02.12.2020

Xplore

Preliminary Design Review

swiss space center

eSpace EPFL Space Center

MARS SOCIETY SWITZERLAND

maxon

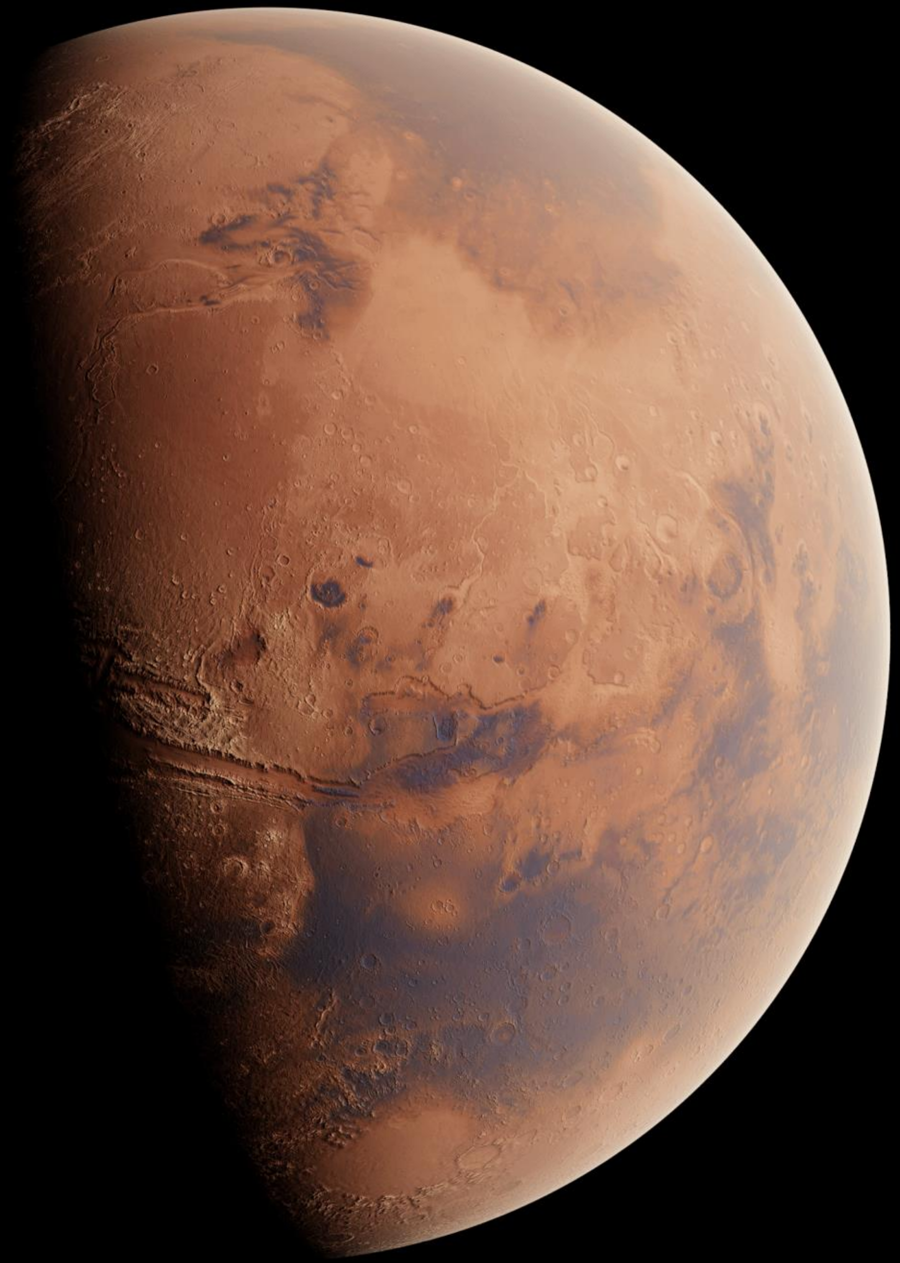
rovenso

Preliminary Design Review

Ensure that the first version of design meets the requirements, risks have been identified and mitigated and cost and schedule constraints have been respected.

Agenda

- 4:15 - 4:25pm Introduction, Management & Finance
- 4:25 – 4:55pm System Engineering, Q&A
- 4:55 – 5:00pm **Break**
- 5:00 – 5:20pm Structure, Q&A
- 5:20 – 5:40pm Avionics, Q&A
- 5:40 – 6:00pm Navigation, Q&A
- 6:00 – 6:05pm **Break**
- 6:05 – 6:30pm Handling Device, Q&A
- 6:30 – 6:55pm Science, Q&A
- 6:55 – 7:15pm Control Station, Q&A
- 7:15 – 7:20pm **Conclusion**



