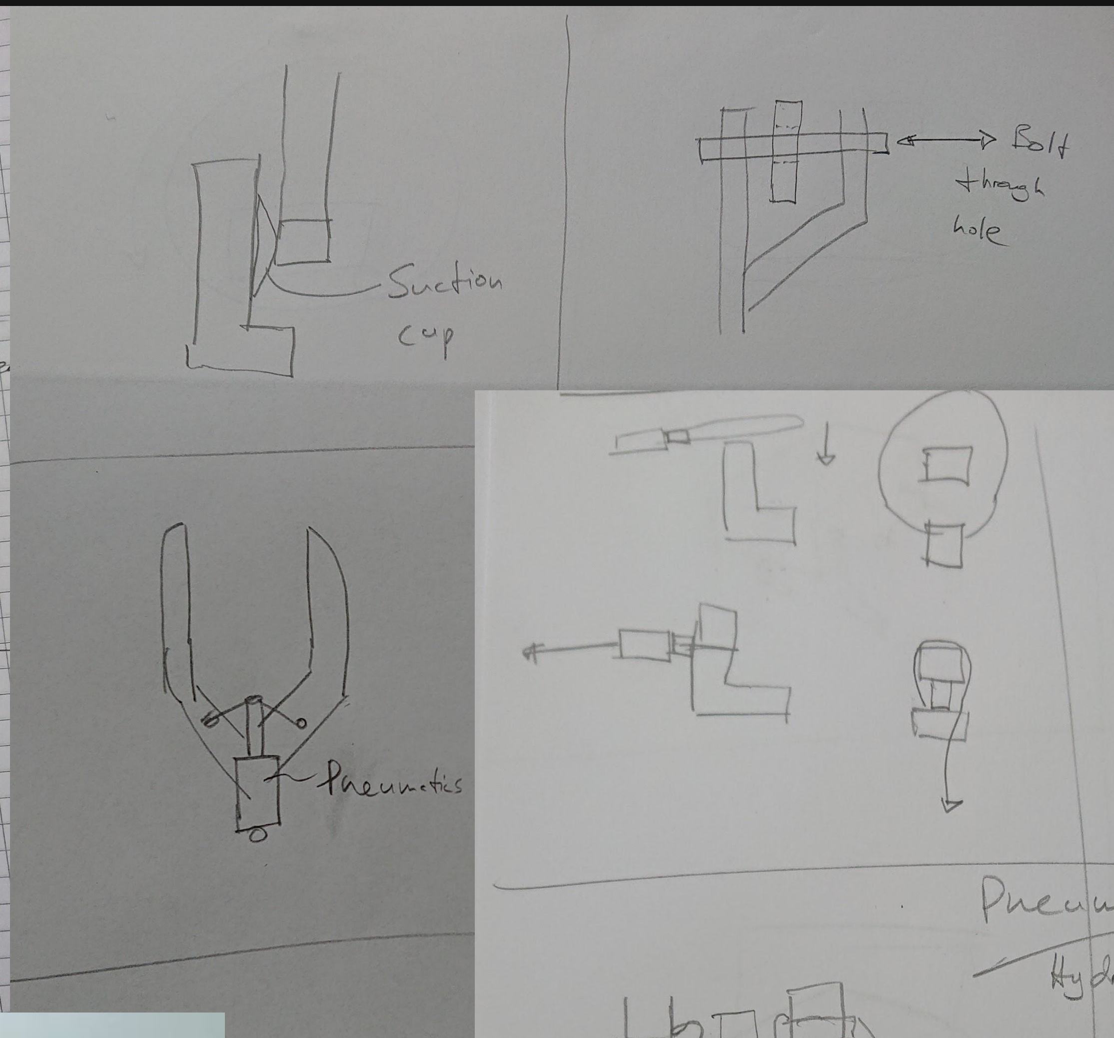
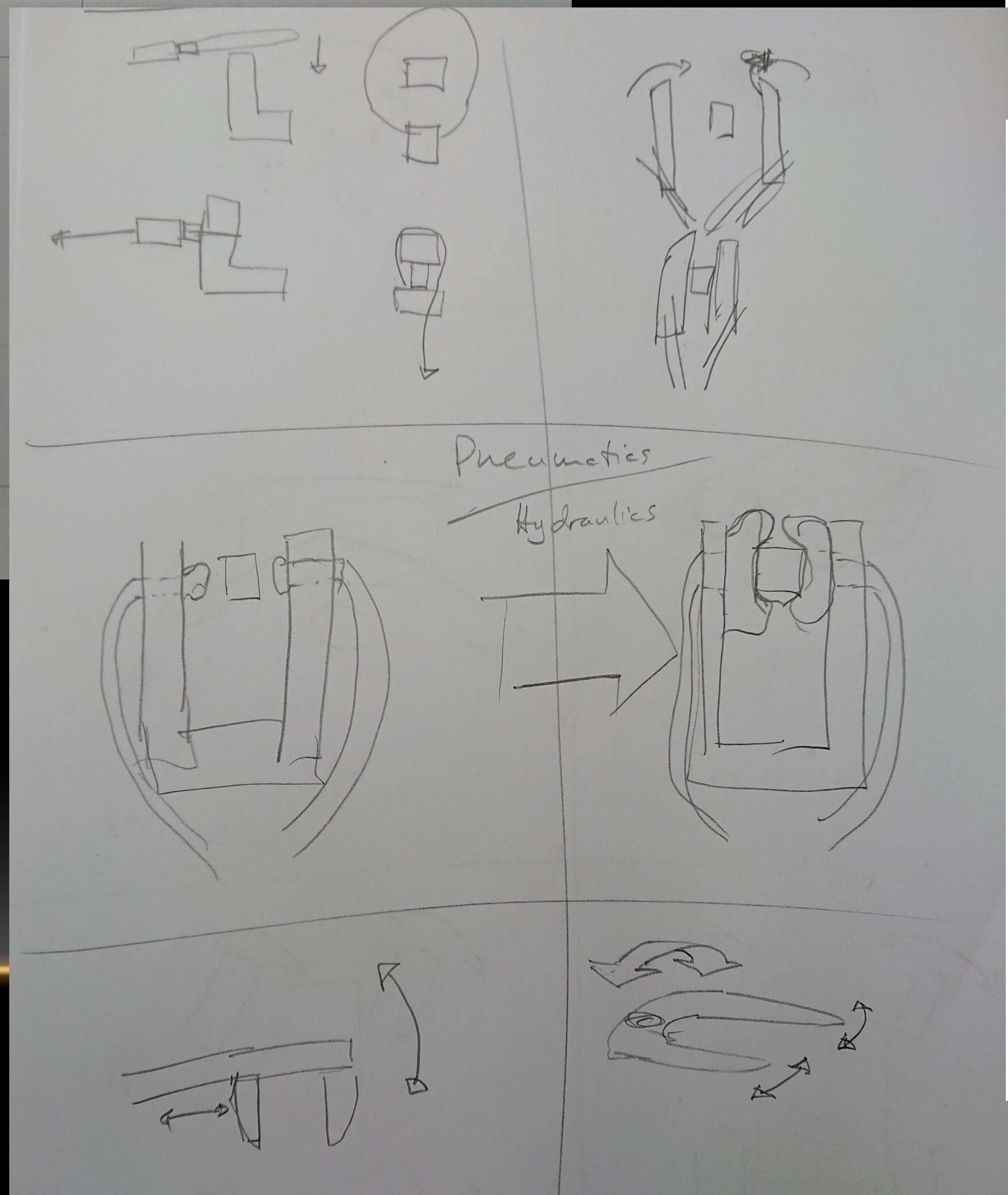
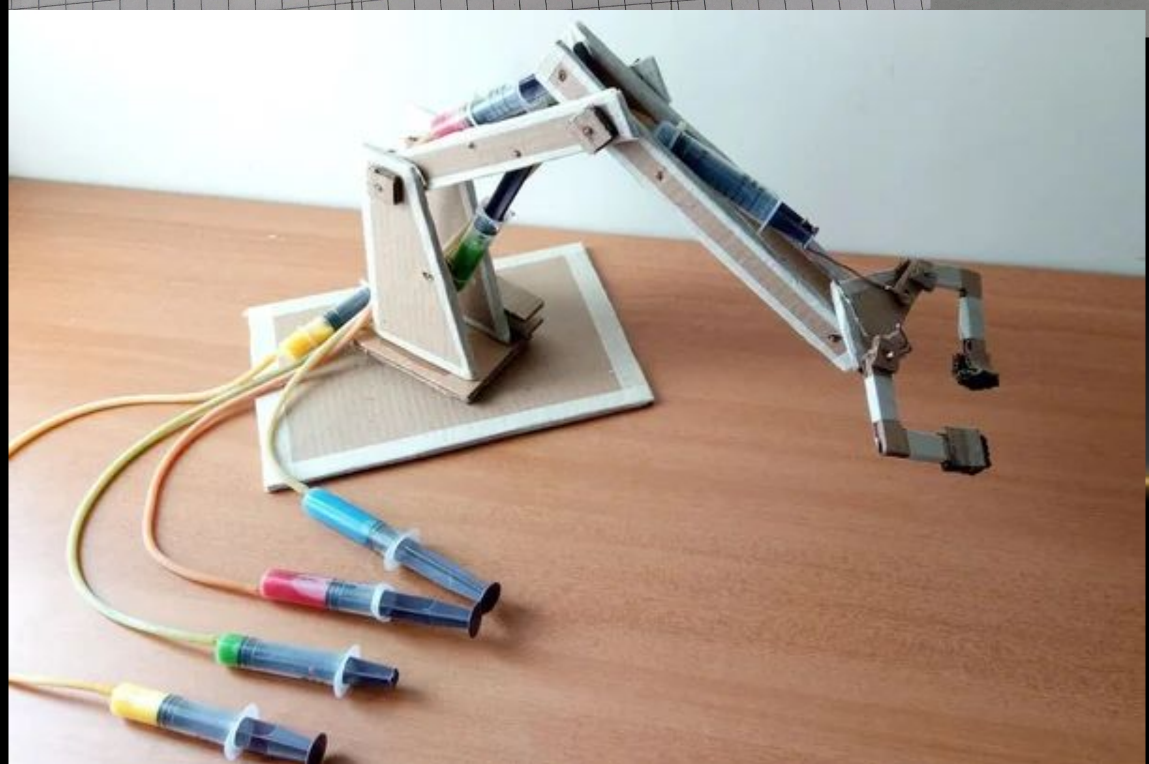
GRABBER: Early stage concepts and existing solutions









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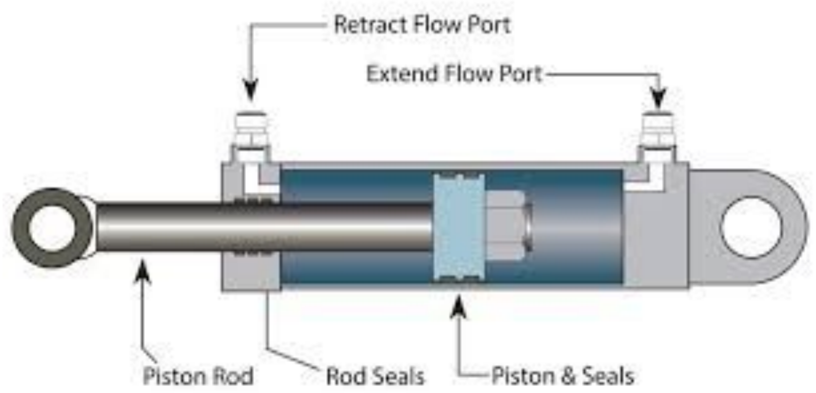
GRABBER: Drive system



	HYDRAULIC/ PNEUMATIC	PURELY ELECTRICAL
PROS	• Easy to adapt pressure/strength → +4 • Good availability of parts → +3 • More flexible with placement of big parts → +3 • Not vulnerable to sand/dust → +1 • Pressure control possible → +2 • More energy efficient → +4	• Cheap → +2 • Few parts → +2 • Easy implementation → +3 • More off-the-shelf solutions available → +3
CONS	• Unknown difficulty of use in construction →-3 • More parts → -4 • Takes extra space → -2 • Needs electrical supply in addition → -3	• Vulnerable to sand/dirt → -1 • Strong servos need more space → -3 • Machinery exposed on the outside → -1 • Leads to heavy arm → -2
TOTAL	**5 PT**	**3 PT**

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GRABBER: Prototype

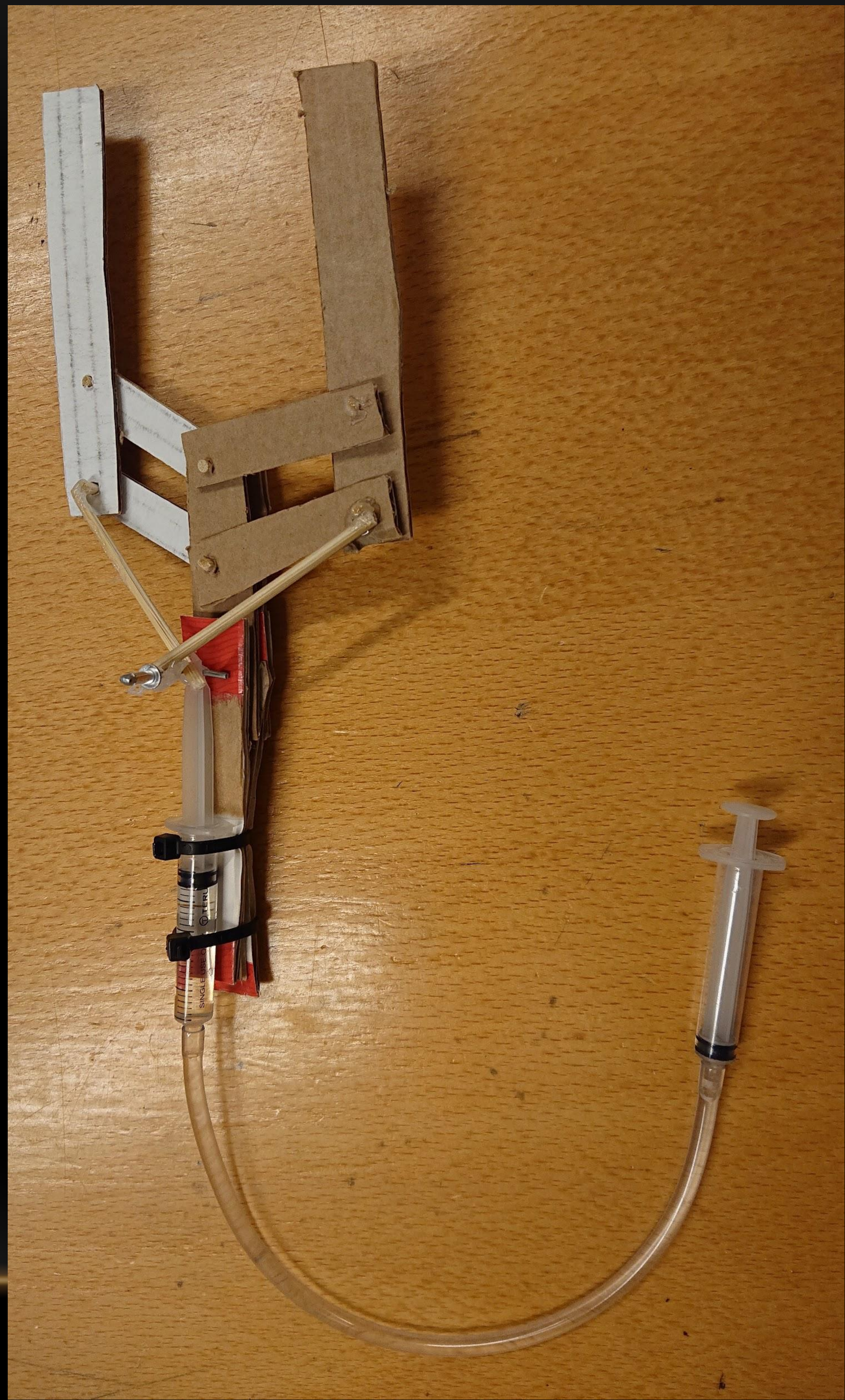
Hydraulic grabber prototype

Materials: Cardboard, wood sticks, zip-ties, etc.

Actuator: Syringe used as hydraulic cylinder

OBSERVATIONS:

- Syringes are cheap and easily available
- Easily available tubes and syringes fit well together
- Hydraulic (Water) works better than pneumatics (air)
- Syringe piston is unstable sideways
- The pull of the syringe is more stable than push
- End of piston should be kept intact to maintain structural integrity
- Piston is easily pushed completely out of cylinder, must be carefully avoided on final model



CONTROL : Several technologies

BLUETOOTH

Easily used with a smartphone → +3 Cheap and easy to set up → +3 Low power consumption → +2
Low Range → -5 Connectivity Unreliable → -3
0 PT

RADIO FREQUENCY

High Range → +5 Signal not blocked by obstacles → +4
Limited number of channels → -4 Need to build a custom controller → -3
2 PT

INFRARED

Can communicate a lot of informations → +3
Controller less comfortable than a smartphone or a joystick → -3 Low Range → -5
-5 PT

WI-FI

Can be controlled from far away → +4
Complicated set up for basic tasks → -3 High power consumption → -2 Needs local Wifi-network → -5
-6 PT

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CONTROL : Radio Frequency Controller and Camera

6 channels available :

- tracks (forward/backward)
- turning(left/right)
- moving the grabber
- activate the grabber's pliers
- moving the camera

All the components are available in the lab

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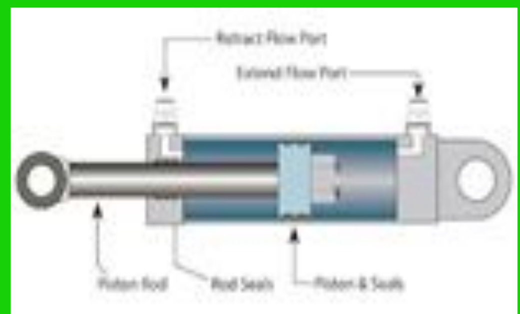
MORPHOLOGICAL MATRIX

Movement	 Continous tracks 5PT	 Wheels 3PT	 Legs -2PT
Grabbing	 Hydraulic/pneumenatic 5PT	 Electrical 3PT	
Control	Bluetooth 0PT	Infrared -5PT	Radio frequency 2PT

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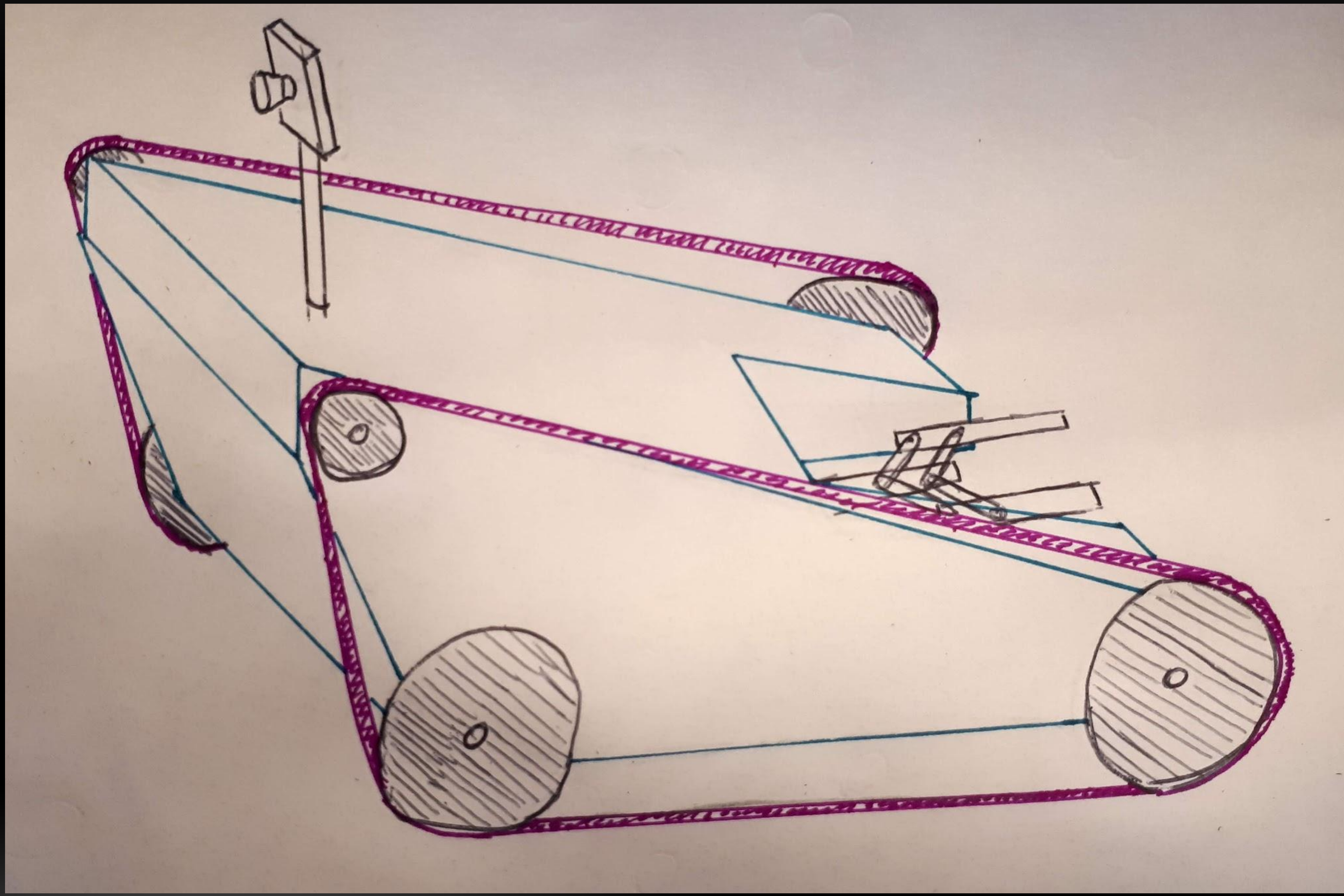
ROVER CONCEPT DESIGN

SHAPE: 3 wheels, we need good climbing abilities but we don't need them both going backward and forward.

MOVING: Toothed rubber tracks for good performances in sand and good traction on smooth terrains

GRABBER: Hydraulic control, located in the back of the rover

VIEW: Camera on a 360° rotating telescopic arm for better view on sides and back



COMPONENTS INVESTIGATION: Motor

The soft prototype testing showed that more powerful motors are needed. Primarily components available in the mechatronic lab should be recycled in order to avoid waste. As the dc motors there lack documentation, the best way to check their suitability was by testing them. For this purpose the previously described soft-prototype was used. It showed that the dc motor (ZYTD520) provided enough torque and speed for our setup. Therefore no further research on motors was needed. The tests showed that a maximum current of 1.5A needed to be provided to the motor.

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COMPONENTS INVESTIGATION: Batteries

Alkaline	NiMh	Lithium Polymer(LiPo)	Lead acid
• Small size, adjustable placement • Easily replaceable, available in the lab • easy to handle	• High power output • rechargeable • easy to handle • available in lab	• High power output • relatively small size • rechargeable • Team member has experience from university project and lends personal one	• High power output • rechargeable
• Low power output • Only certain type rechargeable	• large size and inconvenient shape	• not easy to handle (can be dangerous)	• Too big • too heavy • not available in lab

The size and the power output were crucial factors for the performance on the mars surface and for meeting the size requirements. Therefore we used 14.8V LiPo-batteries to power the motors and rechargeable Alkaline batteries to supply the arduino and other electrical components.

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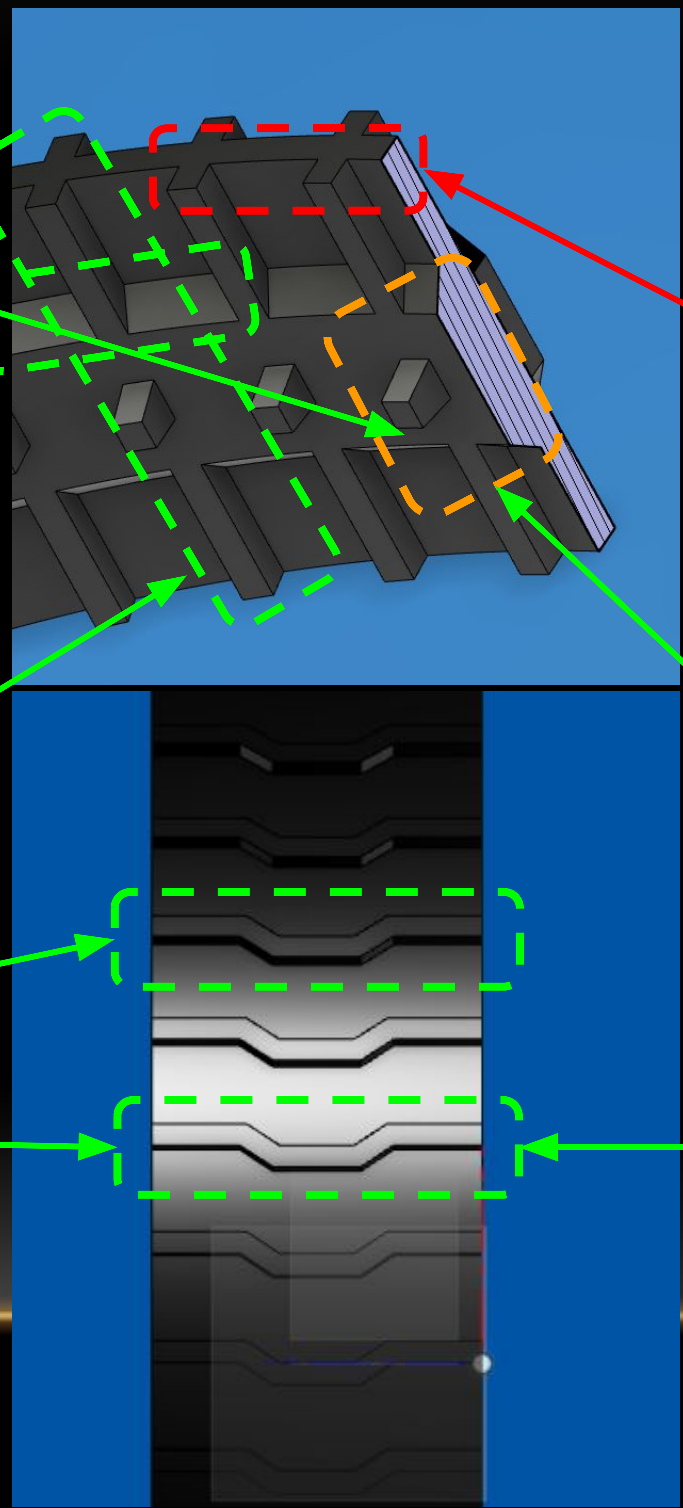
COMPONENTS INVESTIGATION: Tracks

Prototype 1
Design features:

- Central teeth and thicker mid region for restricting sideways motion
- Chamfer enabling support-free 3D-print, also gives self-centering ability under tension
- Internal teeth to give sufficient drive wheel-track traction
- Crosswise teeth continuous to limit axial “folding”
- Treads to give sufficient ground traction

First design

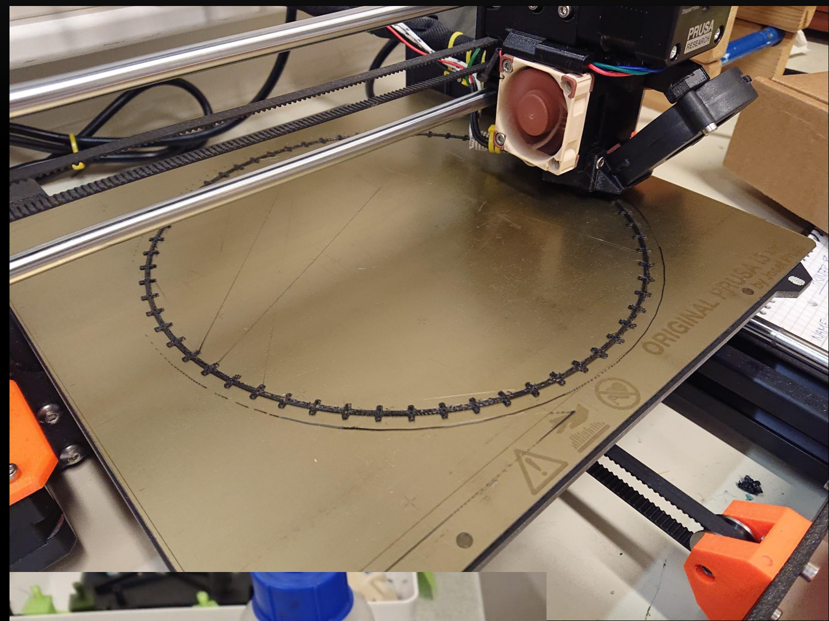


Results

1. Withstands tension very well, while still flexible enough
2. Too small clearance between track teeth and wheel teeth on printed parts
3. Central teeth not enough to avoid sideways slipping
4. Excellent traction on all test surfaces

PRODUCTION EXPERIENCES: Tracks

The tracks were made by 3D-printing. Instead of building on experiences from the previous years of the project, we decided to attempt an innovative approach and try a totally different material. Despite knowledge of the material, none of us had experience with it from before. The material is a flexible Polyurethane (TPU) 85A filament with the brand name NinjaFlex. This material is notoriously difficult to work with, and very flexible. Its flexible nature mostly rules out the use of support structures. The filament is extremely sensitive to changes in the setup, all normal 3D-printing issues are amplified.



Due to these difficulties, all track-wheel issues were resolved by altering the wheels. Despite the troubles, the final tracks turned out better than expected. By choosing a maximum track length that fit exactly inside the printer volume, each track could be made in one continuous piece. No gluing or assembly. Once the print succeeded, the tracks turned out both strong and flexible. Their traction on all test surfaces appeared to be as good as or better than all other tested solutions.

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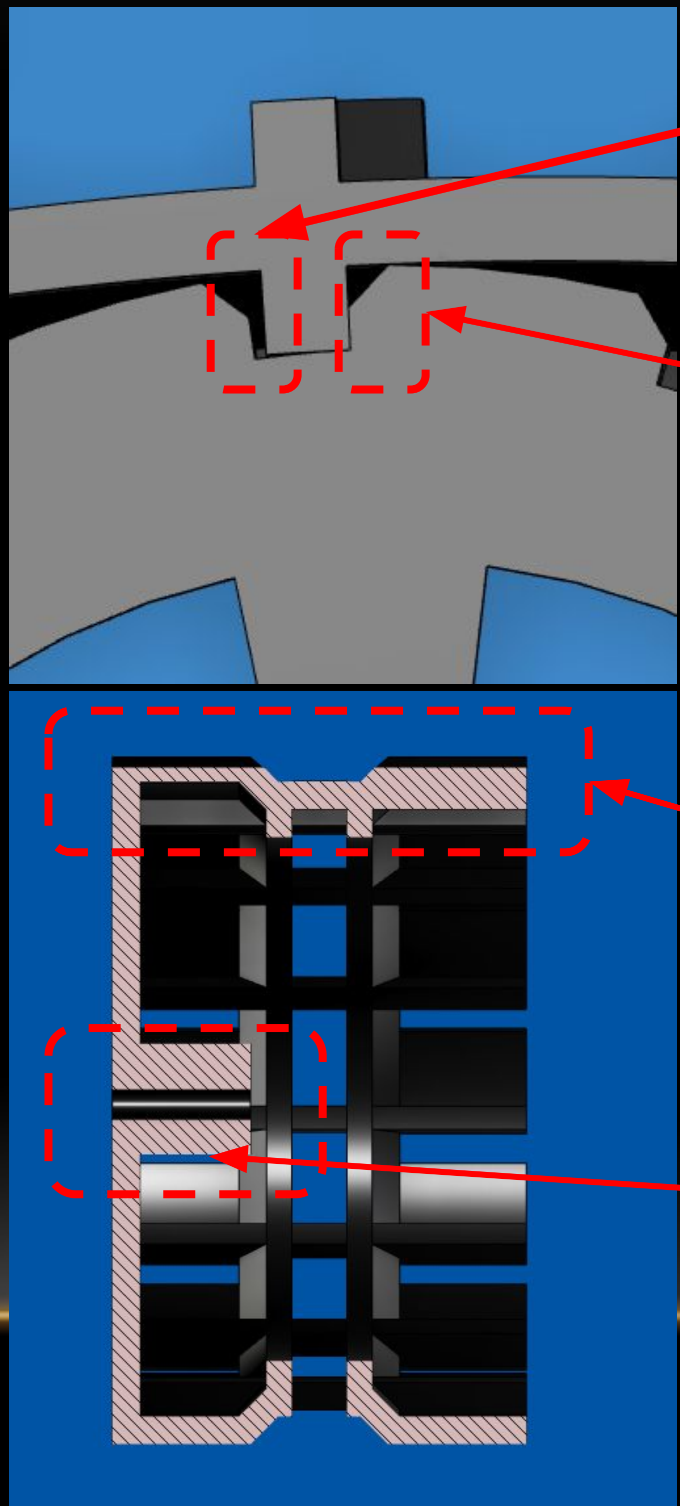
COMPONENTS INVESTIGATION: Drive wheels

Prototype 1

Design goals:

- Must be able to withstand track tension
- Tracks must not slide off during sideways hill climbing
- Should preferably be quick to make due to limited 3D-printer availability

First design



Results

1. Too small clearance between track teeth and wheel teeth on printed parts
2. Chamfer increases chance of track teeth entering wheel teeth, but decreases traction
3. Tension creates too large deformations
4. Shaft hole too small due to a decision to change motor type

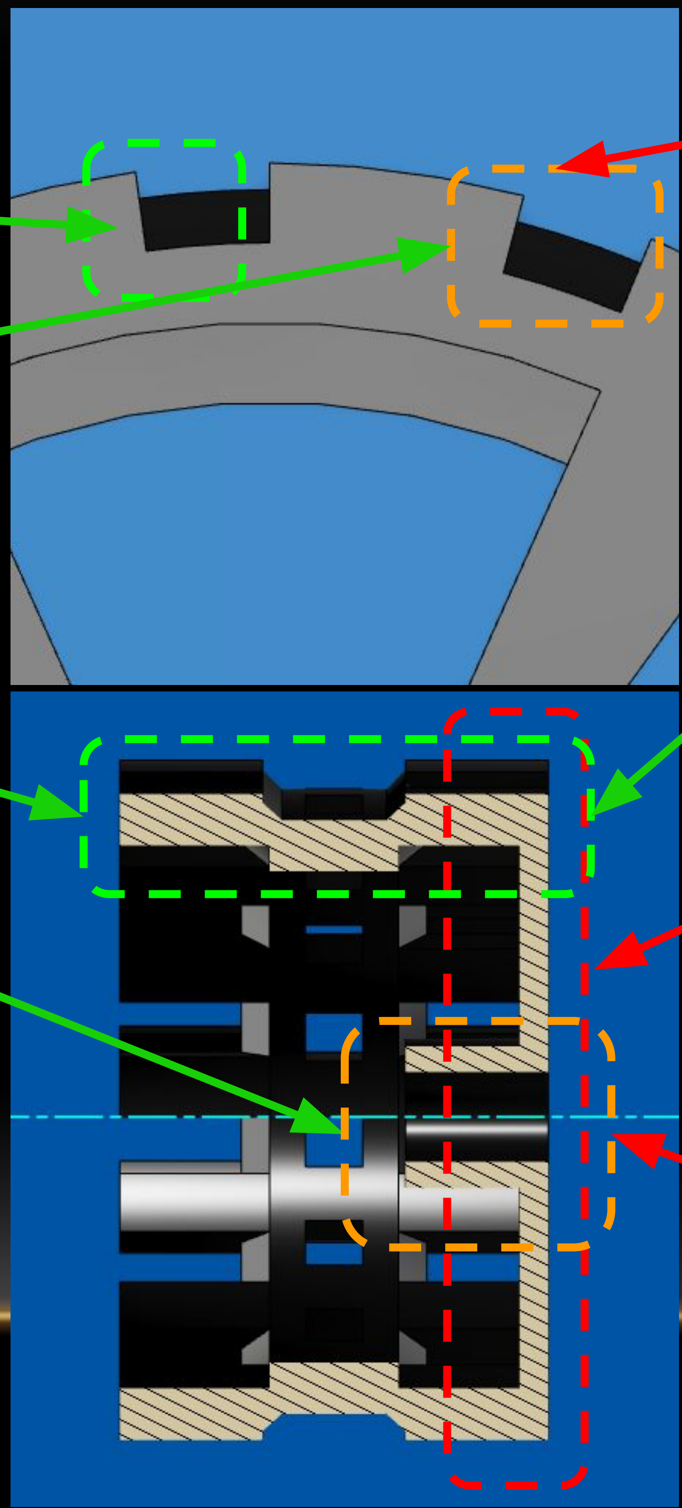
COMPONENTS INVESTIGATION: Drive wheels

Prototype 2

Improvements:

1. Chamfer removed
2. Clearances increased
3. Axial dimensions increased
4. Shaft hole changed for new motor

Second design



Results

1. Still too small clearance between track teeth and wheel teeth
2. Radial deformations reduced
3. Tension creates large axial deformation, track slides off
4. Wheel hard to mount, too small clearance

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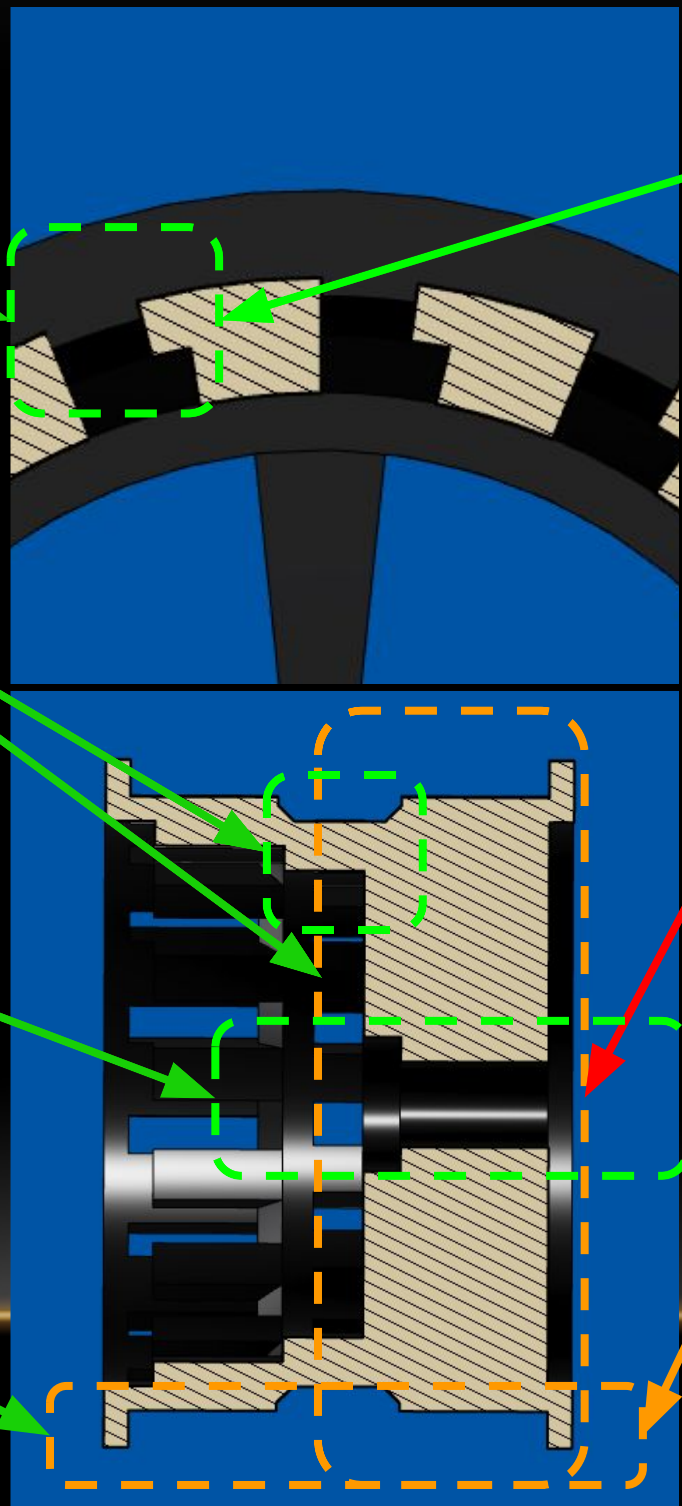
COMPONENTS INVESTIGATION: Drive wheels

Third design

Prototype 3

Improvements:

1. Clearances further increased
2. Print density and dimensions increased for reinforcement
3. Shaft clearance increased
4. Ridge added to avoid the track sliding off



Results

1. Traction between track and wheel perfect, teeth engage
2. Deformations decreased, but still a problem
3. Track stays much longer on, but still slides off
4. Perfect shaft fit, no tools required for assembly

COMPONENTS INVESTIGATION: Free wheels

First design

Needs	Solution	Observations
High ground clearance	**External diameter of 80 mm.** Considering 10 mm as distance between the shaft center axis and the edge of the frame, this will be (at least) 30 mm from the ground.	**Good diameter dimension**, great ground clearance to avoid getting stuck on mars dump. Dimensions compatible with the maximum allowed dimension.
Avoid friction and losses of energy (also under tension).	**Simplest bearing mounting** on the side of the wheel. Bearing fixed by blockage both on the wheel and on the shaft.	**Bad behaviour under the tension** of the tracks (the bearing was not in the middle). **Difficulties to produce** the shaft and the wheel's fixture in the exact dimension for the circlips.

+

Non compatible with the shape of the tracks. They have central teeth that badly fit on the wheel.