Management

Project Introduction
Organization
Competition
Timeline
Cost Estimate

Management Team

Jonathan Wei

President

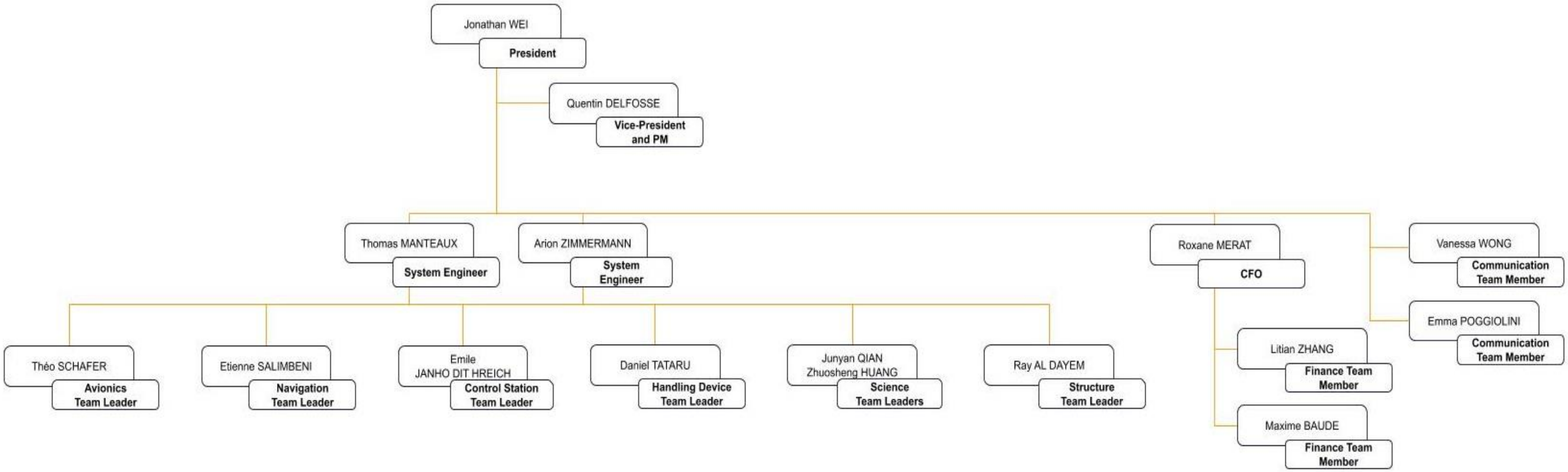
Quentin Delfosse

Project Manager

We are building a Mars Rover in order to compete at the European Rover Challenge

Education: learning by doing, learn to work together and learn from experts

Innovation: start from ideas and build upon them



Organization Chart

EPFL

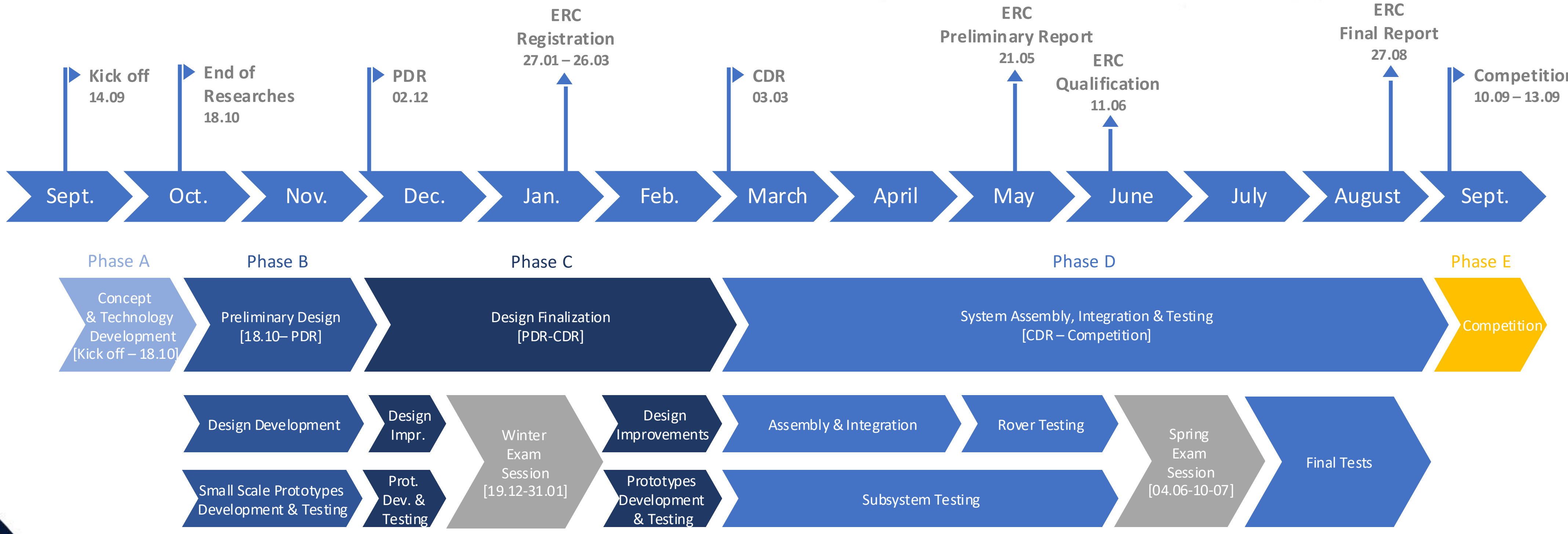
- Théo Schäfer — **Avionics Team Leader**
  - Josef Thomas — **Software**
  - Myriam Rihani — **Software**
  - Omar El Maki — **Software**
  - Leo Litrico — **Software**
  - Pierre-Louis Gaultier — **PCB Design**
- Etienne SALIMBENI — **Navigation Team Leader**
  - Bastien DARBELLAY — **Software**
  - Harsh JAISWAL — **Software**
  - Noureddine GUEDDACH — **Deep Learning**
  - Samuele LANZANOVA — **Motion Control**
- Emile JANHO DIT HREICH — **Control Station Team Leader**
  - Grégoire LACROIX — **Hardware**
  - Aurelio NOCA — **Software**
- Daniel TATARU — **Handling Device Team Leader**
  - Sami BOUZIRI — **Inverse Kinematics**
  - Hugo BORDEREAUX — **Hardware**
  - Lilian LAPORTE — **Structure**
  - Xavier SERVOT — **Deep Learning**
- Junyan QIAN, Zhuosheng HUANG — **Science Team Leaders**
  - Gloria MELLINAND — **Scientist**
  - Pierre AMADIO — **Scientist**
  - Arthur VARD — **Spectroscopy**
  - Jehan CORCELLE — **Structure**
  - Loris CASTAGNOLO — **Structure**
  - Lorenzo MINERVINI — **Structure**
- Ray Dayem — **Structure Team Leader**
  - Mickael GRINDOZ — **Chassis**
  - Giovanni BOBA — **Structure**
  - Alexis COGNE — **Electronics Bay**
  - Emile CHARLES — **Electronics Bay**
- Loïc DELINEAU — **Testing Team Member**
- Anthony Dawoud — **Testing Team Member**
- Antoine HINARY — **Testing Team Member**
- Mohamed BECHA — **Testing Team Member**
- Charbel ALDAWAILIBI — **Testing Team Member**
- Alexandre DAO — **Testing Team Member**

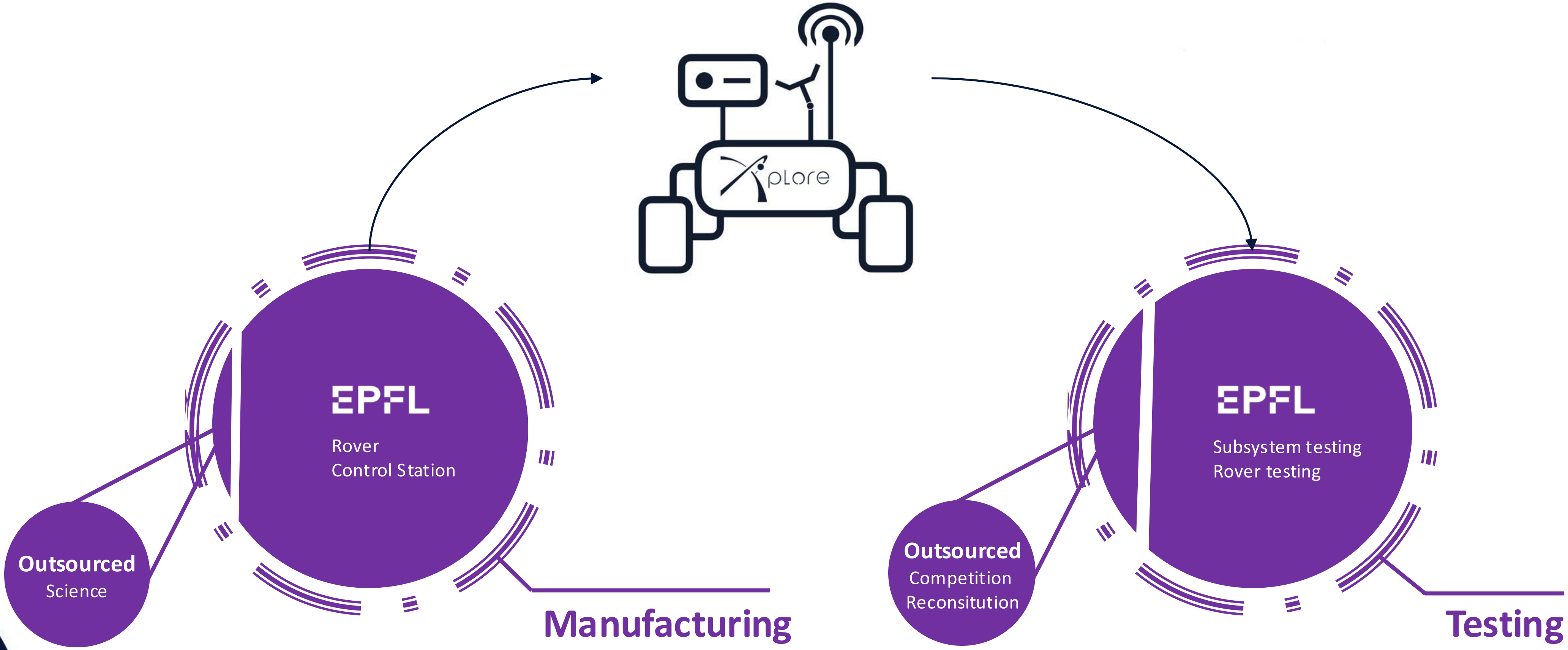
Science
- Collect samples of the surface and subsurface
- Conduct in-situ measurements

Equipment Servicing
- Manipulate objects
- Operate manipulable elements mounted on a panel

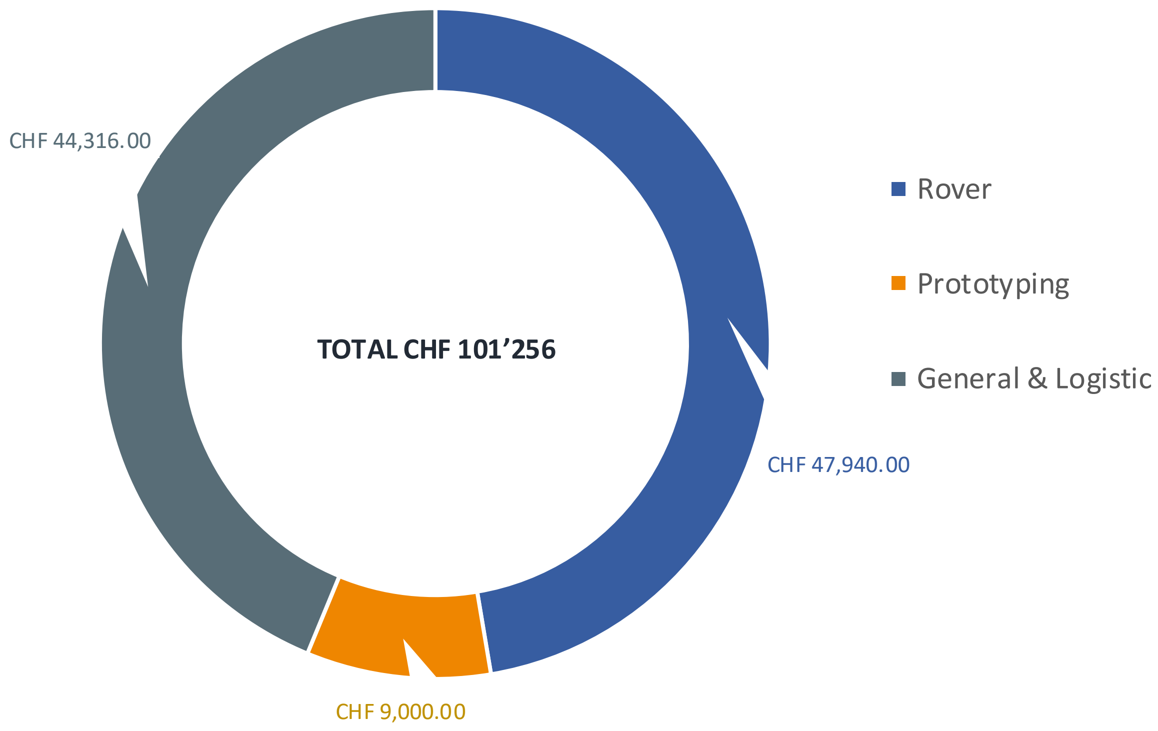
Retrieval & Delivery
- Reach a specific location
- Retrieve a cache
- Deliver it to a given location