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COMPONENTS INVESTIGATION: Free wheels

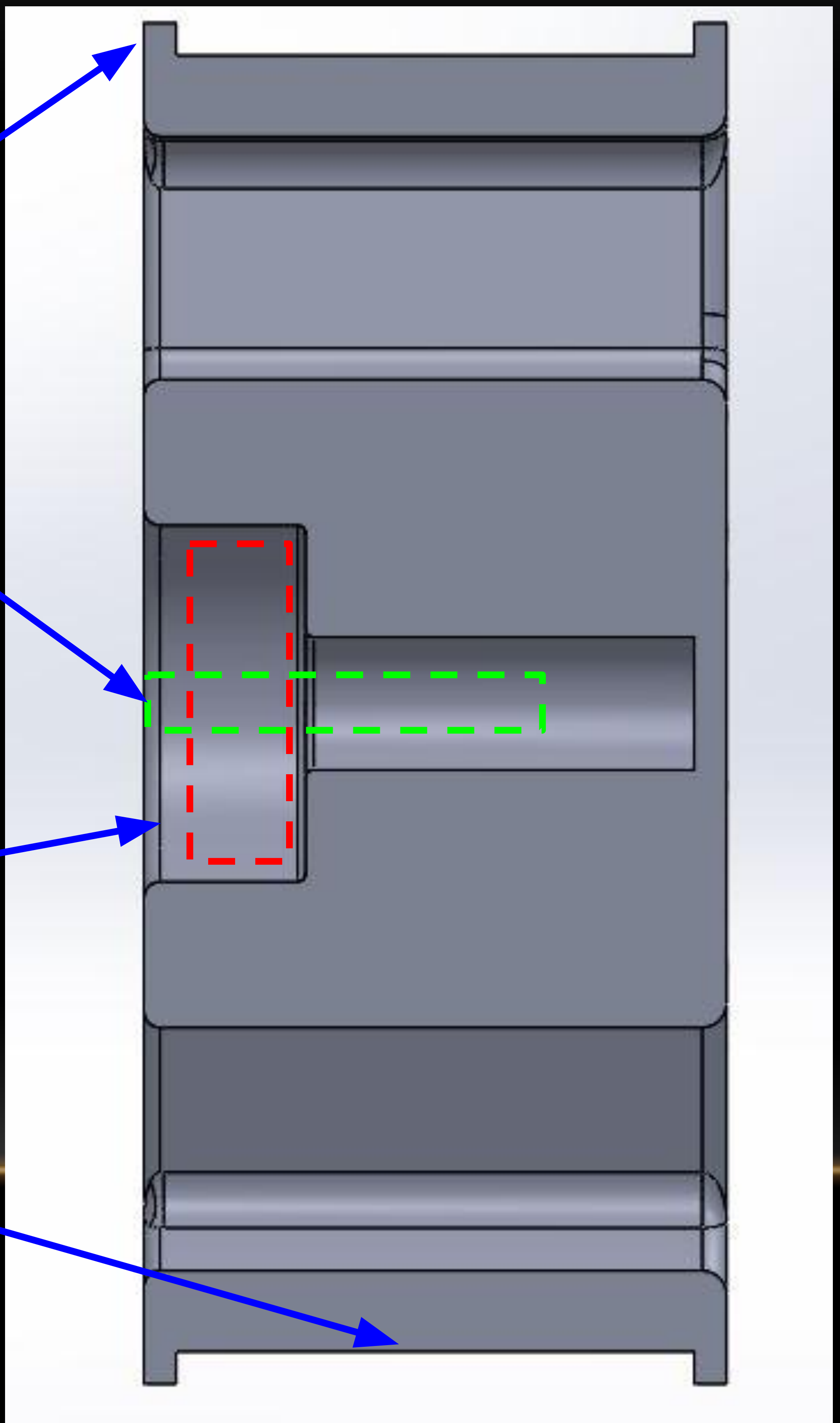
First design

Borders to keep the tracks in the right position ✔

Wheel shaft, fixed in the bearing by interference ✘

Bearing position, fixed by interference ✘

"Flat" face on the wheel ✘



The bearings

Commercial ball bearing 8x22x7

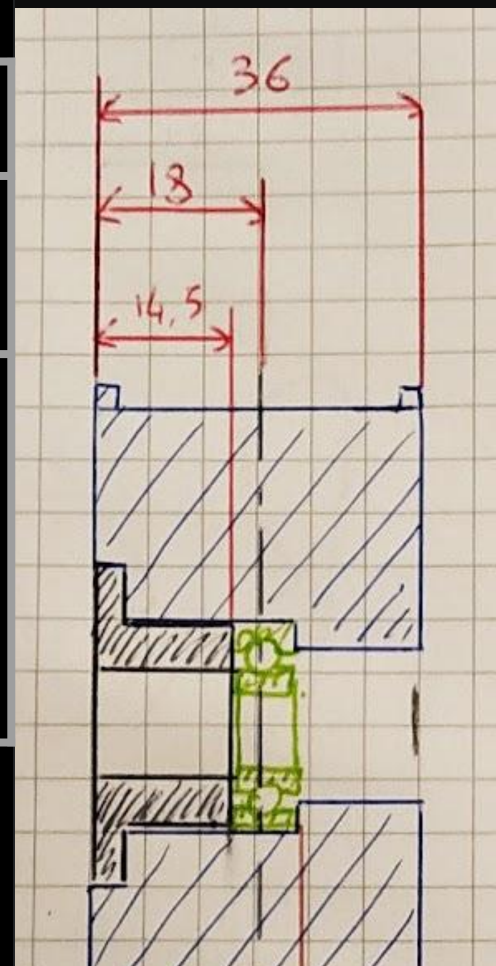
Chosen because of:

- Great availability
- Low cost
- Protected balls location (less sand issues)

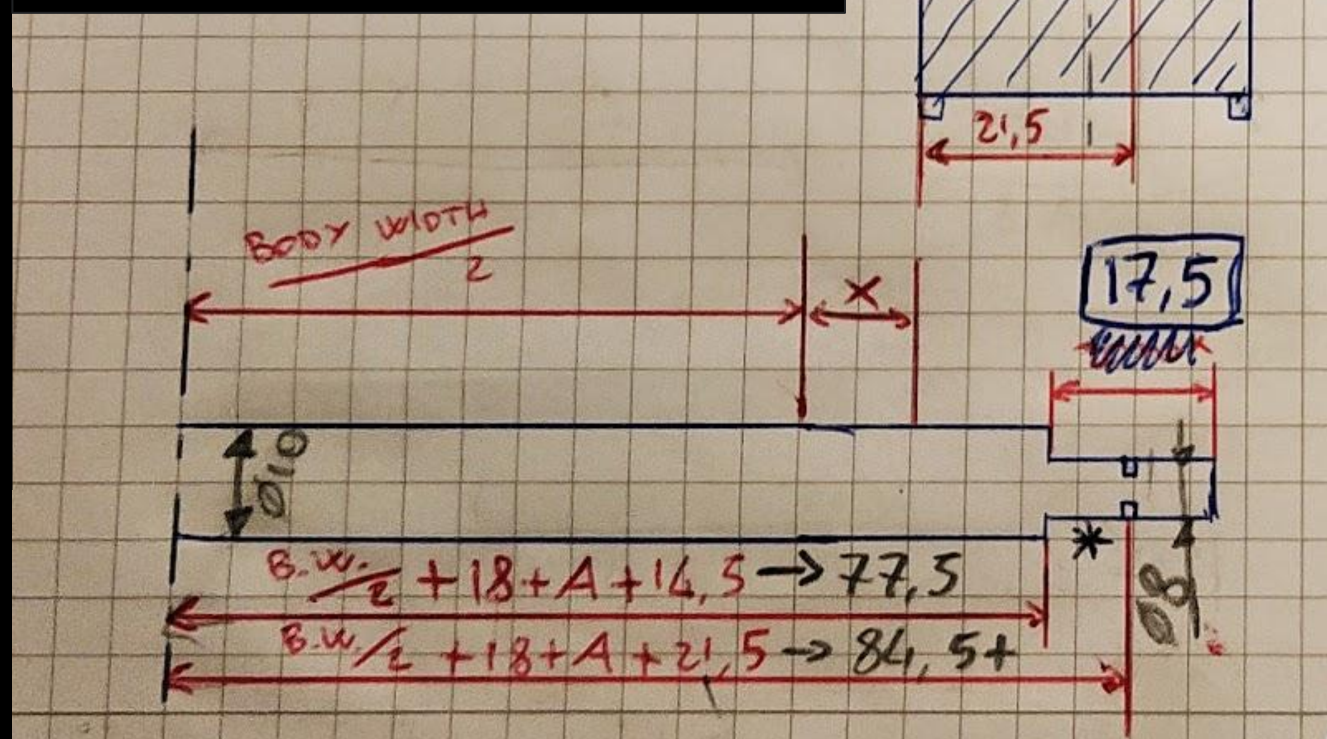
COMPONENTS INVESTIGATION: Free wheels

Second design

Issue	Solution
Presence of central teeth on the tracks	**Furrow on the external face of the wheel**. It allocates the teeth and should keep the tracks in central position.
Bad position and fixing of the bearing	**Properly designed assembly scheme for the bearing**. Central position for the bearing. Shoulder and removable support (fixed with screws) to keep it in position on the wheel. Shoulder and elastic ring to fix the position on the shaft.



***New design of the shaft:**
Considering the body width for the right dimensioning of the distances between the wheels



COMPONENTS INVESTIGATION: Free wheels

Second design

Borders to keep the tracks in the right position ✓

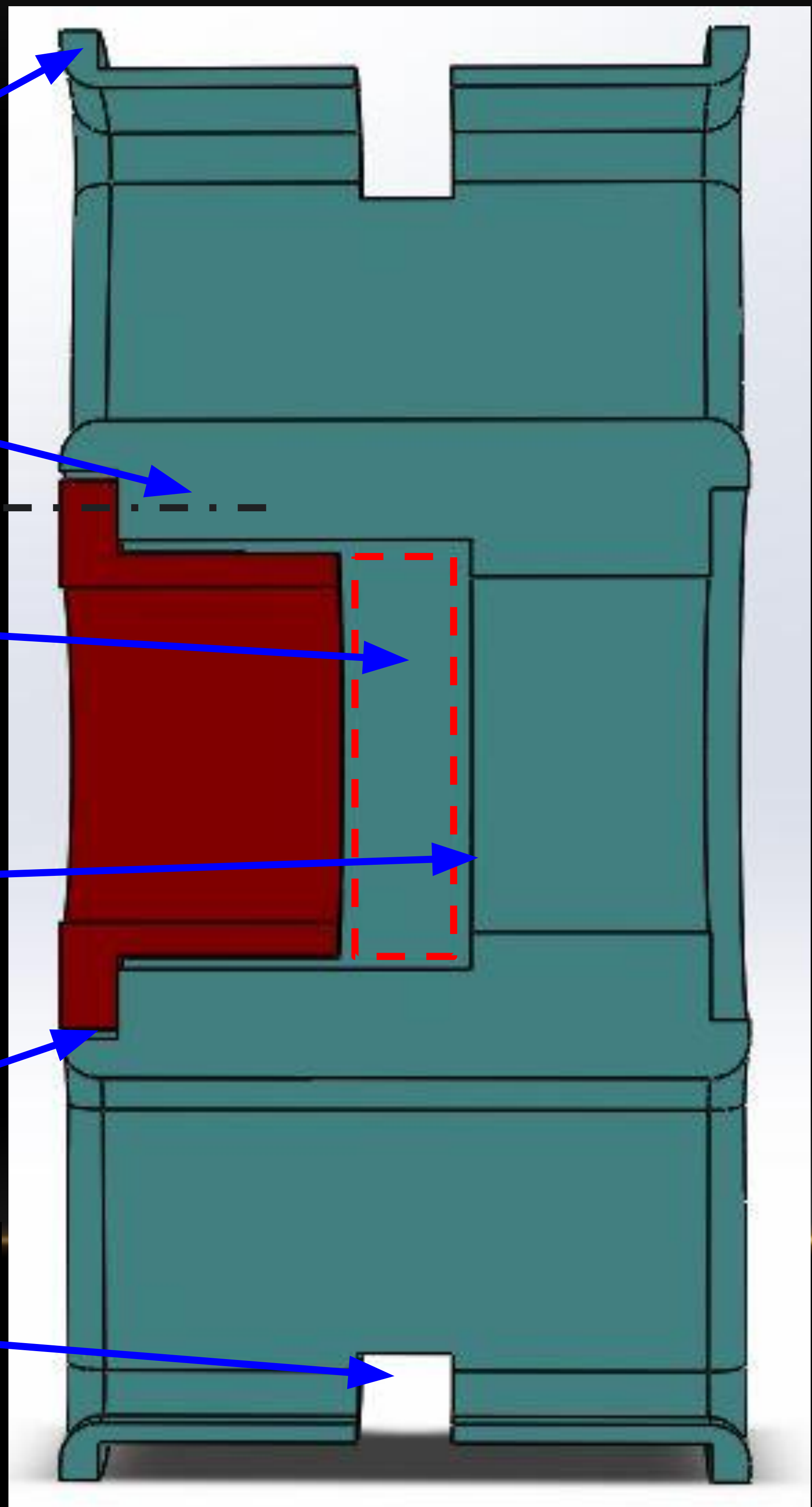
Screws to fix the bearing's support ✓

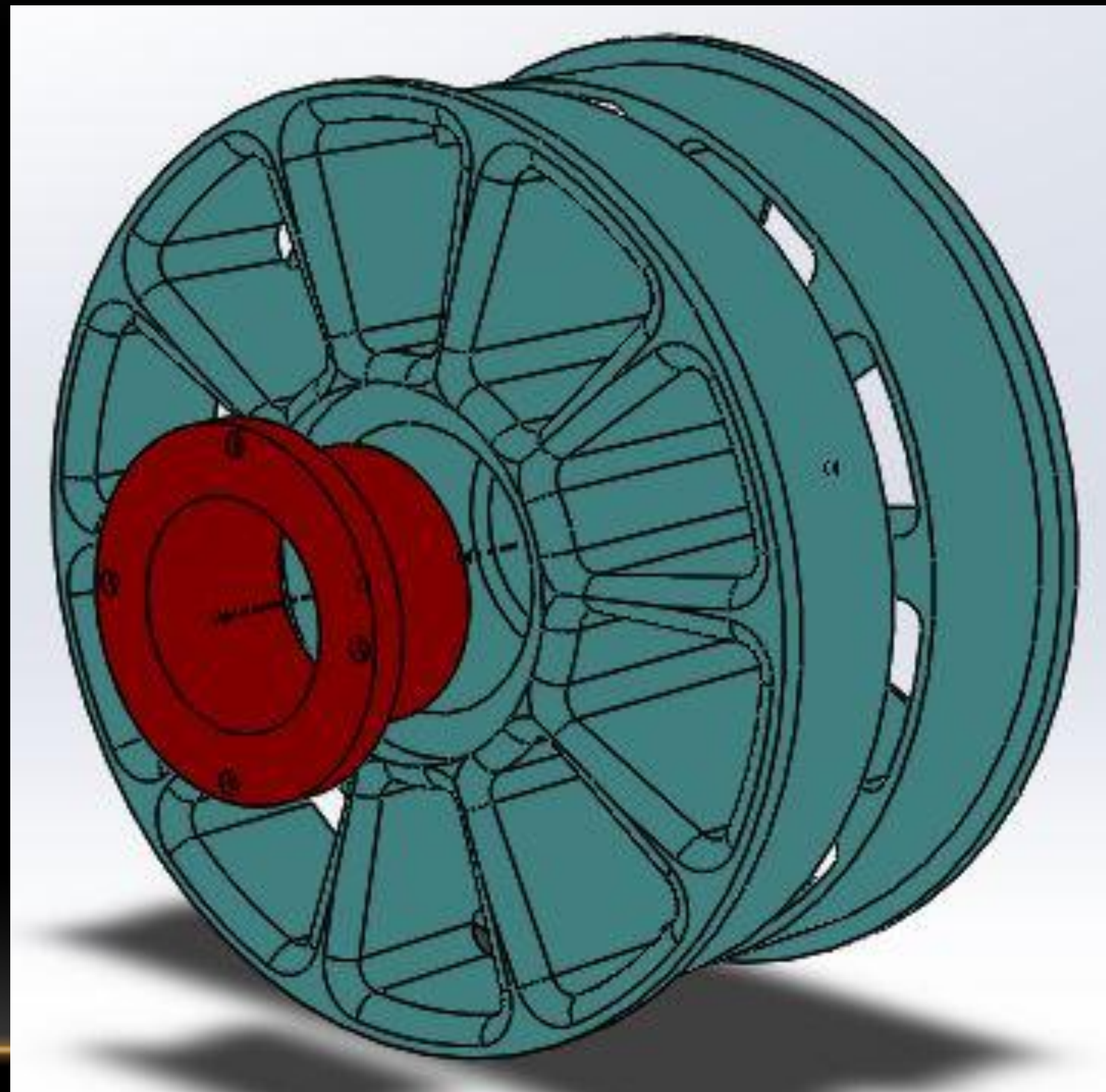
Bearing position in the center of the wheel ✓

Shoulder for bearing's end of stroke ✓

Fixing of the bearing by external support ✓

Furrow for the allocation of the tracks teeth ✓





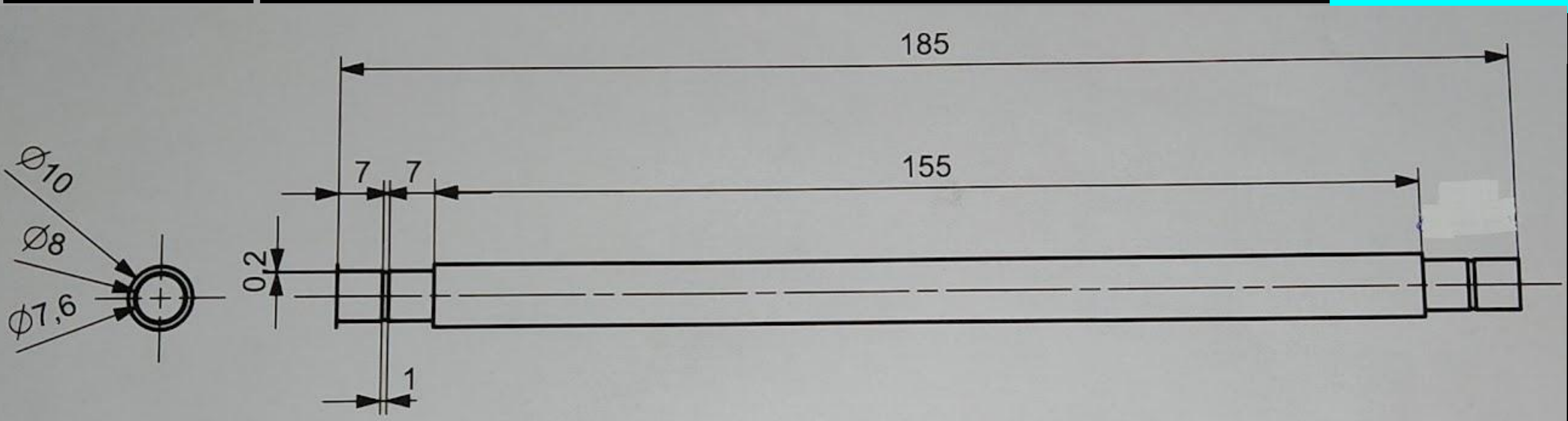
Phase 1: Vision | Phase 2: Needs | Phase 3: Concept | Phase 4: Structure | Phase 5: Production

COMPONENTS INVESTIGATION: Free wheels

Shaft design

The free wheels have to be located on two shafts (one for each axis). Due to the force applied by the rubber tracks, an high bending stability is required.

	Printed PLA	Machine-worked aluminium
PROS	• Easy to hand-work final adjustments perfectly → **3** • Can be printed directly with the frame (no assembly) → **3**	• No problems of mechanical stability → **2** • Stronger supports for bearing and elastic ring → **1** • Possible to machine with very high precision → **2** • Group member approved for using the machines → **2** • Materials available in the laboratory → **2**
CONS	• Lower mechanical stability (for equal diameter) → **-2** • Less precision in final dimension (deforming while plastic cooling) → **-1** • Risk of aborted printing (waste of time) → **-1**	• Difficult to hand-work for final adjustments → **-2** • Needs design of supports on the frame → **-1**
	2 PT	**6 PT**

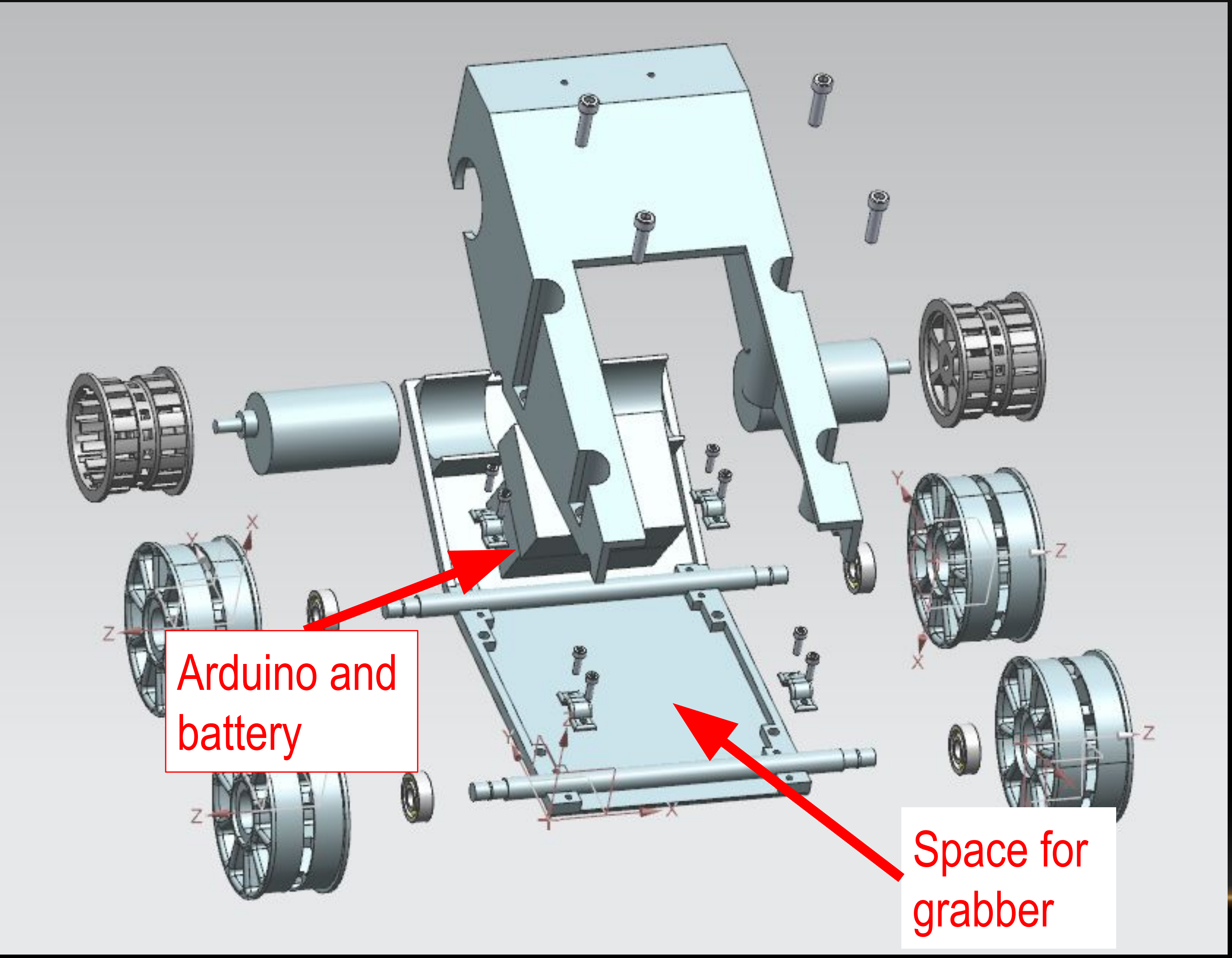


For the right dimensioning of the shafts it is necessary to take into account the design of the frame and the maximum dimensions of the rover.

The length of the shaft is fixing definitely the distance between the wheels!!

Phase 1: Vision | Phase 2: Needs | Phase 3: Concept | Phase 4: Structure | Phase 5: Production

COMPONENTS INVESTIGATION: Frame



The triangular shape worked well in the proof of concept and was therefore chosen.