Navigation
- Autonomous traverse of rough terrain
- Environment analysis for path optimisation and image recognition


Kick off
14.09
End of
Researches
18.10
PDR
02.12
ERC
Registration
27.01 – 26.03
CDR
03.03
ERC
Preliminary Report
21.05
ERC
Qualification
11.06
ERC
Final Report
27.08
Competition
10.09 – 13.09
Sept.
Oct.
Nov.
Dec.
Jan.
Feb.
March
April
May
June
July
August
Sept.
Phase A
Phase B
Phase C
Phase D
Phase E
Concept & Technology Development [Kick off – 18.10]
Preliminary Design [18.10– PDR]
Design Finalization [PDR-CDR]
System Assembly, Integration & Testing [CDR – Competition]
Competition
Design Development
Design Impr.
Winter Exam Session [19.12-31.01]
Design Improvements
Assembly & Integration
Rover Testing
Spring Exam Session [04.06-10-07]
Final Tests
Small Scale Prototypes Development & Testing
Prot. Dev. & Testing
Prototypes Development & Testing
Subsystem Testing


plore
EPFL
Rover
Control Station
Outsourced
Science
Manufacturing
EPFL
Subsystem testing
Rover testing
Outsourced
Competition
Reconsitution
Testing

Overall Project Cost*

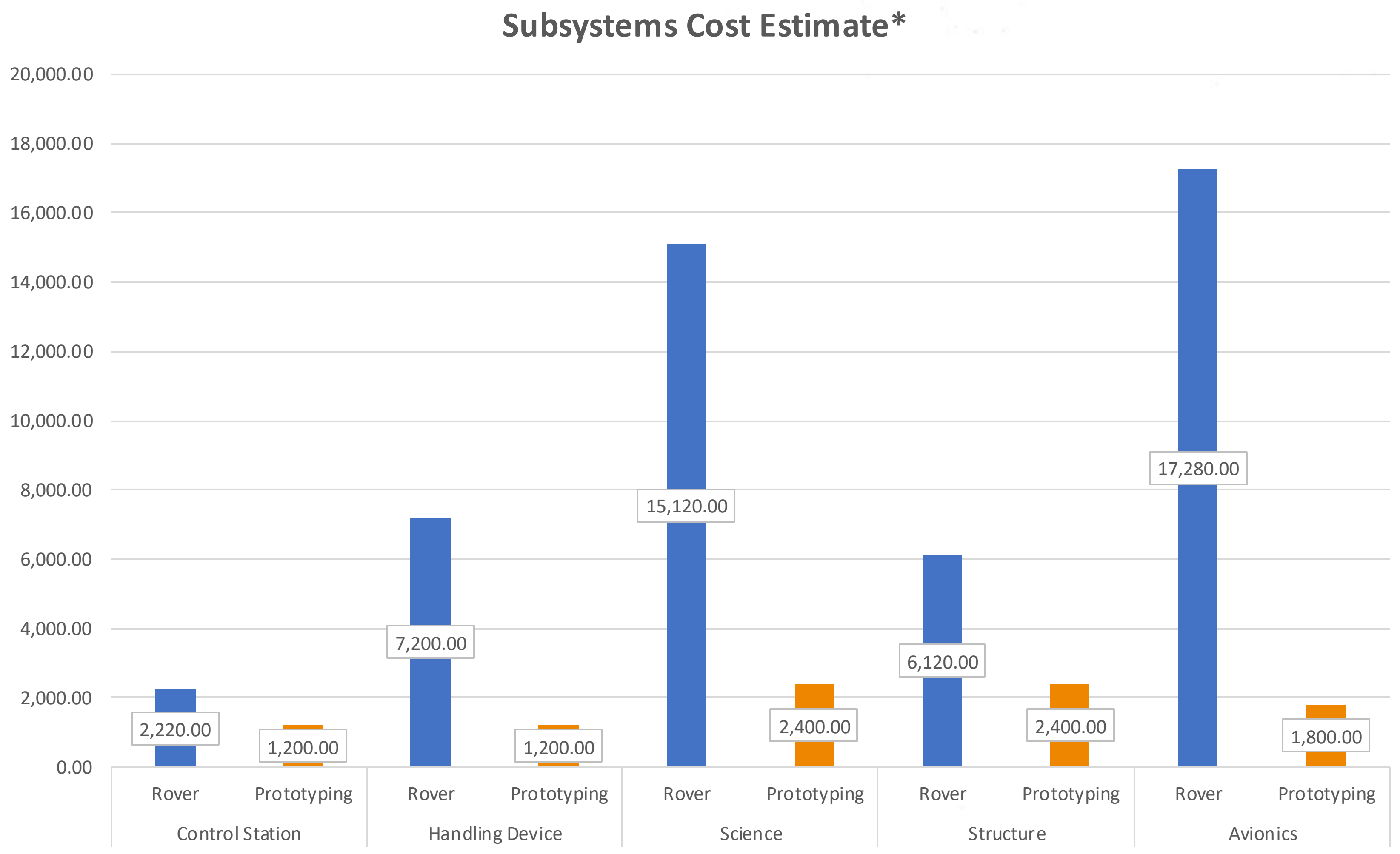


*with 20% contingency

Rover: Estimated cost of the final product by subsystems including contingencies for shipment cost and taxes.