Advantages:

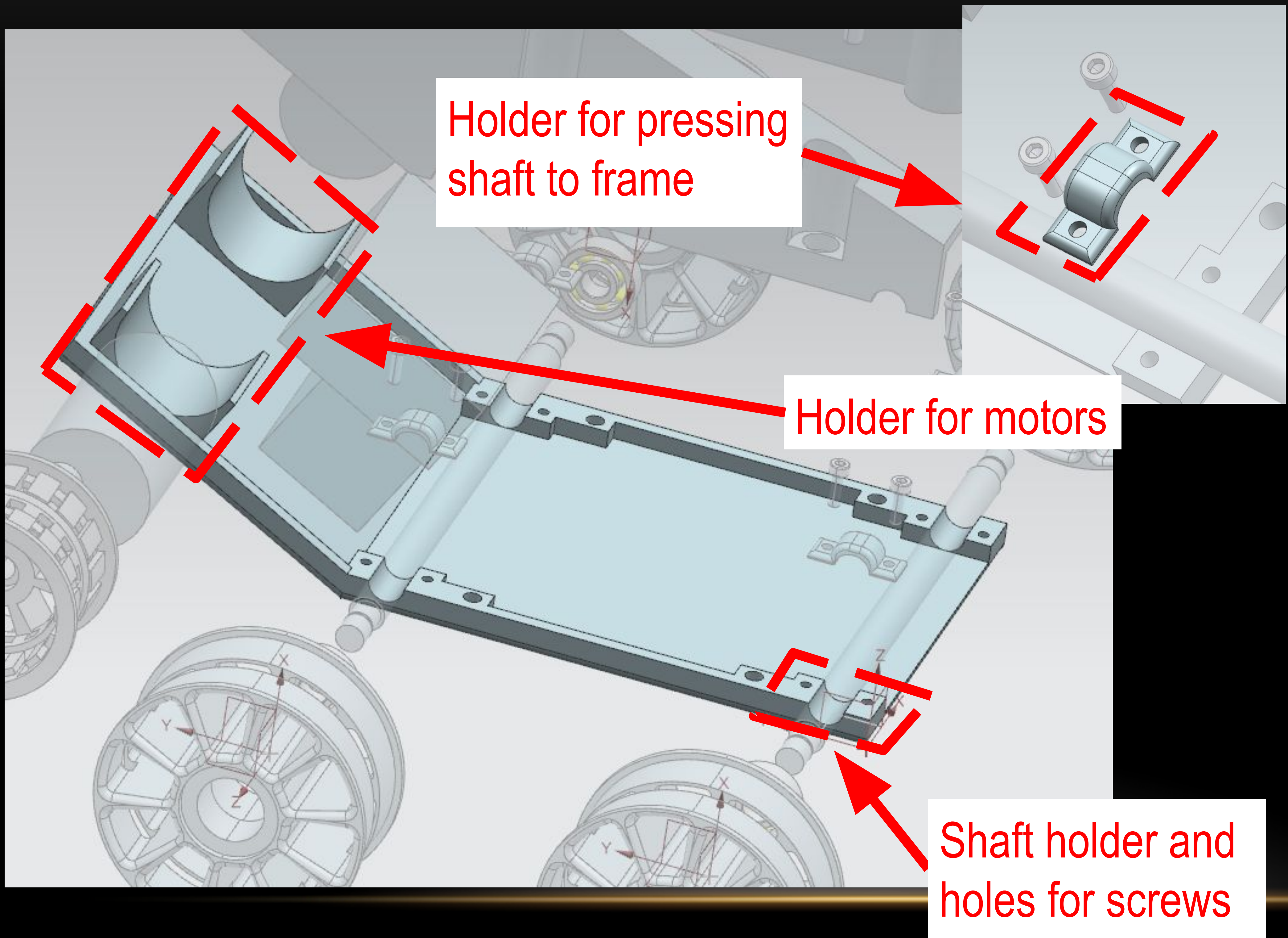
- Weight in front part of rover makes it easier to climb hills and drive over steps
- Continuous tracks allow driving over almost any kind of surface

Adaptions implemented:

- Higher ground clearance
- Translation between drive wheel and free wheel needs to be larger in order to create a larger torque

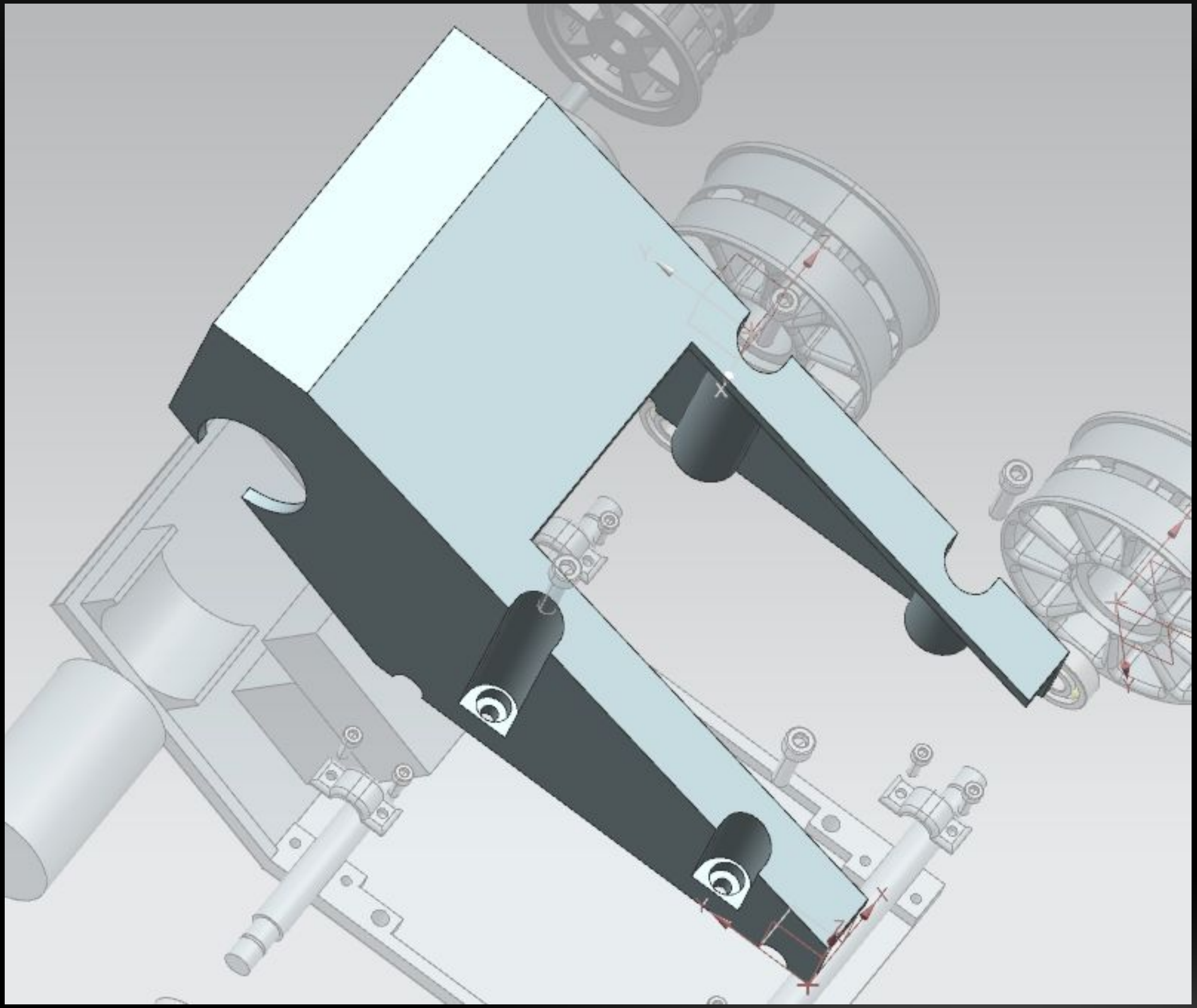
Phase 1: Vision | Phase 2: Needs | Phase 3: Concept | Phase 4: Structure | Phase 5: Production

COMPONENTS INVESTIGATION: Frame



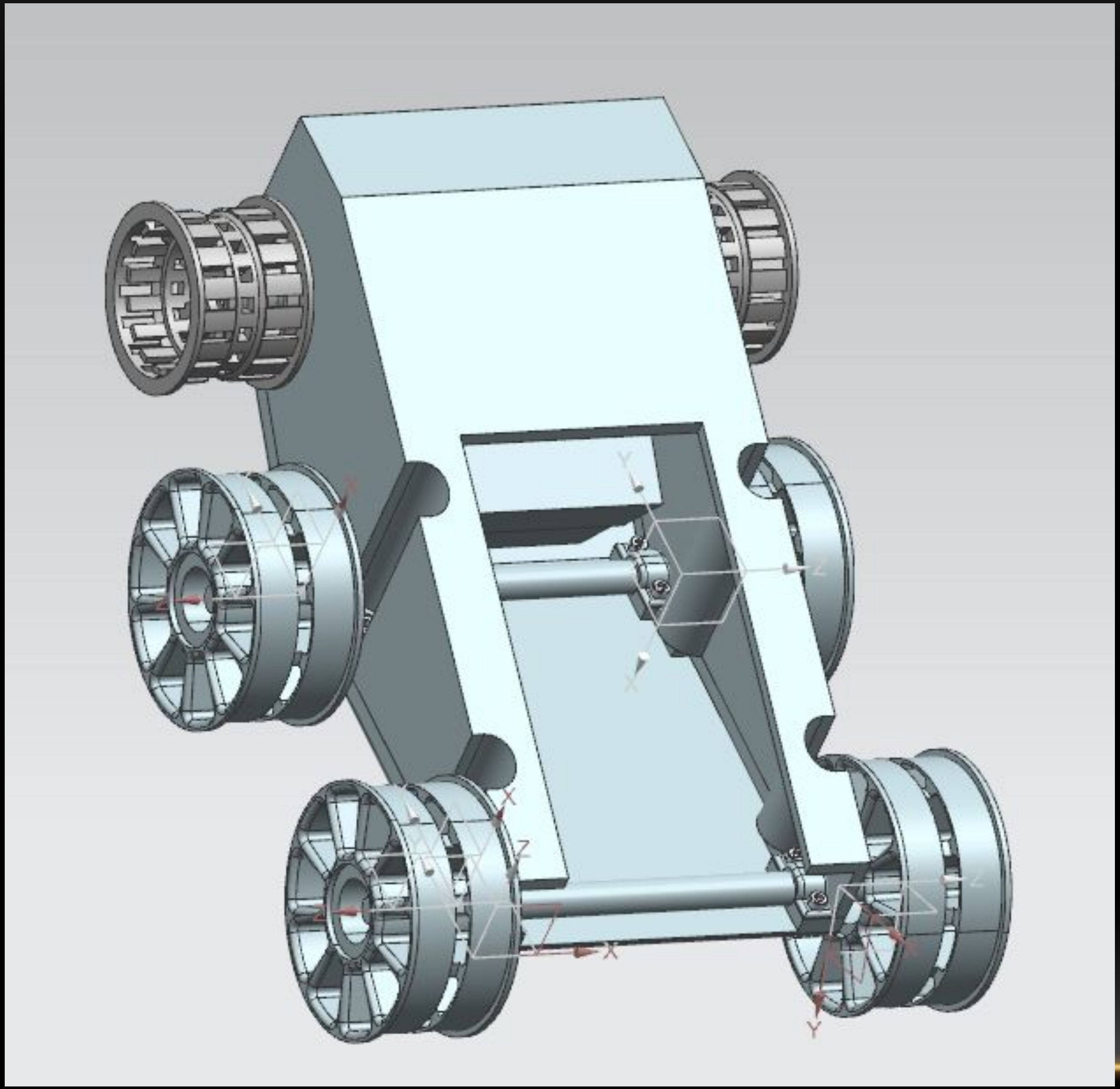
The down part of the frame is the most important part of the frame. An axel (or standing shaft) is used in order to prevent big moments and deformations on the connection to the wheels. The motors are fixed to the frame with straps, distributing the centre of weight more to the front. The front part leaves space for the arduino and the batteries too while the back is reserved for the grabber. The screws carve them selves into the plastic, so no further screw nuts where needed.

COMPONENTS INVESTIGATION: Frame



The upper frame keeps the electronics inside of the grabber and protects it from sand. It is also holding the servo and camera in place. Screws are used to fix it to the down part of the frame. The hole in the back leaves space for the grabber.

COMPONENTS INVESTIGATION: Frame



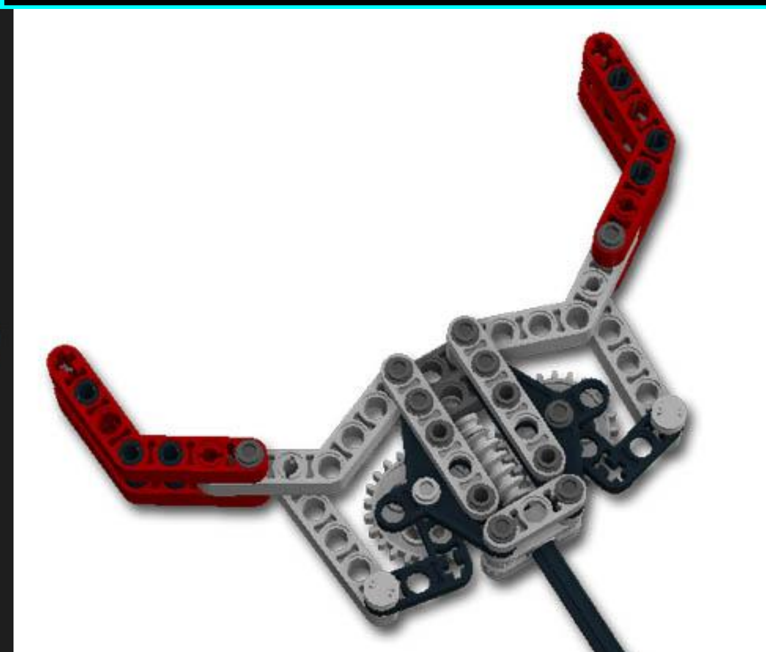
The right proportions were approximated by the height of the steps necessary to climb as well as the size of the wheel. Both frame parts were printed of PLA. Some adjustments after the print were necessary due to the difficulty of fitting all the components into the rover.

Phase 1: Vision | Phase 2: Needs | Phase 3: Concept | Phase 4: Structure | Phase 5: Production

COMPONENTS INVESTIGATION: Grabber

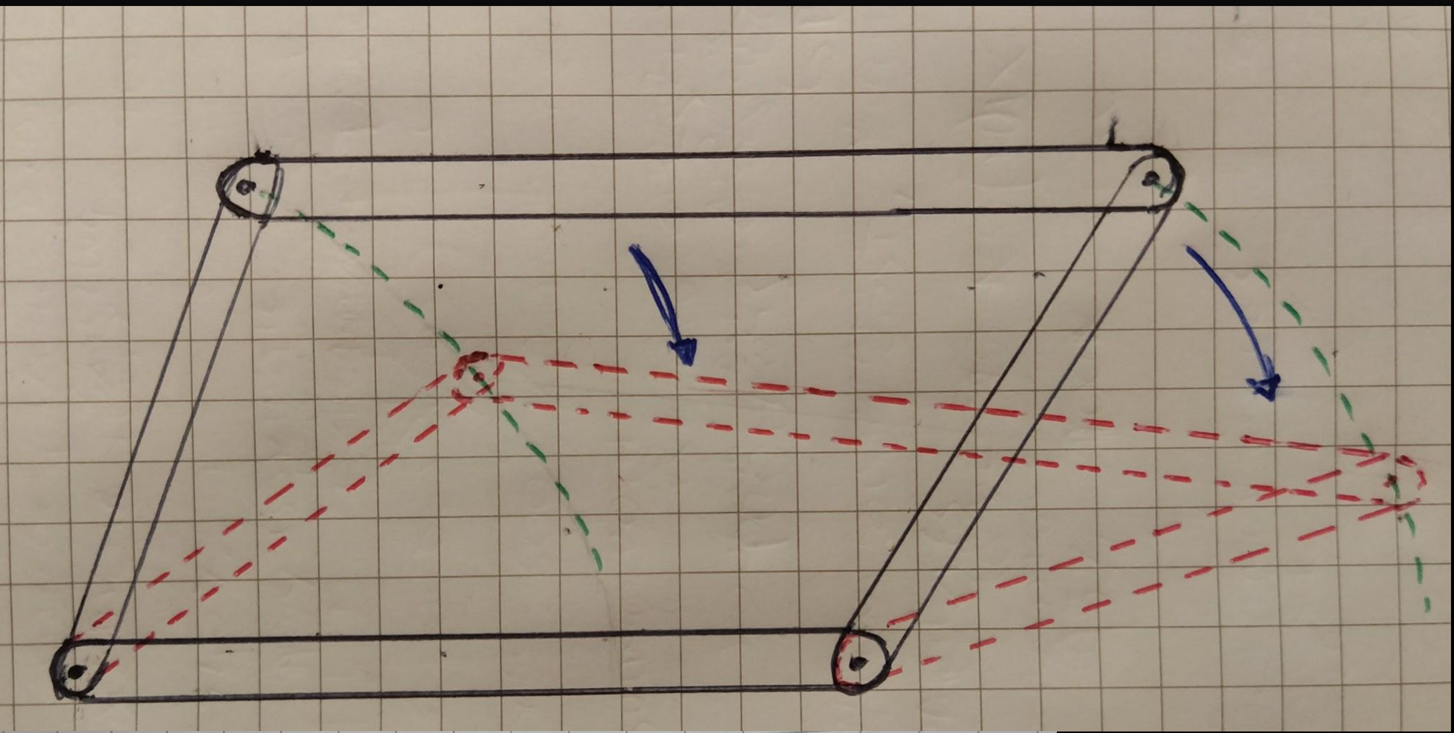
Structural design

NEEDS	Industrial-made grabber ❌	3D designed and printed ❌	LEGO-made ✓
• **Low cost** • **Big availability** (no shipment) • **Structural stability** • **Fast to build** (running out of time)	+ No working issues (hopefully) + Good strength and stability + Less space requirement - High cost (relatively) - Long lead time - Project slowdown (due to long lead time)	+ Easier to adapt to the frame + Almost unlimited number of shapes + Zero-cost - Long design and printing time required - Risk of printing failure - No future adjustments	+ Zero-cost + Recycle (second-hand material) + Possibility of disassemblement after use + Fast to build - Structure has to be adapted to the available components - More space requirements - Working-time needed for assembly



COMPONENTS INVESTIGATION: Grabber

Structural design

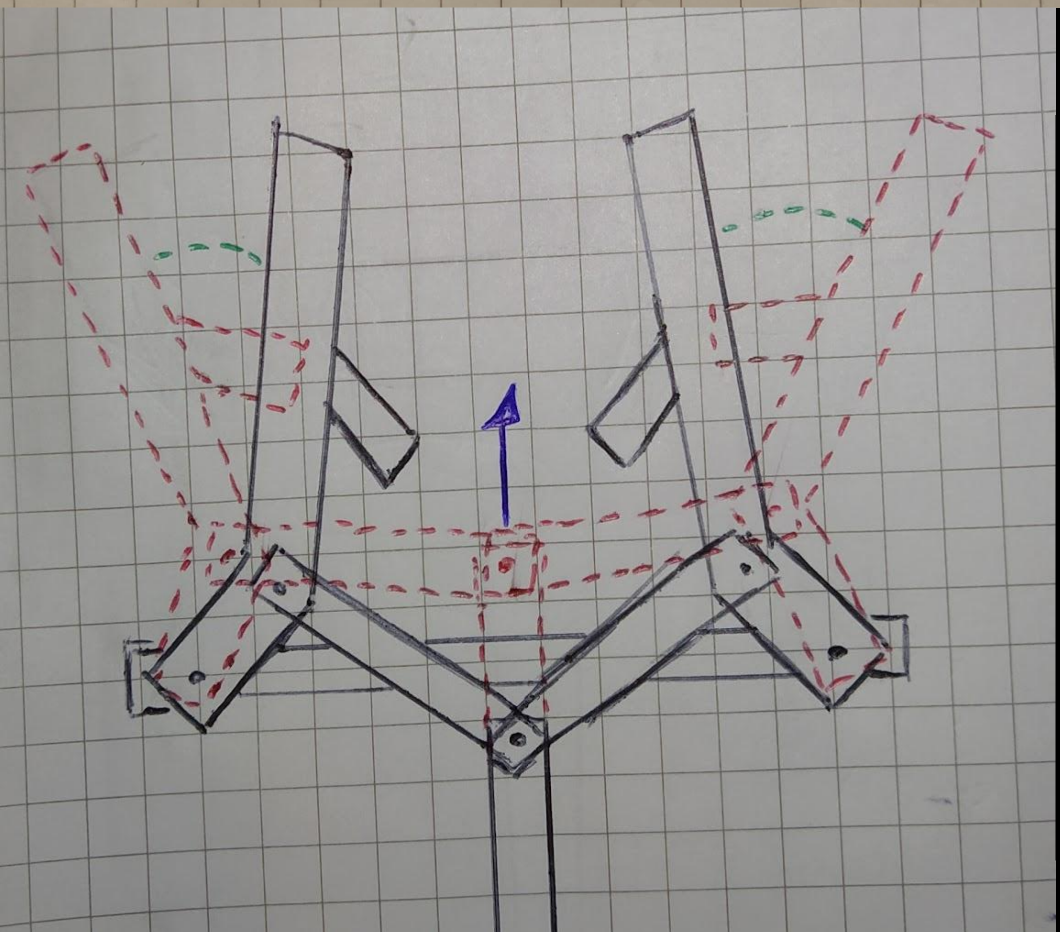


LIFTER:

- **Needs to lift the object from the ground**

→ FOUR BAR MECHANISM

We are able to lift the object and at the same time take it inside/near the rover. This allows us to have less influence on the rover's behaviour (center of gravity, climbing ability…).
Connection link longer than fixed support, we also have inclination to the ground when the grabber is out.



CLAW:

- **Syringes are more stable when pulling** (from soft-prototype)

The claw is designed for taking the object when the linear actuator is pulling. It is designed thinking mainly on how to grab the object from the test

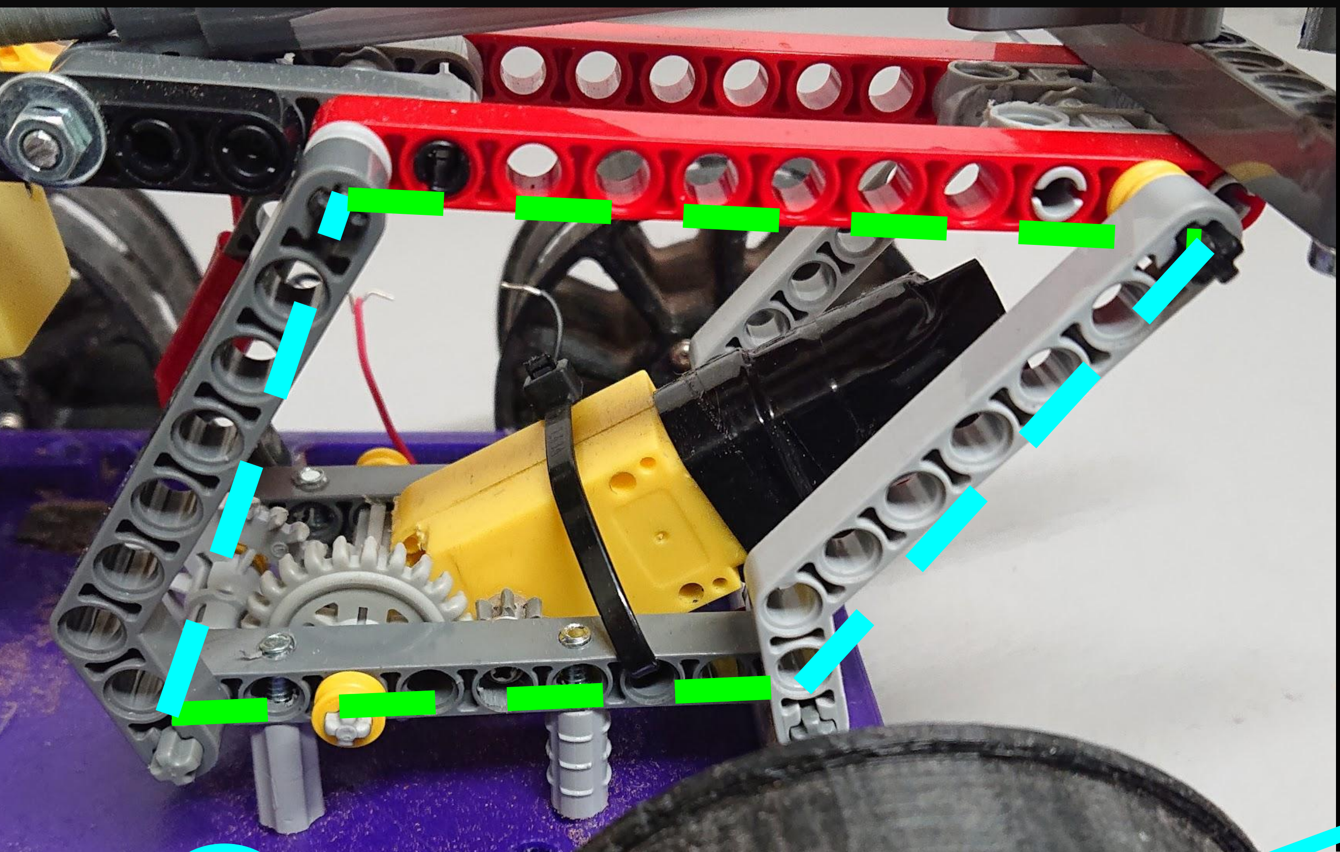
→ We could have difficulties grabbing other type of objects

THE FINAL DESIGN OF THE GRABBER IS DRIVEN BY THE AVAILABILITY OF THE DIFFERENT TYPES OF COMPONENT IN THE LABORATORY!

Phase 1: Vision | Phase 2: Needs | Phase 3: Concept | Phase 4: Structure | Phase 5: Production

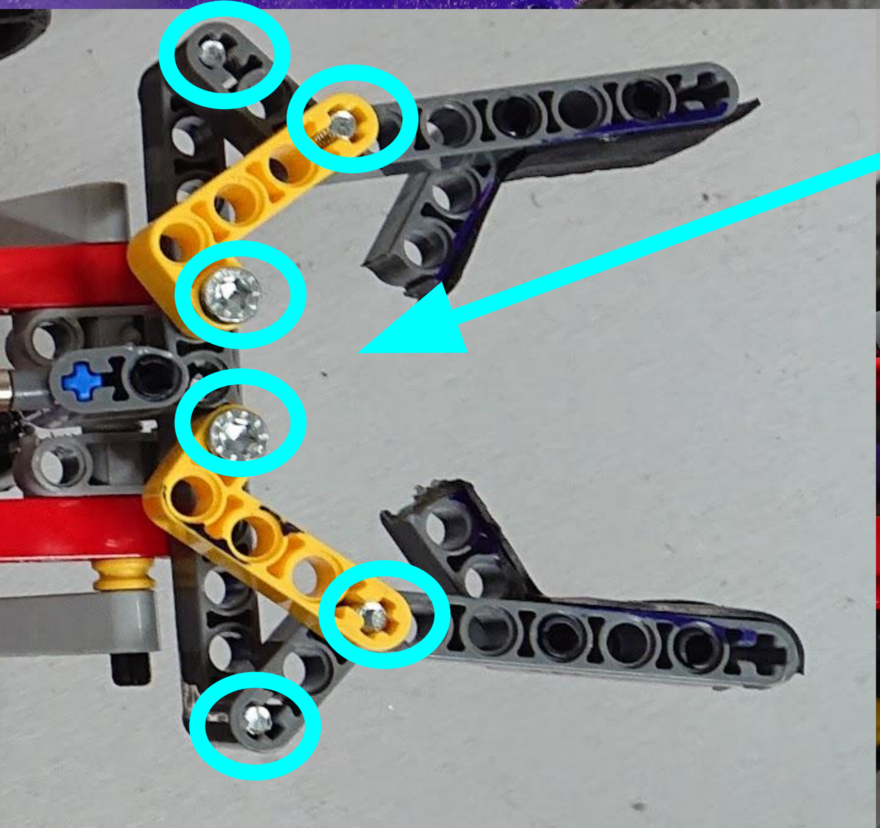
COMPONENTS INVESTIGATION: Grabber

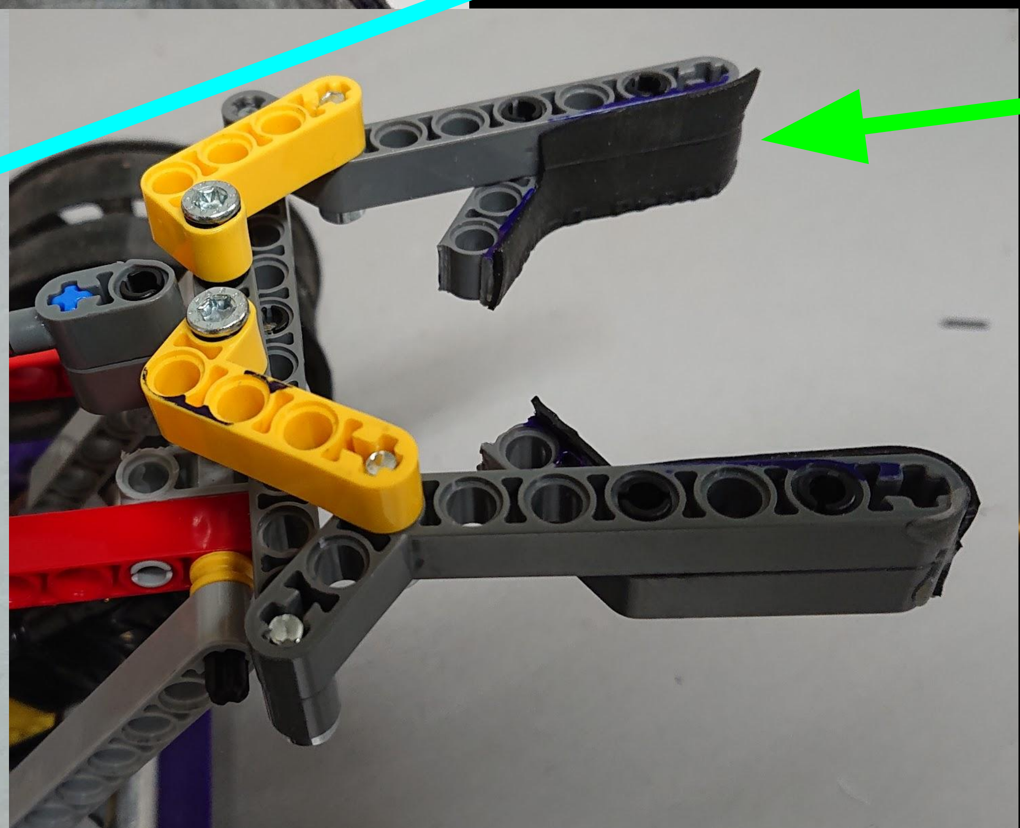
Structural design



Structure of the 4 bar mechanism for the grabber. Detailed structure, size and shape given by the availability of components and compatibility with frame/object

LEGO connections are too weak to resist on the weight of the object. **Original connectors replaced by screws**





Rubber to improve the friction and the grip on the object

Final claw. It is designed for having the best grip on the test object when the object is upright. Other orientations might be pose difficulties.

Phase 1: Vision | Phase 2: Needs | Phase 3: Concept | **Phase 4: Structure** | Phase 5: Production

COMPONENTS INVESTIGATION: Grabber

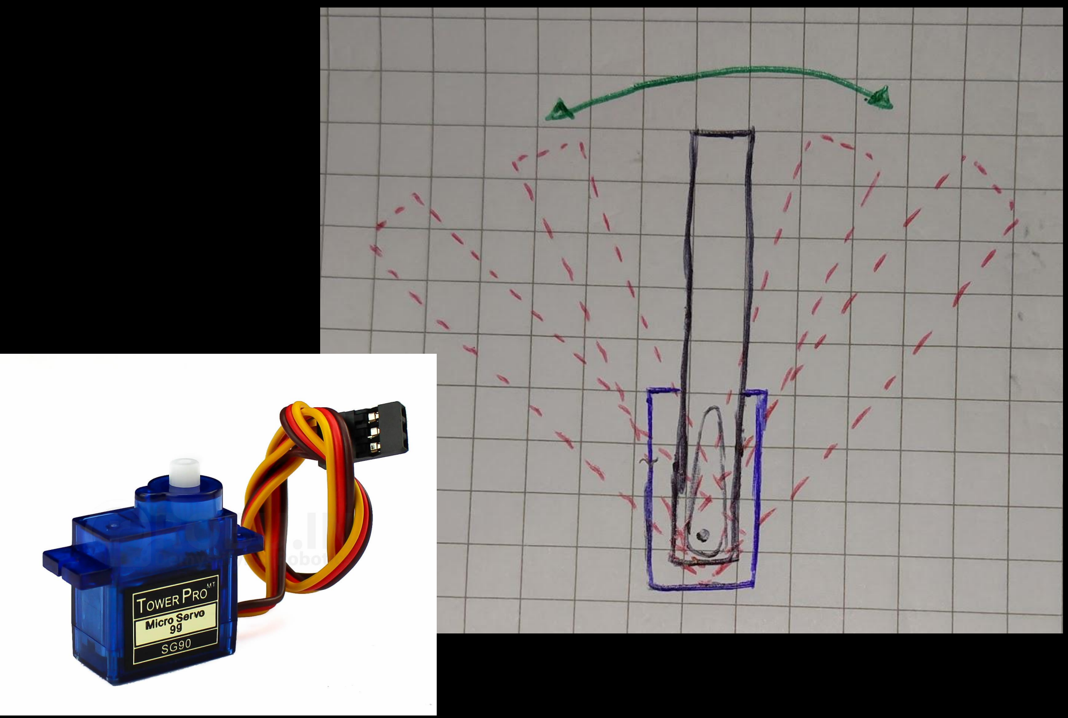
Actuators design: position

To lift/move the object it is necessary to apply a torque on one (or more) of the inclinable arms.

I. Servo motor directly applied on the arm ❌

→

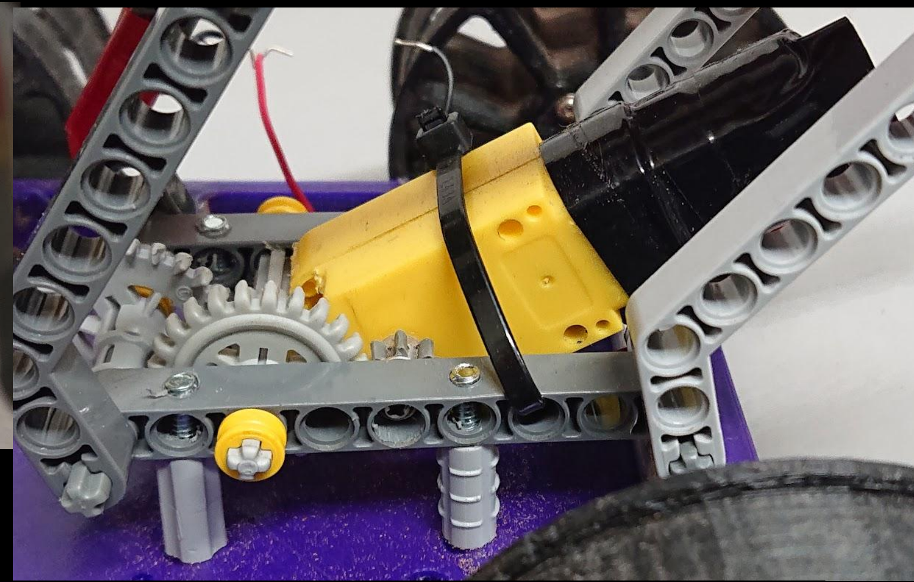
II. DC motor with reduction gears ✔



Easiest way to apply a torque on the shaft.

Too weak to move the grabber when lifting the object.

- \+ stronger/bigger servo not available in the lab
- \+ Save time and money if possible



A DC motor is transmitting the torque to the shaft connected with the arm. The integration of lego components (gears) and general DC motor requires good inventiveness and practical skills. Gear trains with a free connection axis are used for the reduction of the transmission ratio.

WITH THIS ACTUATION WE LOSE THE CONTROL OF THE ANGULAR POSITION, THE DRIVER WILL CHECK IT MANUALLY WITH THE CAMERA!!

Phase 1: Vision | Phase 2: Needs | Phase 3: Concept | **Phase 4: Structure** | Phase 5: Production

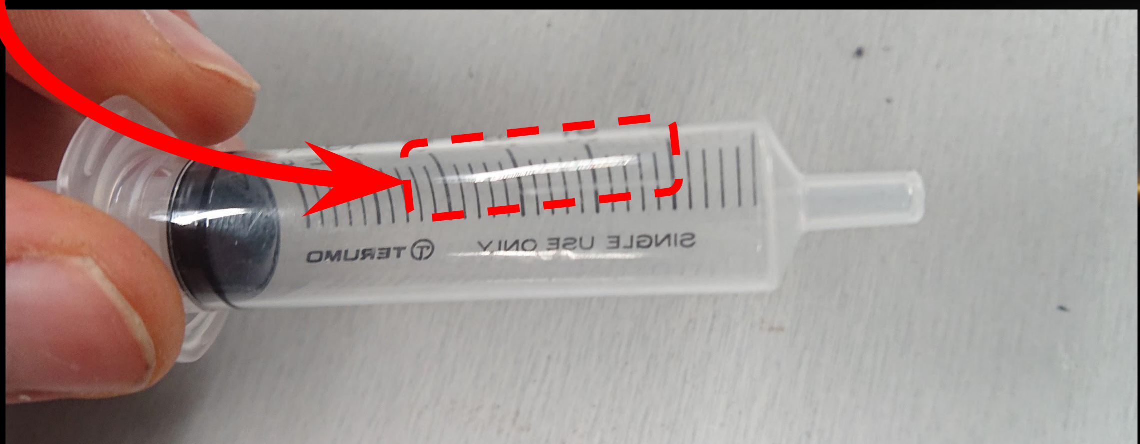
COMPONENTS INVESTIGATION: Grabber

Actuators design: claw

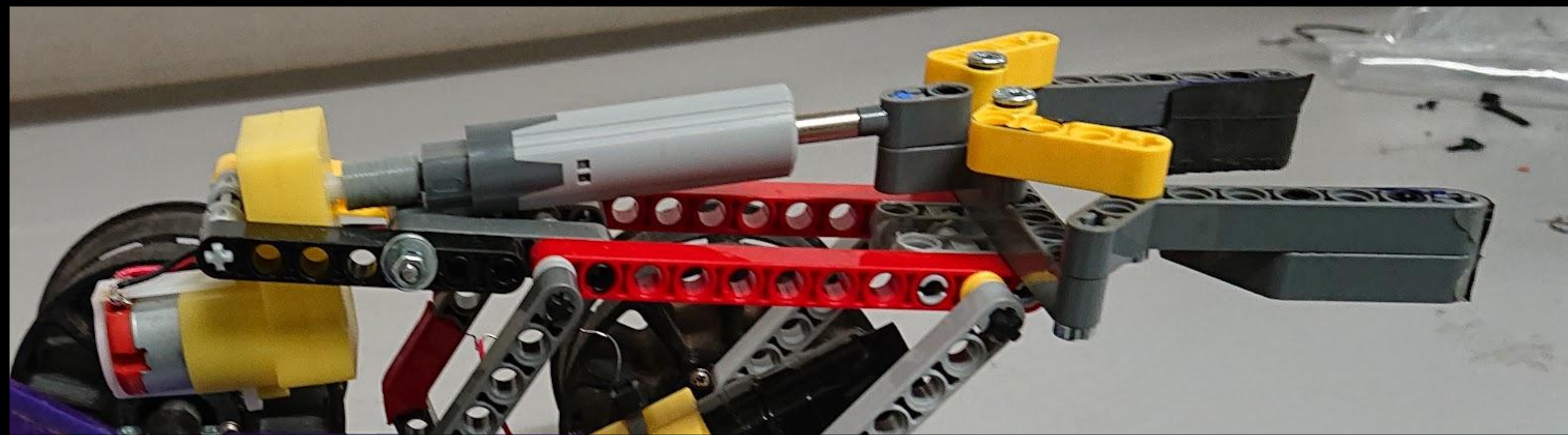
I. Hydraulic control ❌

As in concept design, hydraulic control performed by plastic syringes used as hydraulic cylinders. Syringe fastened with zip-ties. Main cylinder and motor placed inside the rover close to the center of gravity for stability.

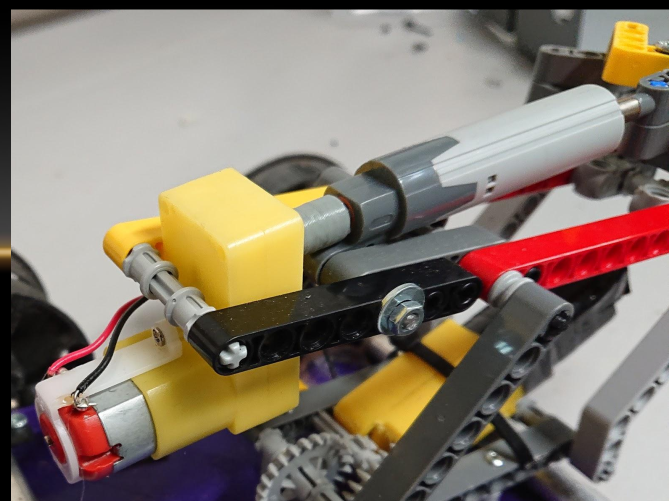
- Grabber structure bigger than expected, **little space inside the rover.**
- **Cylinder cracked under tension from zip-ties**. Syringes not structurally strong enough to withstand grabber loads.

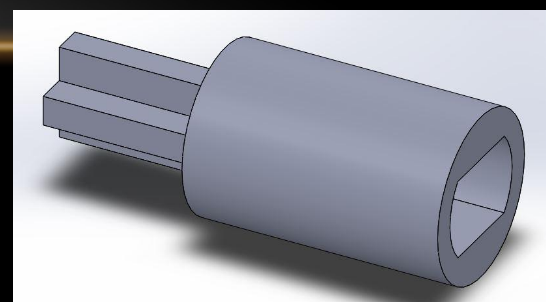


II. Electric control ✔



General DC motor connected to a lego component working as a ball nut screw. The big reduction ratio provided by the gears on the motor and by the linear actuator allows the small motor to apply a good force on the claw. The grip on the object is good. We lose the advantages of the hydraulics, but we save space in the rover, and the result is a reliable solution for our purpose.





A connection element between the motor and the actuator is needed

Phase 1: Vision | Phase 2: Needs | Phase 3: Concept | **Phase 4: Structure** | Phase 5: Production

COMPONENTS INVESTIGATION: System control

Remote Control

<u>Potentiometer : Channel 5</u>
Turning the camera

<u>Switch : Channel 6</u>
Select between "driving" or "manipulating"

<u>Horizontal Joystick : Channel 4</u>
Turning right and left (on-site)
Opening and closing the pliers of the grabber

<u>Vertical Joystick : Channel 2</u>
Going forward and backward
Moving the grabber outside and inside the rover

Phase 1: Vision | Phase 2: Needs | Phase 3: Concept | **Phase 4: Structure** | Phase 5: Production

COMPONENTS INVESTIGATION: System control

Arduino Code

The arduino code includes 4 main parts :

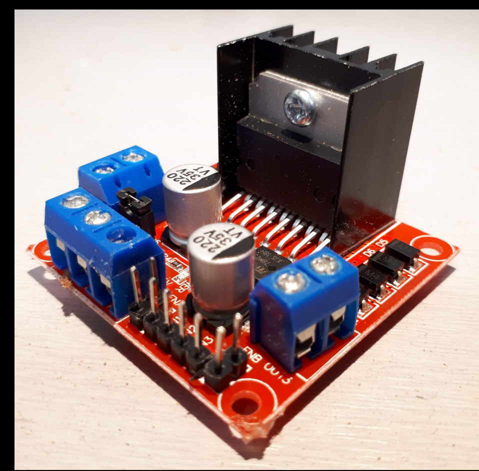
1. All the useful functions for analyzing the signal received by the receiver module
2. One part for driving the rover (going forward/backward & turning left/right)
3. One part for manipulating the grabber (inside/outside the rover & open/close the pliers)
4. Controlling the angle of the camera (basic code for controlling a servo)

4 DC motors are included in the rover in order to move it (2 for driving and 2 for manipulating the grabber). Those motor are all controlled with PWM command (with H-bridge)

```
speedMotor = map(rc_values[RC_CH2], 950, 2000, -150, 150);

if (speedMotor>40){ //drive forward
  digitalWrite(RIGHT_M_1, LOW);
  digitalWrite(RIGHT_M_2, HIGH);
  digitalWrite(LEFT_M_1, LOW);
  digitalWrite(LEFT_M_2, HIGH);
  analogWrite(PWM_M, speedMotor);
}
if (speedMotor<-40){ //drive backward
  digitalWrite(RIGHT_M_1, HIGH);
  digitalWrite(RIGHT_M_2, LOW);
  digitalWrite(LEFT_M_1, HIGH);
  digitalWrite(LEFT_M_2, LOW);
  analogWrite(PWM_M, speedMotor*(-1));
}
```

For example, here we are controlling the forward/backward movement. Usually, the PWM value is included between 0 and 255 but here, 255 was to fast for our this motion, so the new PWM values were included between 0 and 150. The PWM is here influenced by the signal receiving from the remote controlled. Thus, we are able to control the speed for the forward/backward motion.