Prototyping: Budget allocated to testing the designs and developping new solutions.

General and Logictics: Budget allocated to external expenses (travel to the competition, miscellaneous, communication) as well as management (coordinator).



*with 20% contingency

System Engineering

Requirements
ConOps
Technical Budgets
Architectures
Risk Analysis

System Engineering Team

Thomas Manteaux

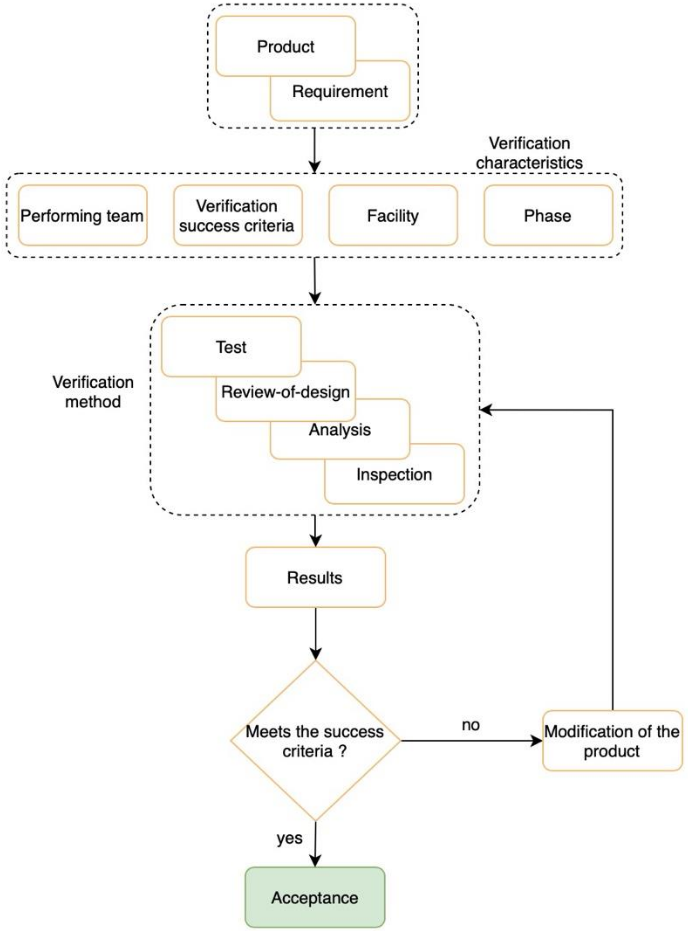
System Engineer

Arion Zimmermann

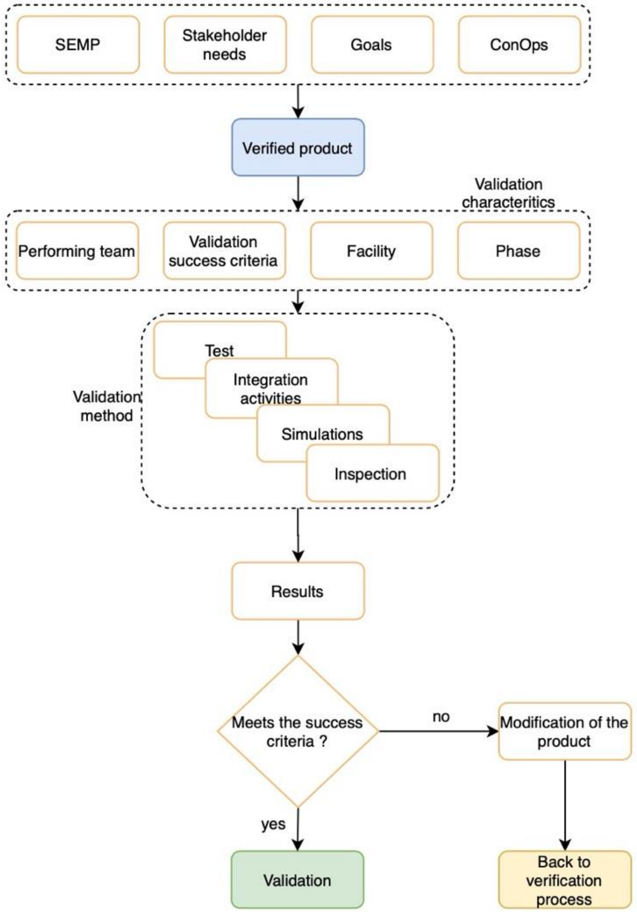
System Engineer

ERC SPACE AND ROBOTICS EVENT → *Mission statement*

ID	Description	Verification method
EPFL_XP_SE_002	The rover shall be able to complete a task within 20-25 min	Test
EPFL_XP_SE_006	The rover shall be able to complete tasks without manual on field intervention	Test
EPFL_XP_SE_007	The rover shall be able to withstand temperatures between 10°C and 30°C	Test
EPFL_XP_SE_008	The rover shall be at max 50 kg	Test Review-of-design
EPFL_XP_SE_009	The rover shall fit in a 1.2 x 1.2 m planar box	Test Review-of-design



Verification process



Validation process

Requirement
Shall statement
Verification success criteria
Verification method
Facility
Phase
Performing team
Results

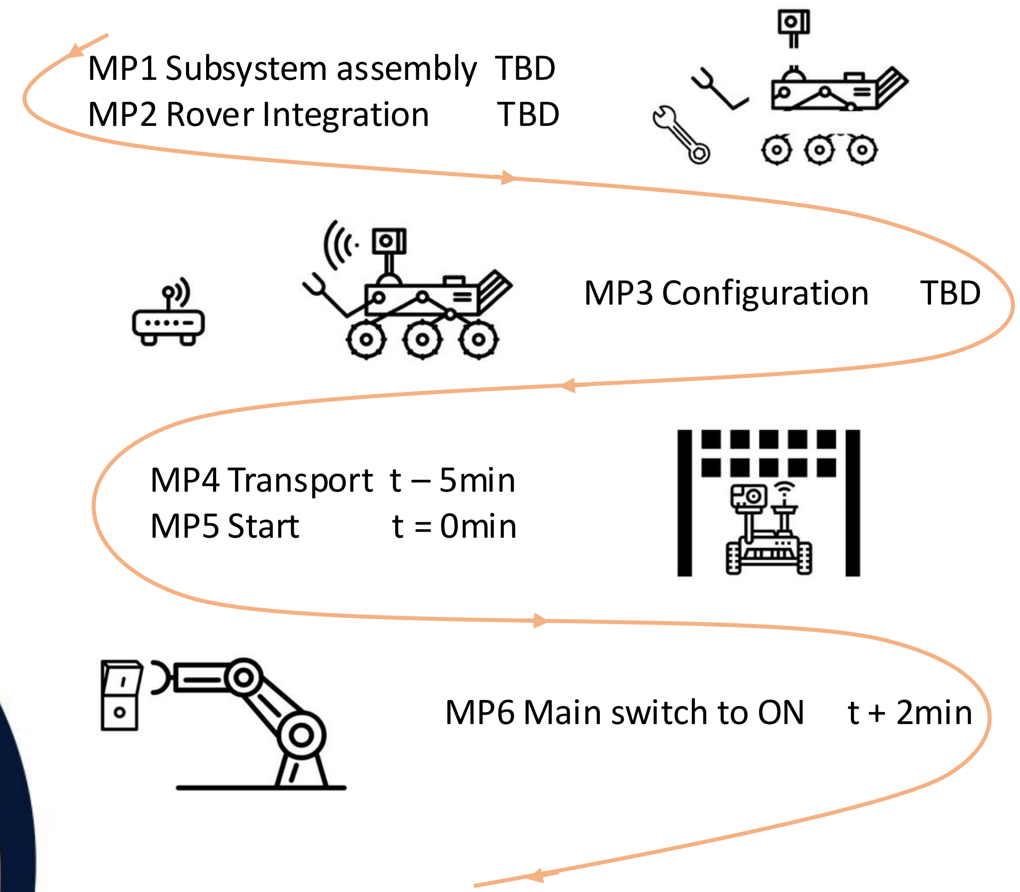
Verification table

Verification & Validation methods

Mission objectives

- Maximum velocity of the rover 0.5m/s
- Communication Rover - Control Station up to 150m
- Climb slopes up to 20°
- 0.2m high rocks and holes to overcome
- On-board mass and volume measurement of soil samples
- 1.5kg load to be carried with the arm
- 0.025kg of soil below 0.25m to be recovered
- 0.150kg of soil surface to be recovered
- 0.5V accuracy voltage measurement (1V-24V)
- A4 AR Tag to detect

Manipulation Task Concept of operations



Start time	TBD	t + 14 min
Phase	MP2	MP13
Name	Rover Integration	Voltage measurement
Description	Assembly of the subsystems on the rover	Measurement of the voltage on the panel
Duration	TBD	1 min
Structure	-	-
Avionics	Integration of the boards into the AV bay Assembly of the batteries on the rover	Voltage sensor data acquisition
Navigation	Integration of the camera on the structure	-
Control Station	CS setting up	Control of the arm Camera stream and voltage display
Handling Device	Integration of the arm	Keep the sensor connected with the terminals
Starting Criteria	Start of parallel assembly of the systems	The voltage sensor is ready to measure the voltage
Ending Criteria	Validation of the whole rover based on pre-defined criteria	The voltage is displayed on the CS

MP7 Rover alignment t + 4min
MP8 Contact t + 5min
MP9 Position report t + 6min

MP10 Reference markers detection t + 7min

MP11 Switches t + 8min

MP12 Contact with terminals t + 12min
MP13 Voltage measurement t + 14min

MP14 Plug pull-out t + 16min
MP15 Plug insertion t + 18min

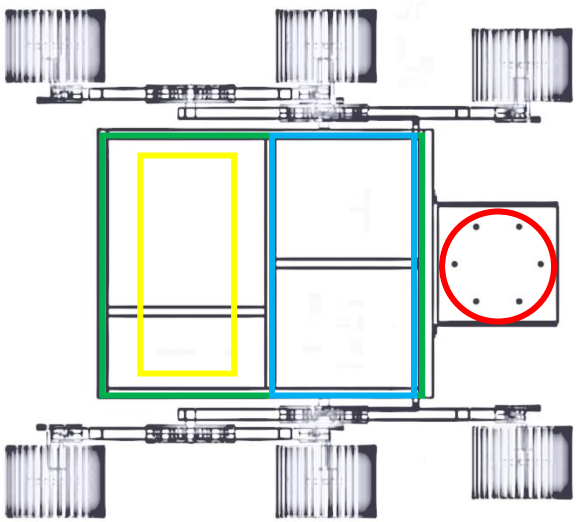
MP16 Buttons actuation t + 20min

MP17 Buttons and socket detection t + 23min
MP18 Buttons and socket localisation t + 24min