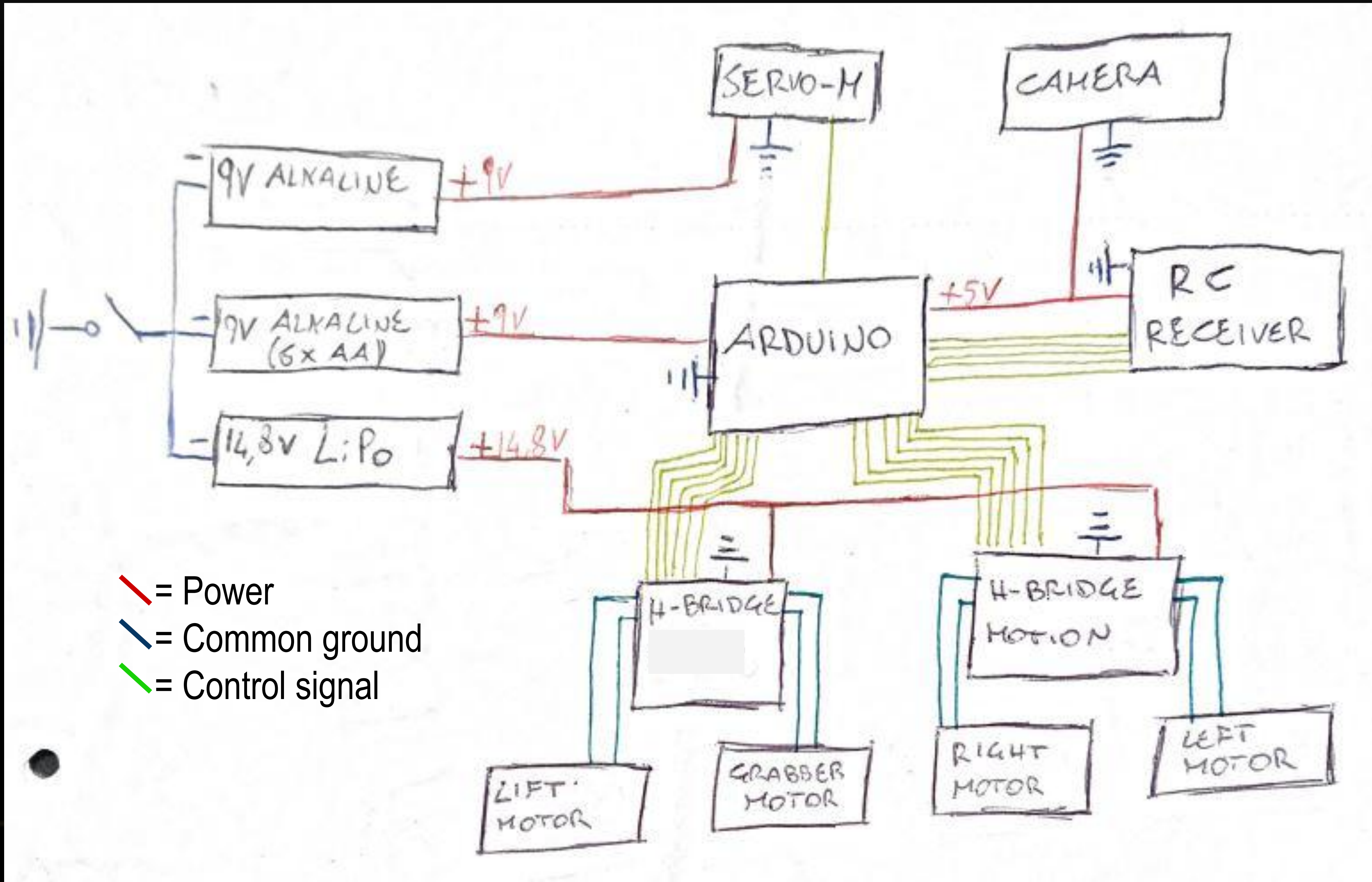
H-bridge used on the rover

COMPONENT CONNECTION: The electrical system

The different electronic devices have to be connected with a relatively simple electrical system. It is possible to distinguish between the "control system" and the "power system". The main difference is the current driven by the circuit (much higher for the power system). Due to the different power voltages it is also necessary to power the components with different supplies (the easiest way is to use different batteries). Different power supplies are connected to a common ground, using a switch on the ground it is possible to open all the circuit and turn off the rover.

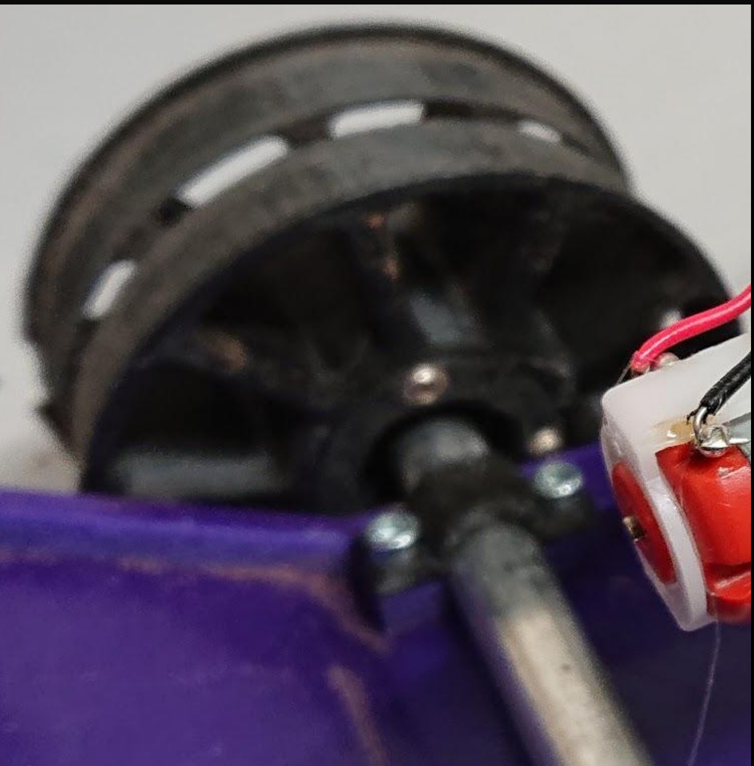
COMPONENT	INPUT(S)	OUTPUT(S)	VOLTAGE
Arduino	6x Analog (from RC)	8x Digital (4 to each H-bridge) 5x PWM (2 to each H-bridge + 1 to servo)	5V - 12V
Motion H-bridge	4x Digital (from arduino) 2x PWM (from arduino)	4x Power output (to motion motors)	12V (high current)
Grabber H-bridge	4x Digital (from arduino) 2x PWM (from arduino)	4x Power output (to grabber motors)	12V (high current)
Servo motor (camera)	1x PWM (from arduino)	/	4.8V - 6V
Camera	/	/	3V - 5.5V
RC receiver	/	6x Analog (to arduino)	4V - 5.5V

COMPONENT CONNECTION: The electrical system



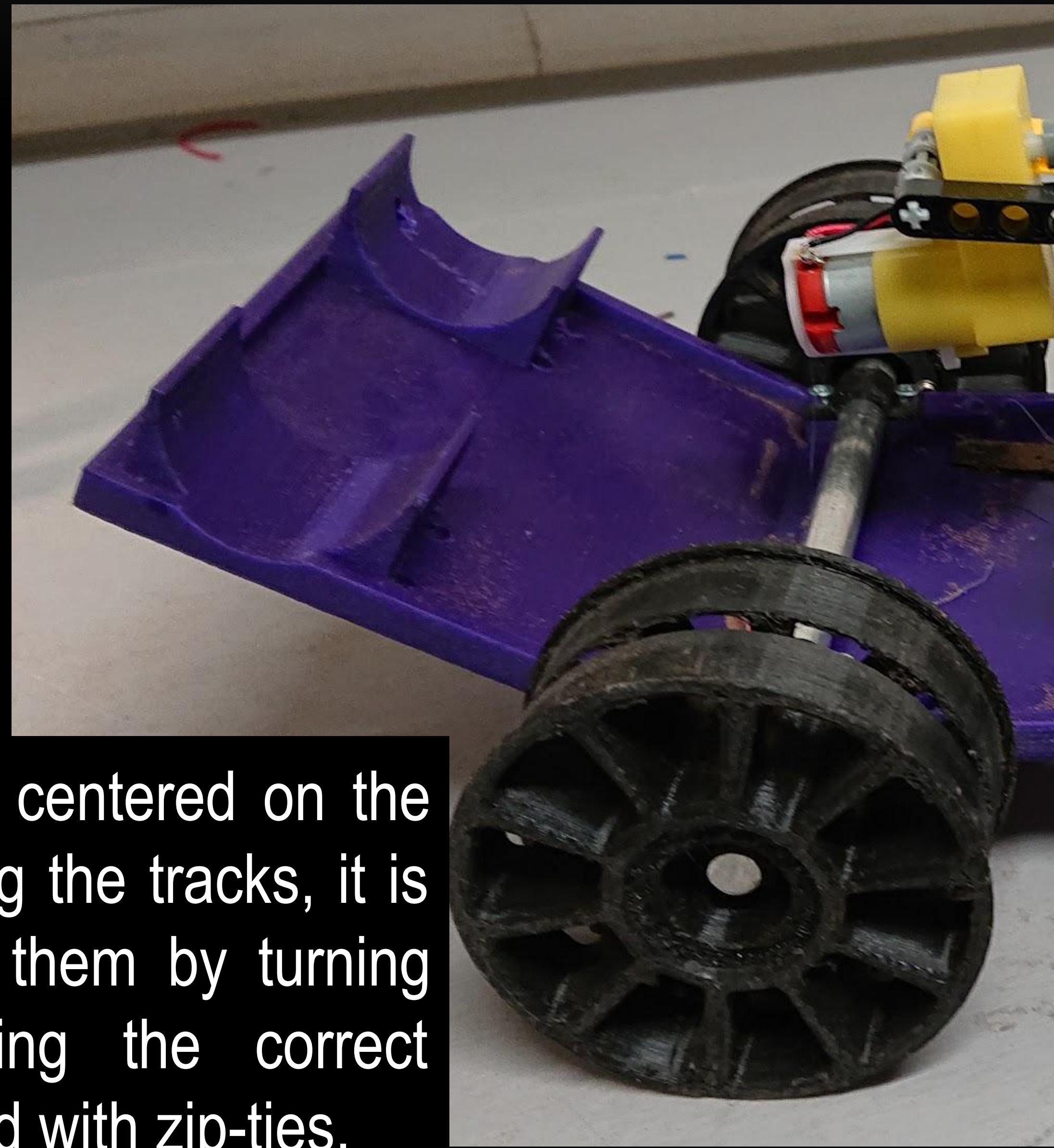
COMPONENT CONNECTION: Rover assembly

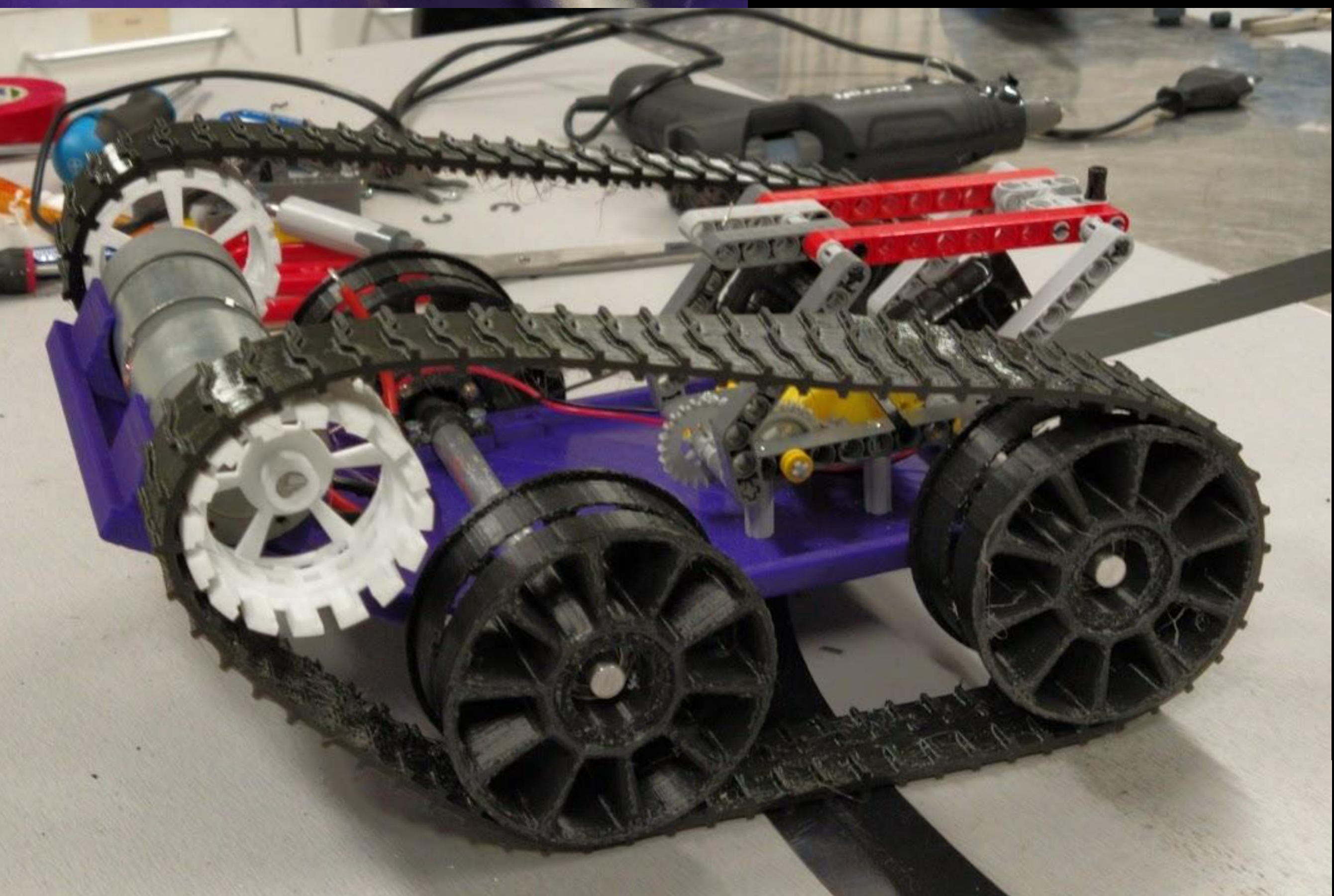
Motors, wheels and tracks



Shafts fixed on the frame with 3D-printed supports and screws. Very good stability of the free wheels on the frame.

Motor fixed on the frame on specific supports designed according to the motor’s diameter. Fixed in the right position with zip-ties.



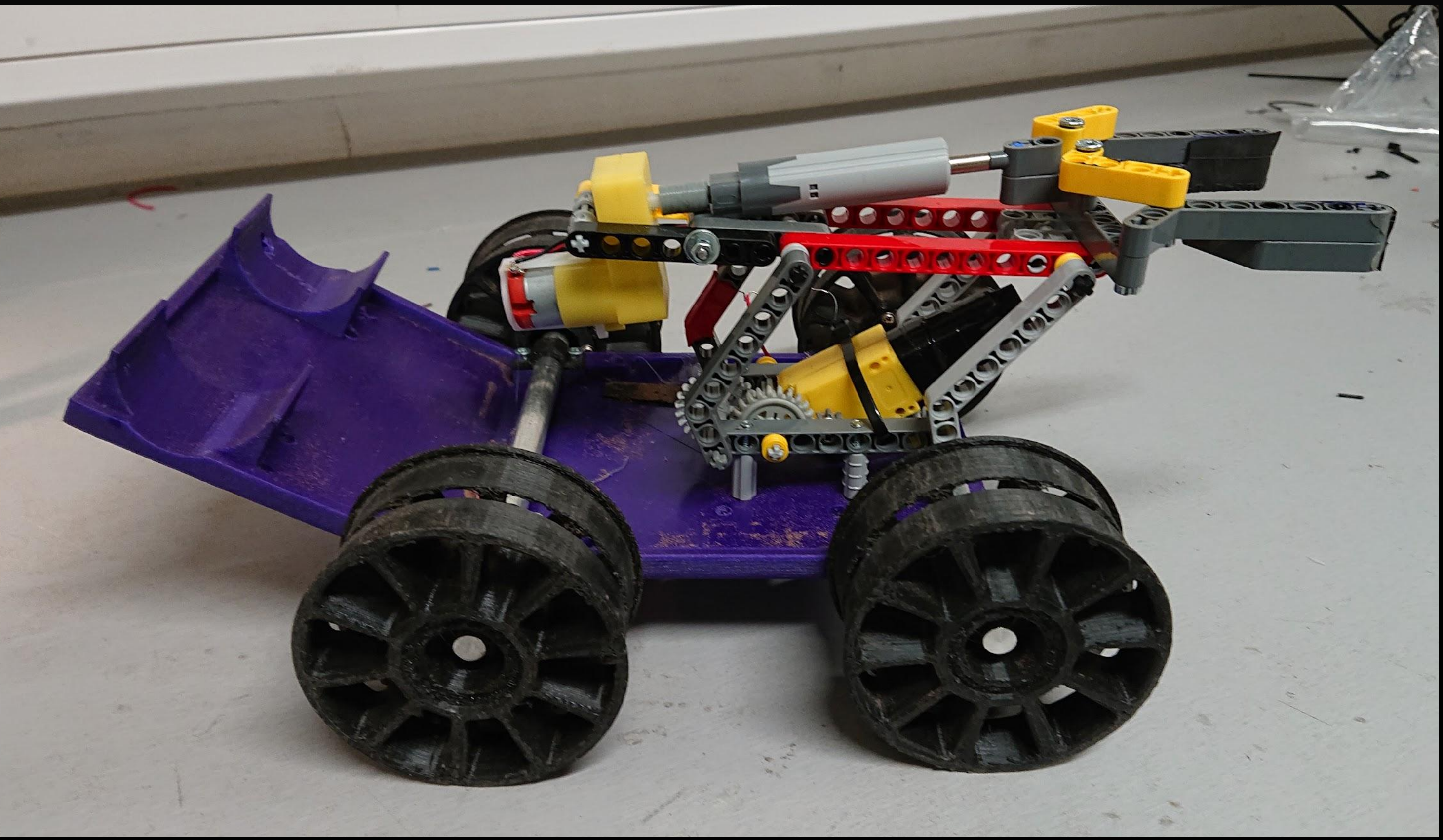


The motion shafts are not centered on the motor’s axis. After mounting the tracks, it is easily possible to tension them by turning the motors. After reaching the correct tension, the motors are fixed with zip-ties.

IMPORTANT TO ALIGN THE WHEELS ON THE SAME AXIS TO PREVENT FALLING OF THE TRACKS!!

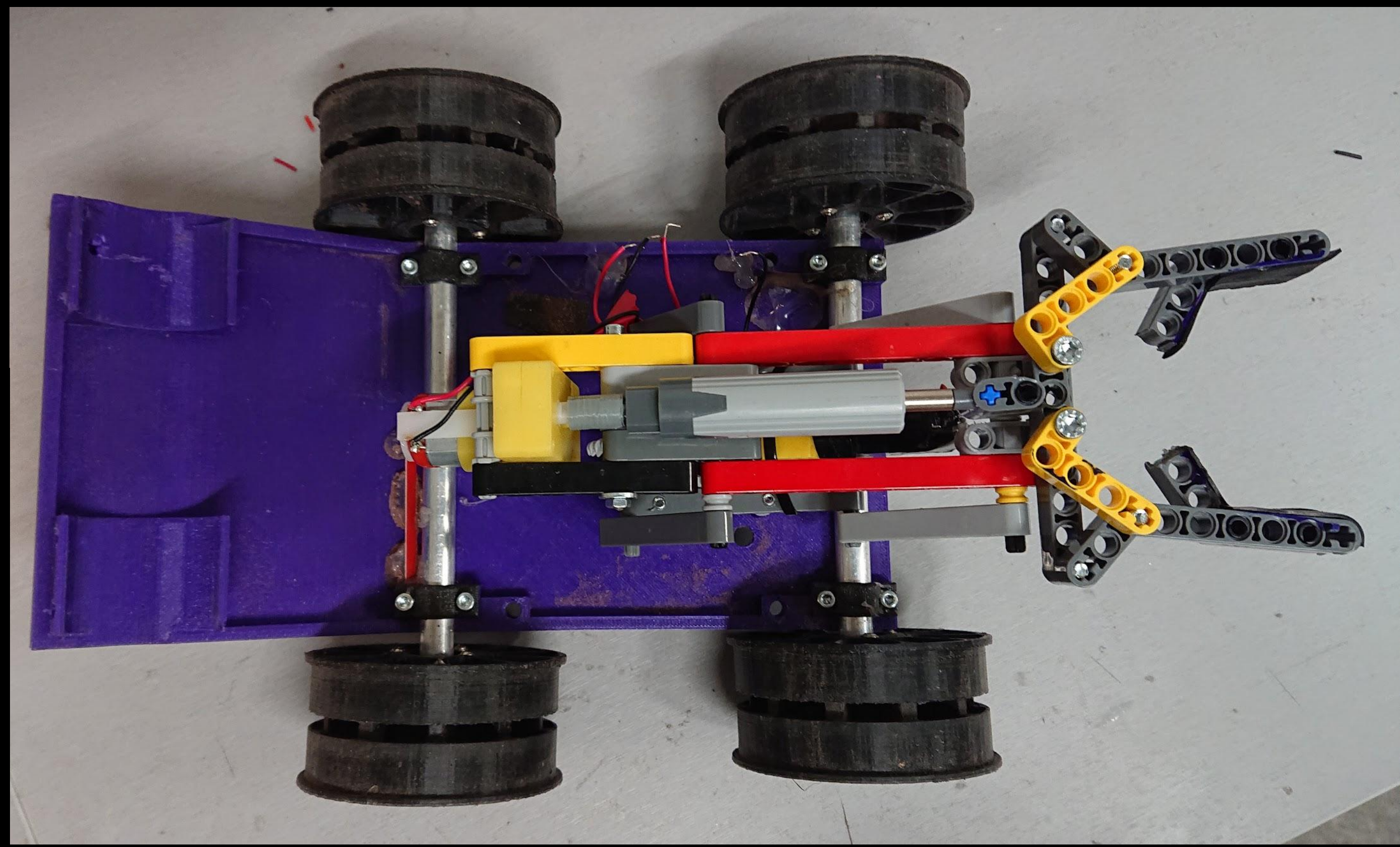
COMPONENT CONNECTION: Rover assembly

Grabber



Grabber located in the back of the robot. The shape of the tracks and the position of the motors let free space mainly in the back. Moreover, the aim is to not limit the movement of the rover when grabbing the object. With this configuration the climbing abilities are not affected by the presence of the object. The base of the grabber is fixed with screws and lifted from the ground to allow the mounting of gears.