MP19 End t + 25 min
MP20 Rover disassembly TBD

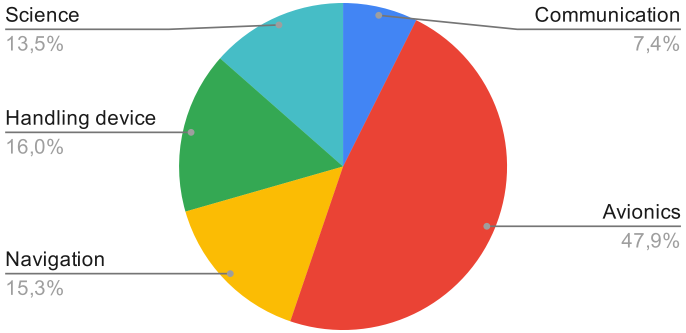
Budget*	Avionics	Structure	Science	Handling Device	Total
Mass (g)	15000	11000	9900	5000	40900
Mass w/ 20% contingency (g)	18000	13200	11880	6000	49080
Current state w/ contingency (g)	16990	TBD	11030	6240	TBD

* for Science task, the most critical task

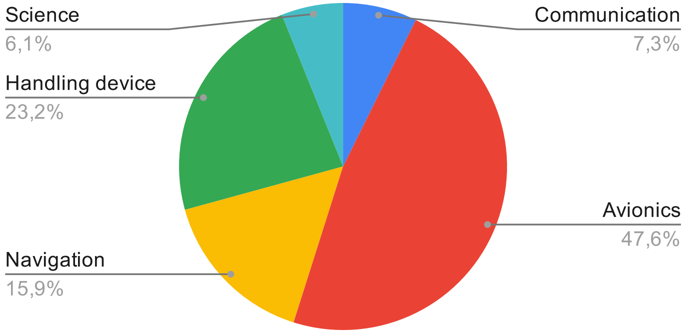


- Biggest mission is Collection task
- 246Wh with 20% contingency
- We aim 250-300Wh battery packs at 24V
- Nominal discharge rate: 3C