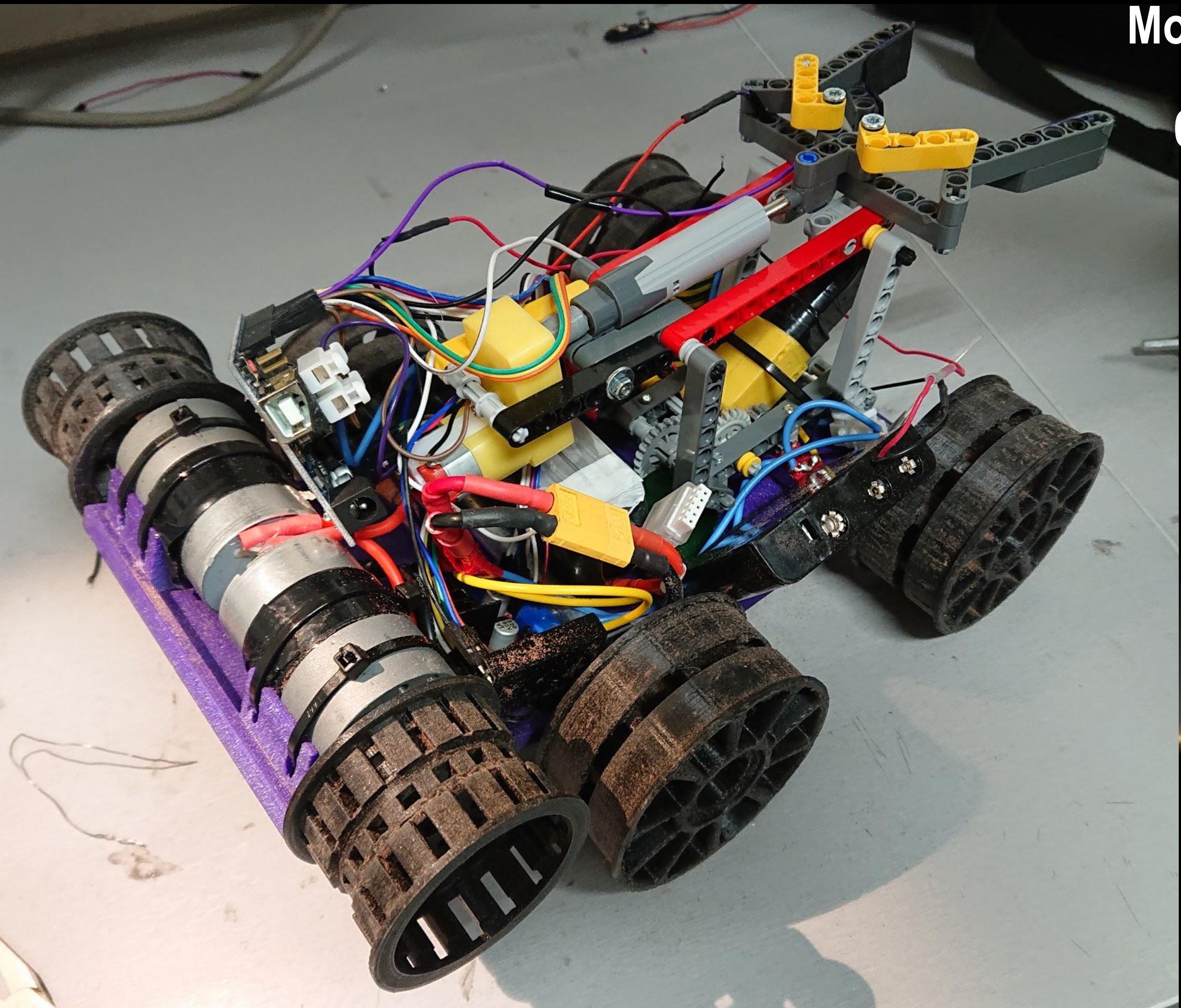
THE GRABBER STRUCTURE IS MUCH BIGGER THAN EXPECTED COMPARED TO THE DIMENSIONS OF THE FRAME. We had some mounting issues while trying to fit everything inside the frame.
THE HEIGHT OF THE GRABBER ALLOW US TO REACH THE OBJECT ONLY WHEN IT IS IN THE VERTICAL POSITION!

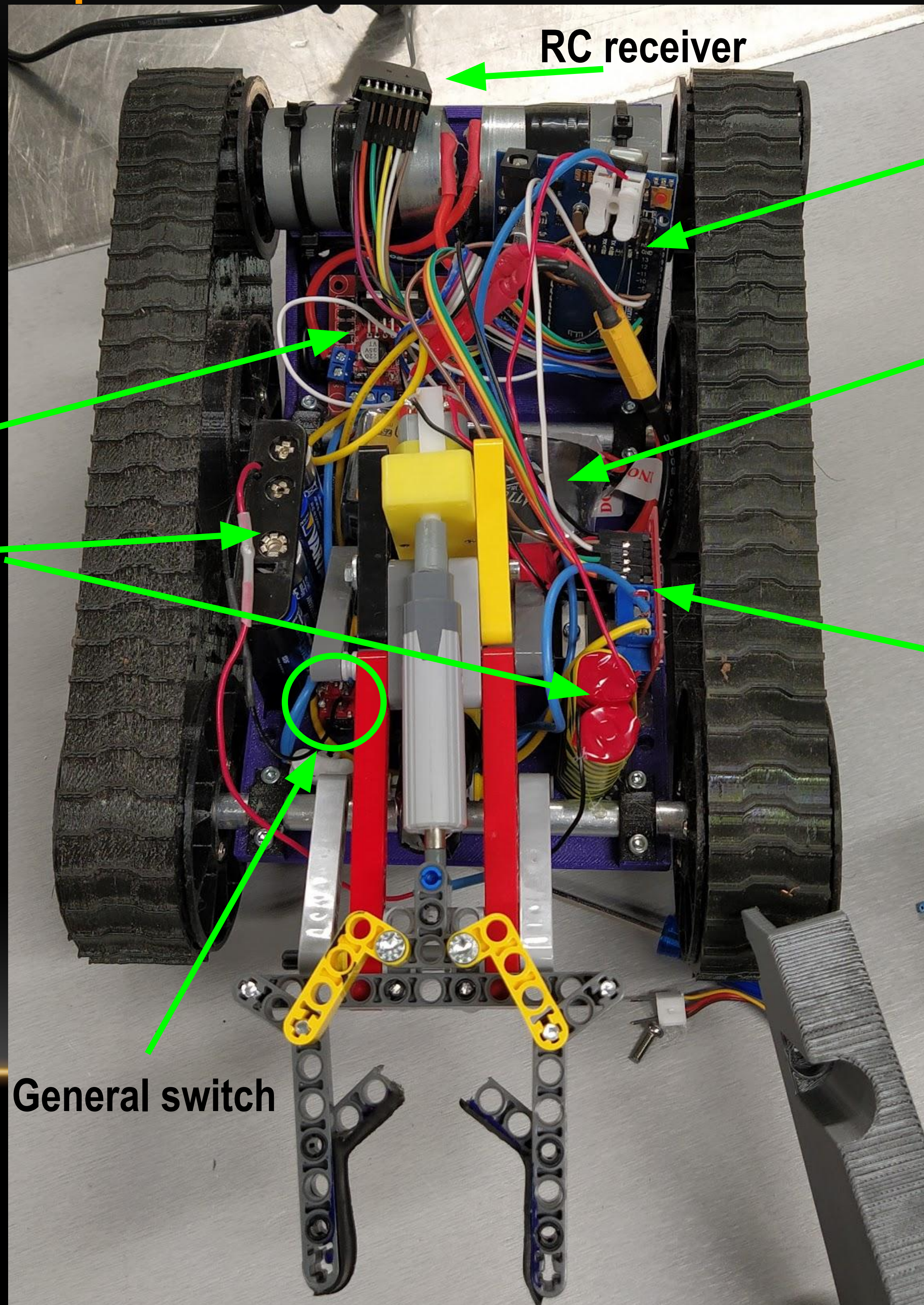


COMPONENT CONNECTION: Rover assembly

Electronic components

All the electronic devices and the wiring have to be located inside the frame. The availability of space, the position of different electronic components and the wiring management weren't considered enough during the design phase. Many tries were performed in order to fit everything inside the small available space.This made a tidy wiring system difficult to achieve.



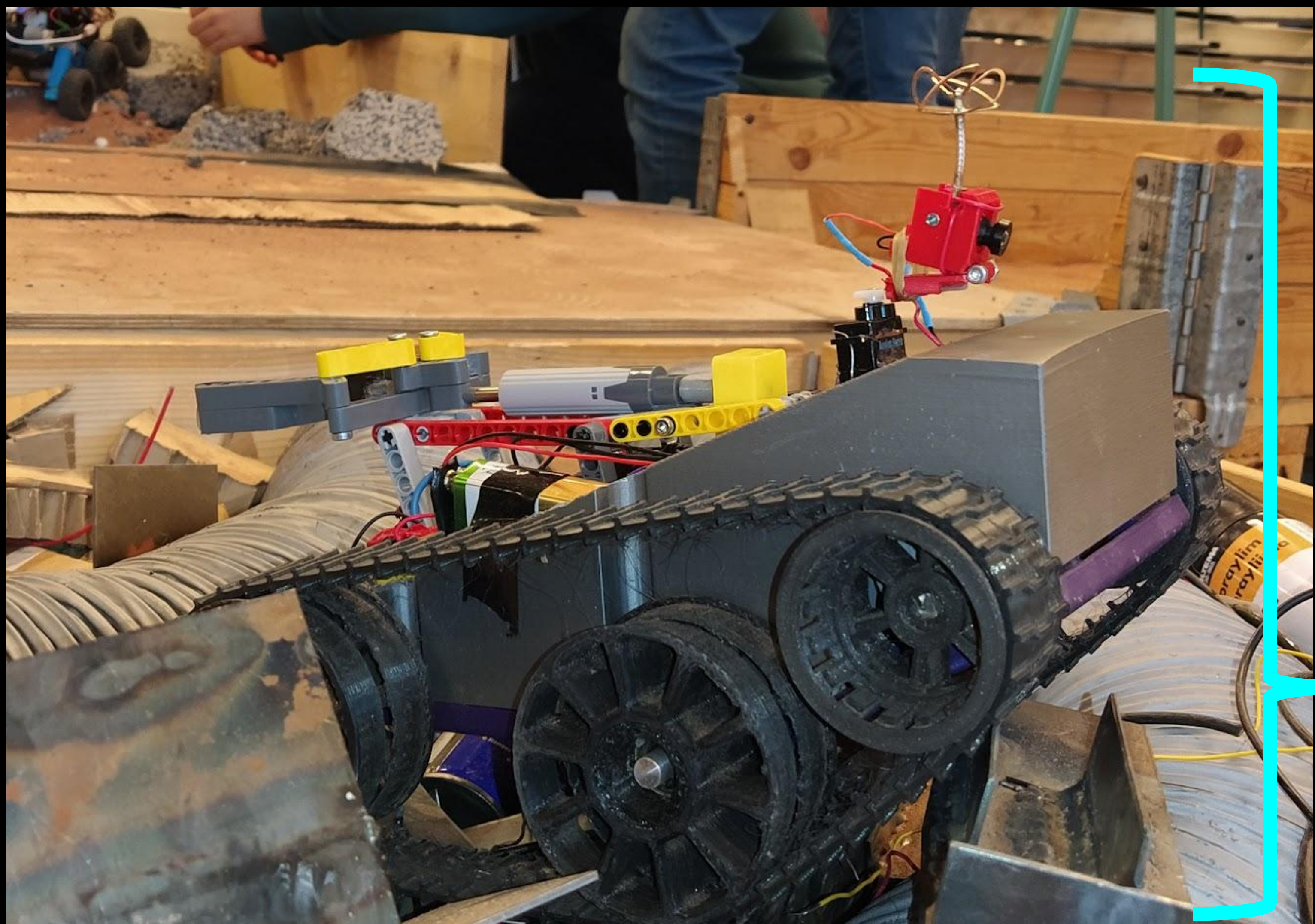


Phase 1: Vision | Phase 2: Needs | Phase 3: Concept | Phase 4: Structure | **Phase 5: Production**

COMPONENT CONNECTION: Rover assembly

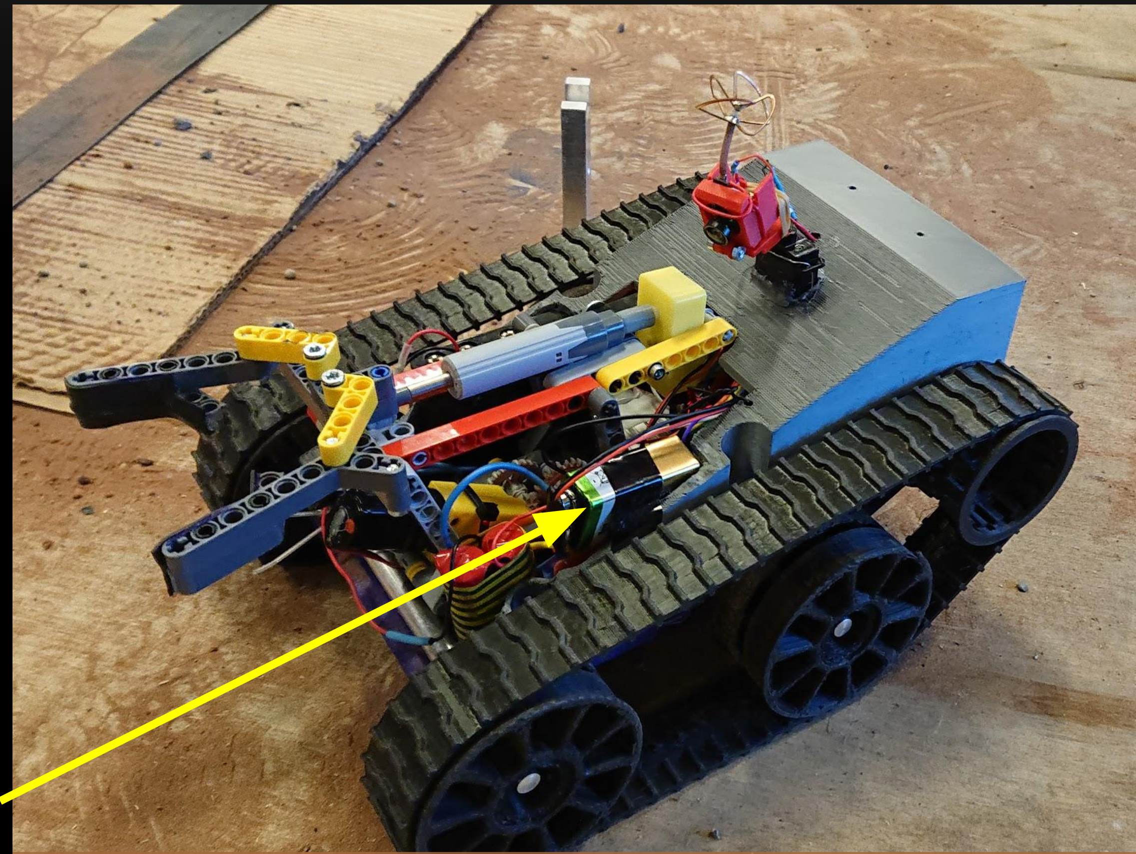
Body and camera

After mounting the functional components and testing the rover, it was necessary to connect the camera and mount the body on the frame. The camera has to rotate in order to see both forward when moving and backward when grabbing. It is mounted on a non-continuous servo motor with a rotation angle of about 180°, enough for our needs. The servo was mounted by shaping a hole in the frame with a soldering iron. The servo is fixed on the top of the body in order to put the camera at the highest position on the rover.

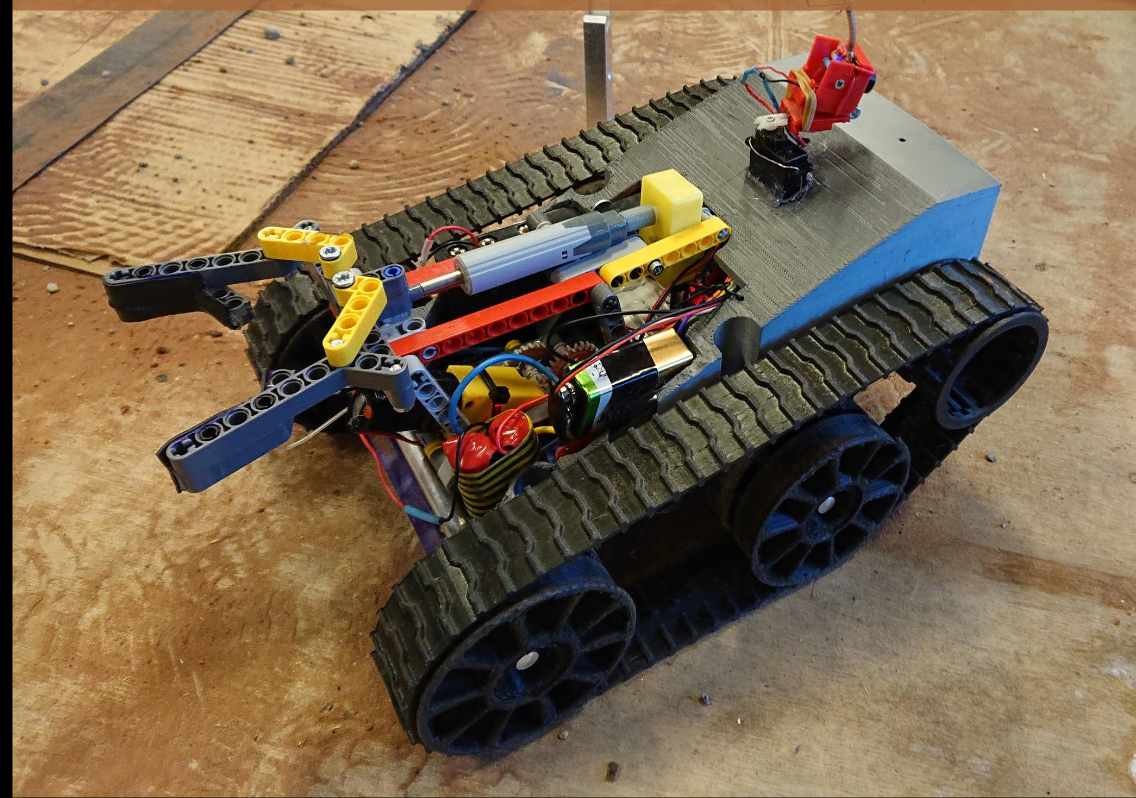


Due to the low power provided by the AA batteries and the short duration of the charge, the servo is powered by a dedicated 9V battery

Check of the final dimension before fixing the servo. MAX height = 20cm

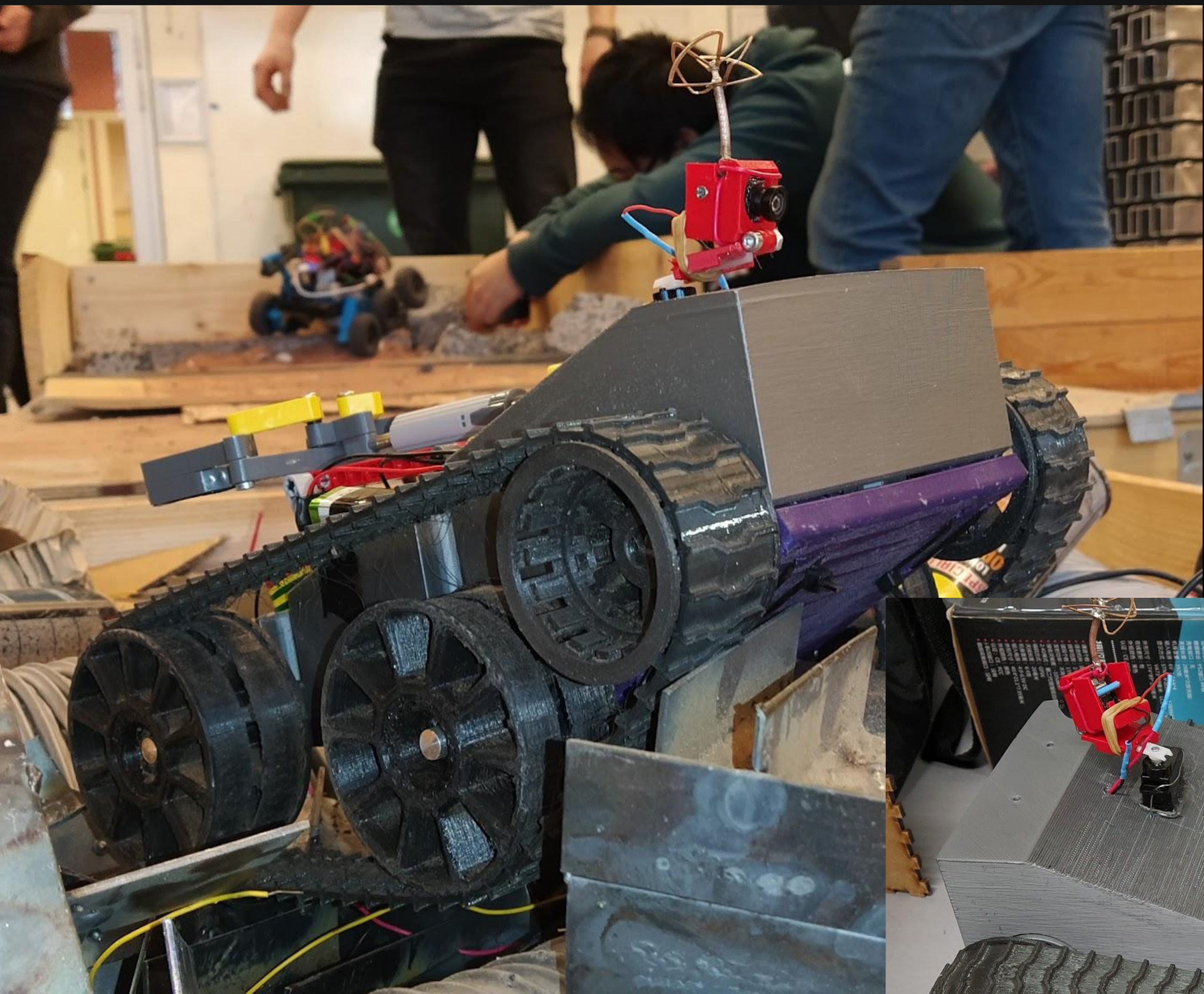


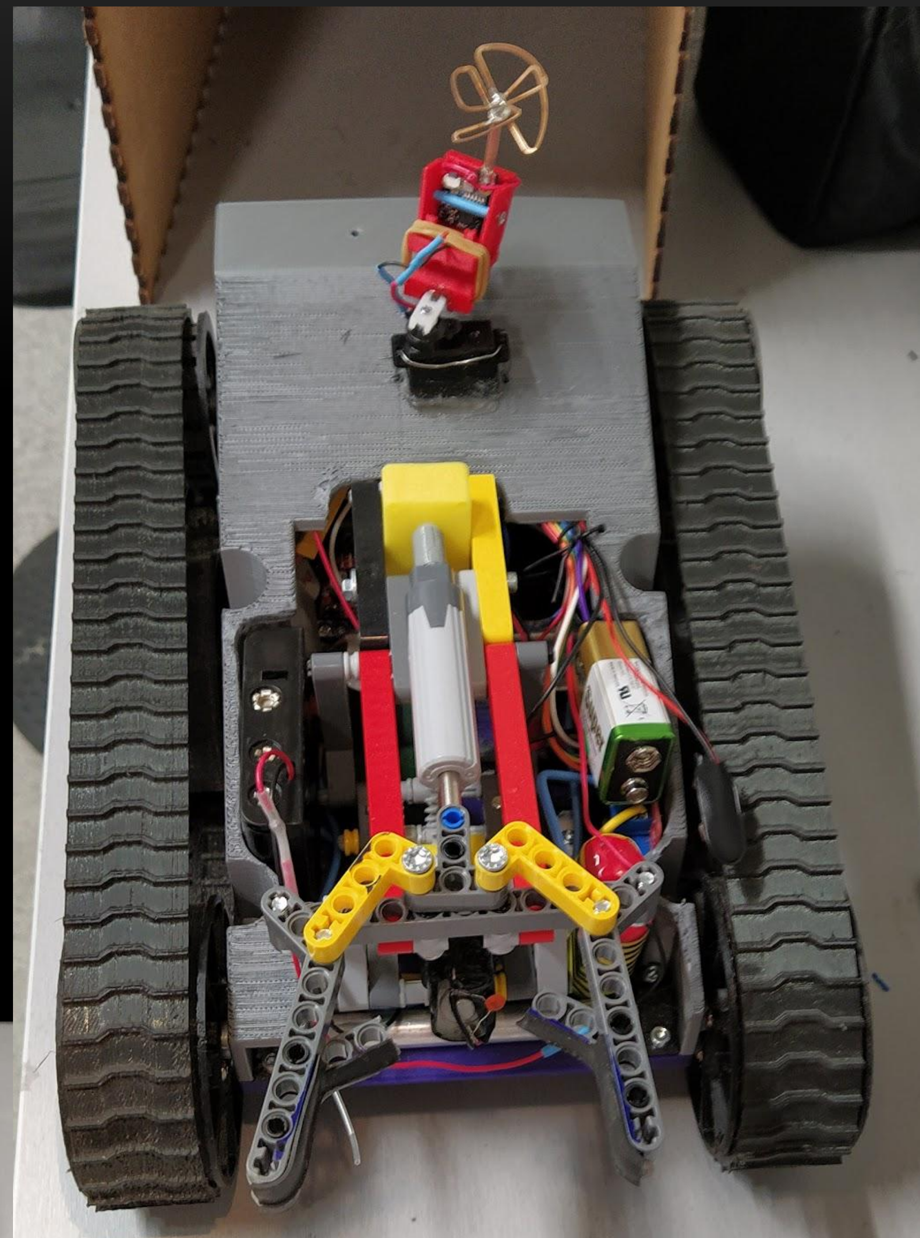
The two possible positions for the camera



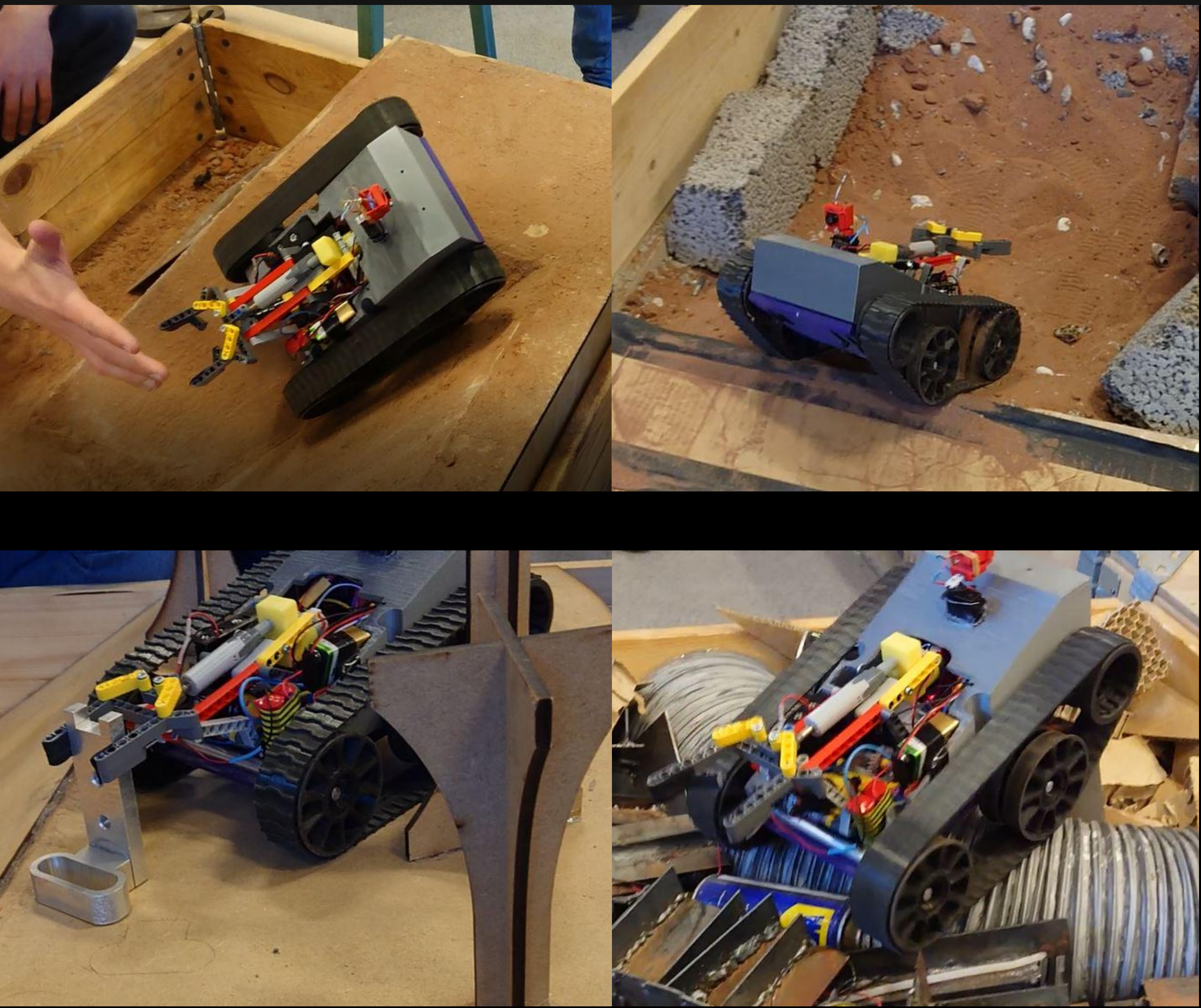
Phase 1: Vision | Phase 2: Needs | Phase 3: Concept | Phase 4: Structure | **Phase 5: Production**

"THE BEAST"





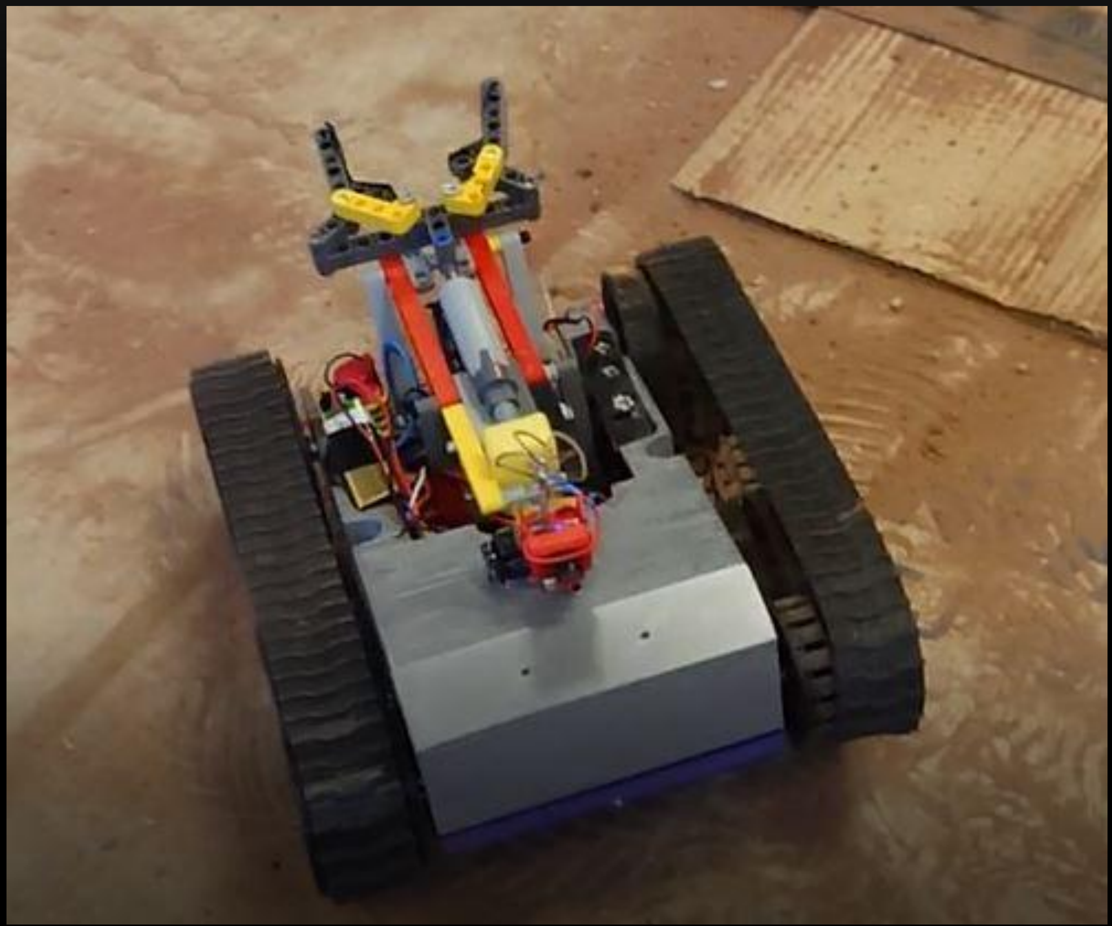
FINAL TEST: Successes



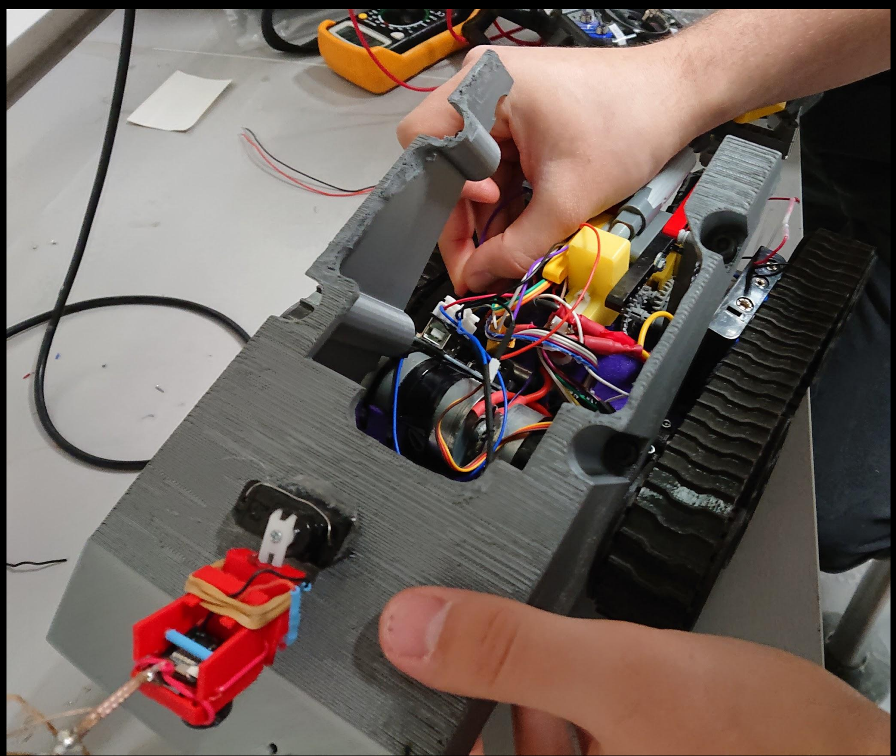
- **Extremely good motion on all kinds of terrains.** The rubber tracks ensure a great traction on both smooth and bumpy grounds. As planned, the shape of the robot gives good climbing abilities on risings and steps.
- **The single components are working as intended.** We didn't have surprises about the behaviour of the single components of the rover.
- **Very good stability of the structure against falls and crashes.**
- **Good power.** Thanks to the "big" motors and to the LiPo battery we didn't have a problem of power in all the situations.
- **No sand issues.** We didn't have particular problems related with the presence of sand.
- **Dimensions respected.** The rover respected the maximum dimensions given by the project requirements.

Phase 1: Vision | Phase 2: Needs | Phase 3: Concept | Phase 4: Structure | **Phase 5: Production**

FINAL TEST: Issues and considerations



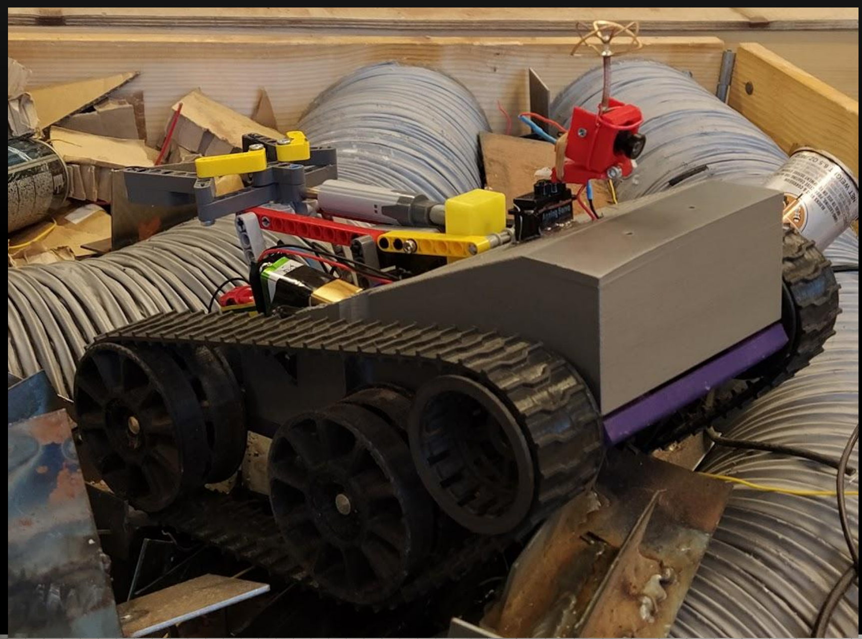
- **Tracks sliding of from the wheels.**
  This problem affects the reliability of the rover, it must be solved for future development of the project.
  CAUSES: Under-evaluation of the tension of the tracks. After 24h under tension, the drive wheels in PLA start losing the mechanical stability, the deformation allows the tracks to slide off. Non perfect alignment between the wheels can also be involved.
  POSSIBLE SOLUTION: Re-design of the driving wheels and of the tracks. Change material, increase thickness and infill of the wheels. Increase the dimension of the internal teeth on the tracks for maintaining them in the correct position. Center the link shaft-wheel in the center of the driving wheel.

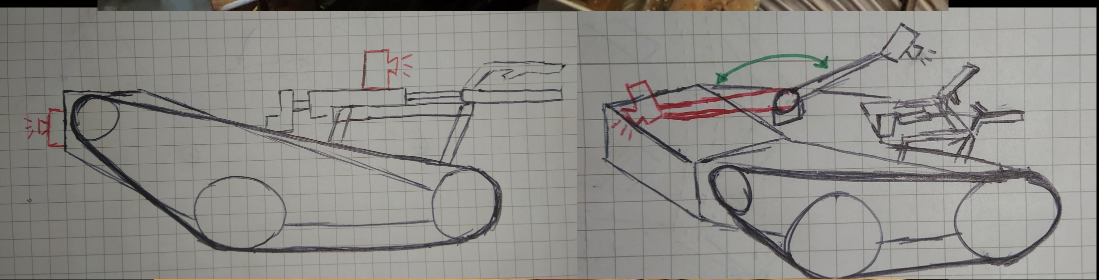


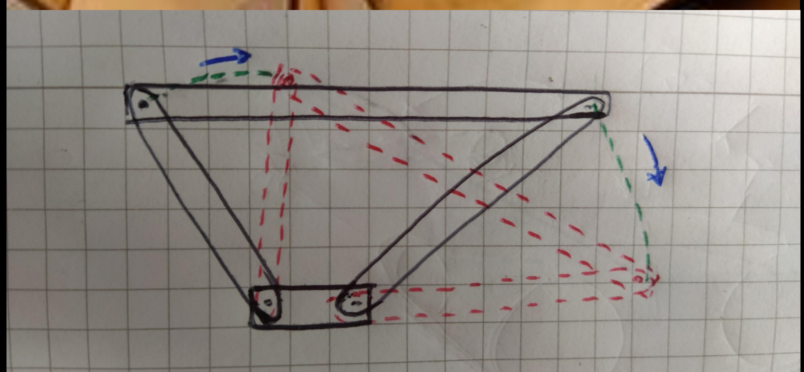
- **Frame difficult to assemble + bad position for the switch**
  Having the upper part and the walls to be mounted at the end, the final assembly of the rover was quite complicated. The switch located in the bottom part of the rover easily turns the rover off when going on difficult terrains.
  CAUSES: Under-evaluation of the lack of space in the rover, need of a switch not considered in the design phase.
  POSSIBLE SOLUTION: Re-design of the frame. Walls made as part of the bottom frame, so to have easier location of components and wires. The switch should be located on a wall instead of at the bottom.

Phase 1: Vision | Phase 2: Needs | Phase 3: Concept | Phase 4: Structure | **Phase 5: Production**

FINAL TEST: Issues and considerations







- **Difficult position of the camera**
  The position of the camera doesn't allow the driver to have a good view in all the situations. When going forward it is not easy to see what there is just in the front of the rover. When grabbing is very difficult to see clearly the object and understand the distance between it and the grabber. The camera is also very exposed in case of falling.
  CAUSES: Short time for the design of the camera system.
  SOLUTIONS: I) Mount the camera on an arm. In this way, moving the servo, it is possible to approach the camera to the grabber or to the front of the rover. **II) Mount two cameras.** One for the driving in the front and one for the grabbing on the grabber. **The camera should also be protected with a rolling cage.**

- **Poor adaptability of the grabber**
  The grabber itself works well, but it can only grab the required object when this is in the vertical position. If the object falls there is no possibility to grab it.
  CAUSES: Height of the grabber increased with respect to the first design, no time to re-think it.
  SOLUTIONS: I) Make the grabber with other material instead than LEGO. This should allow to decrease the dimension. **II) Re-design the structure of the lifting motion of the grabber.** Shorter supports should improve the inclination, allowing to grab lower objects without radically changing the design of the grabber.

Conclusion

Overall the project proved to be very successful for us. Even though we were the smallest group and had therewith quite a bit of time pressure we could deliver a very good result. Even though each group member had a different cultural background this proved to be an enrichment for the group. Everyone was willing to contribute his own unique perspective and compromise, so the group harmonized quite well.

As well as that a few good decisions proved themselves crucial in the design process. Firstly the rapid prototyping in the concept phase provided key insights, preventing many mistakes and taking the design process to a physical stage early on. It showed for example that the frame's shape worked really well and that the tracks could work. The unconventional and innovative idea to print the tracks in continuous parts was a risk and not easy to accomplish, but it saved a lot of assembly time and work very well on all surfaces.

Not every idea from the concept phase could be implemented in the end. A good example for that was the hydraulic grabber. With more time and resources it could well have been implemented. If one understands the product design as an iterative process, rather than a one way road, this is not a problem. The grabber improvised of lego parts worked very reliably.

Our vision of an environment friendly design, ease of use and ease of repairs also had to get lower priority in order to complete a functional prototype on time.

To conclude, we have all learned a lot both regarding the product design process and mechatronics principles, and we had fun doing so.

Appendix: Hours of contribution

Name	Hours of contribution
Nabil	100
Hauk-Morten	100
Adrien	100
Gabriele	100