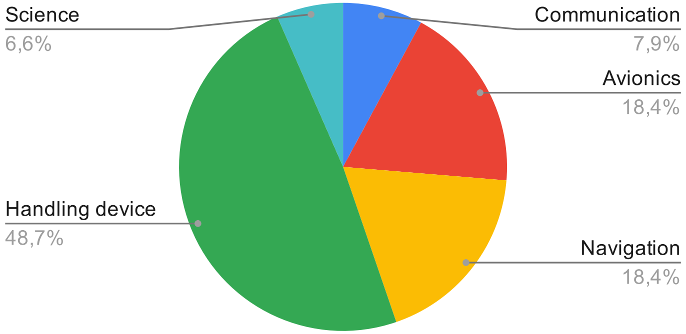
Required energy for Science: 196 Wh



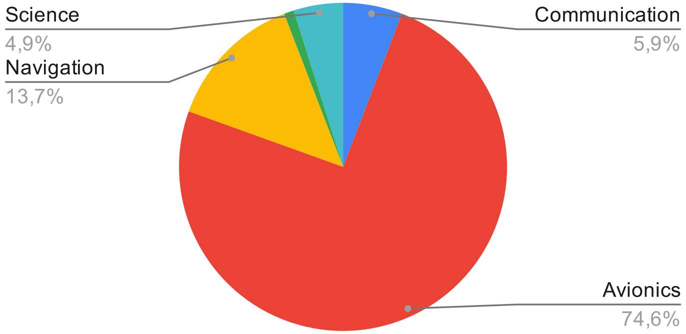
Required energy for Collection: 197 Wh



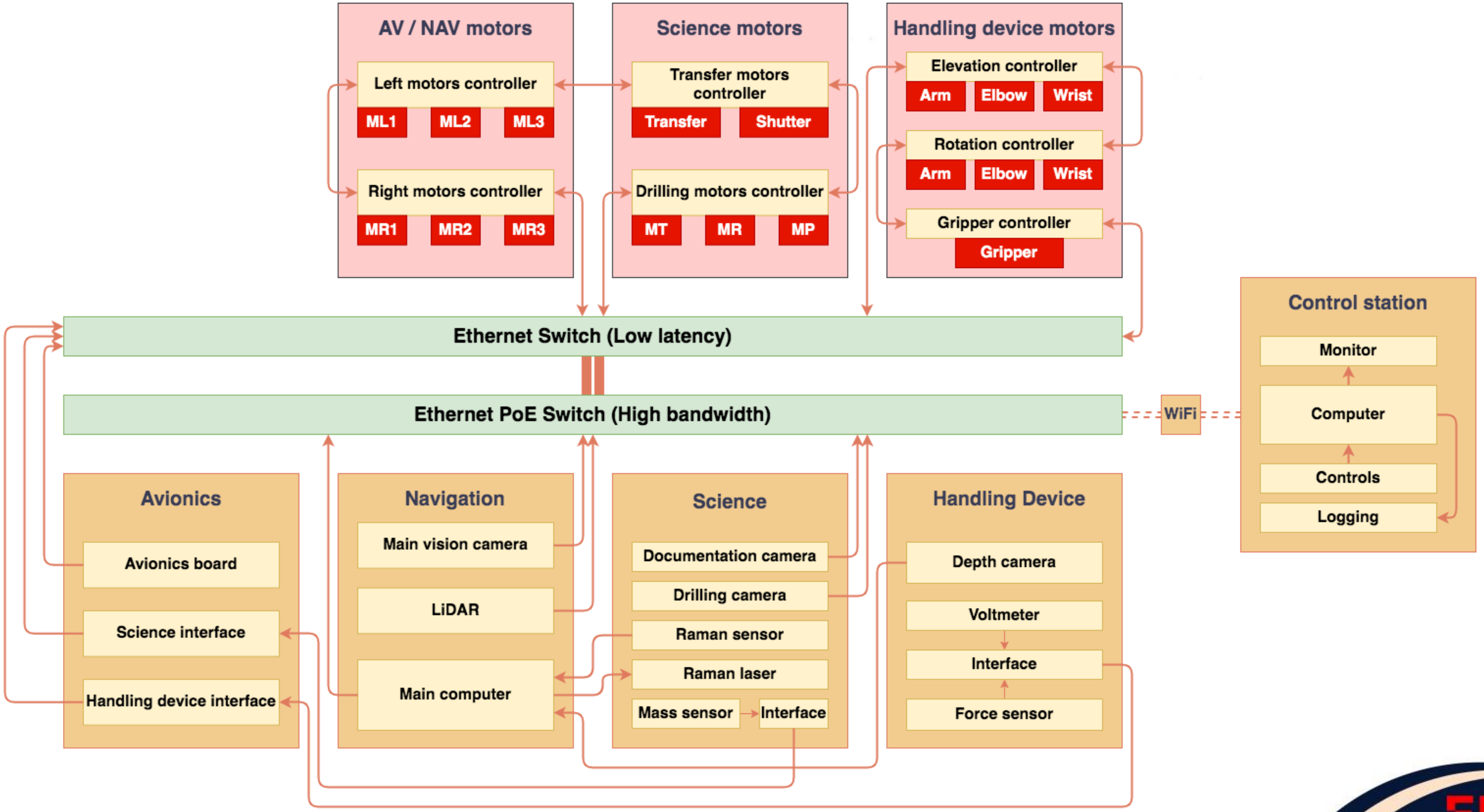
Required energy for Maintenance: 182 Wh



Required energy for Navigation: 246 Wh

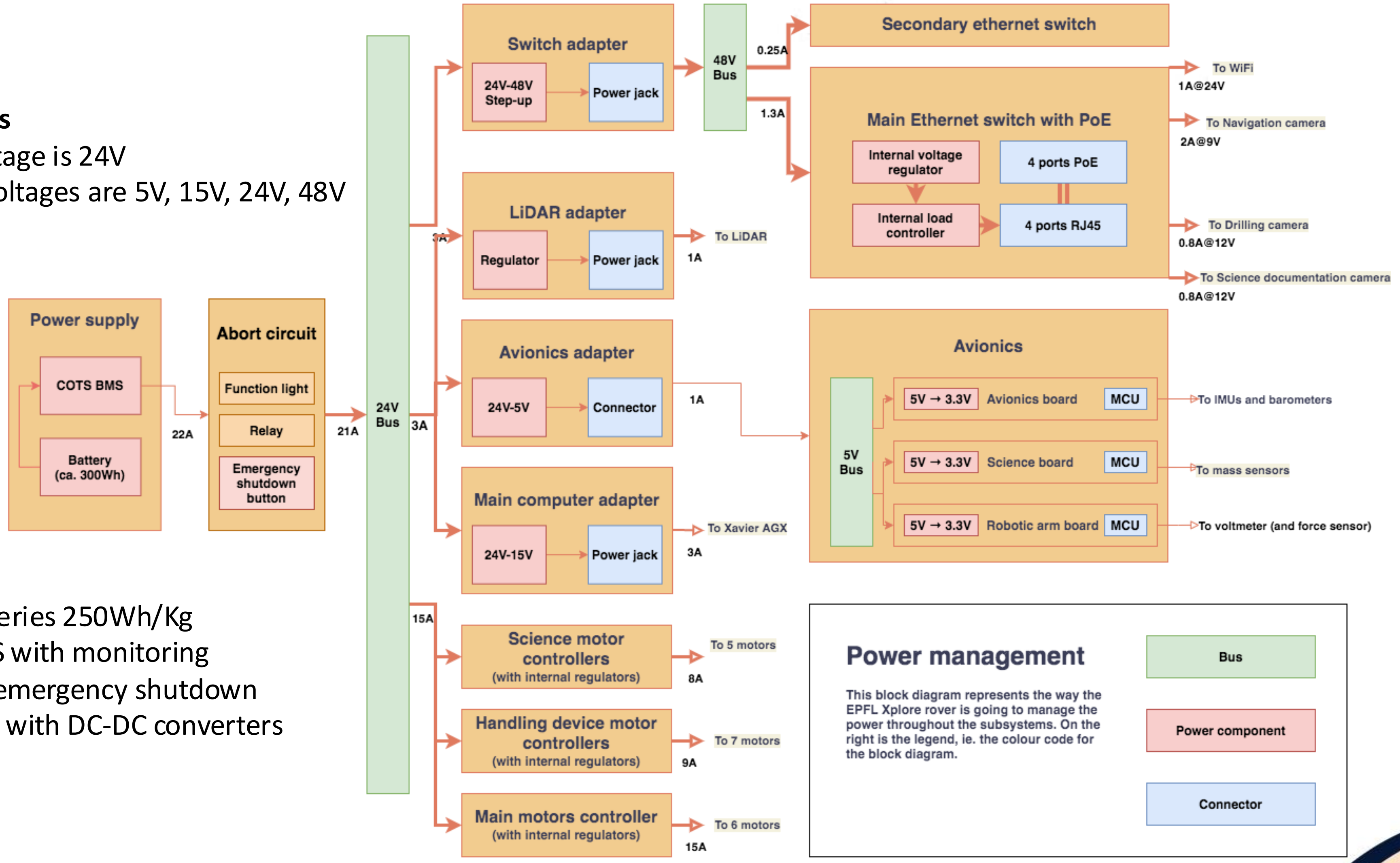


Power Budget



Hardware Architecture

Requirements
- Input voltage is 24V
- Output voltages are 5V, 15V, 24V, 48V



Featuring
- NMC Batteries 250Wh/Kg
- COTS BMS with monitoring
- Relay for emergency shutdown
- SRAD PCB with DC-DC converters

Power Distribution

EPFL

Brief

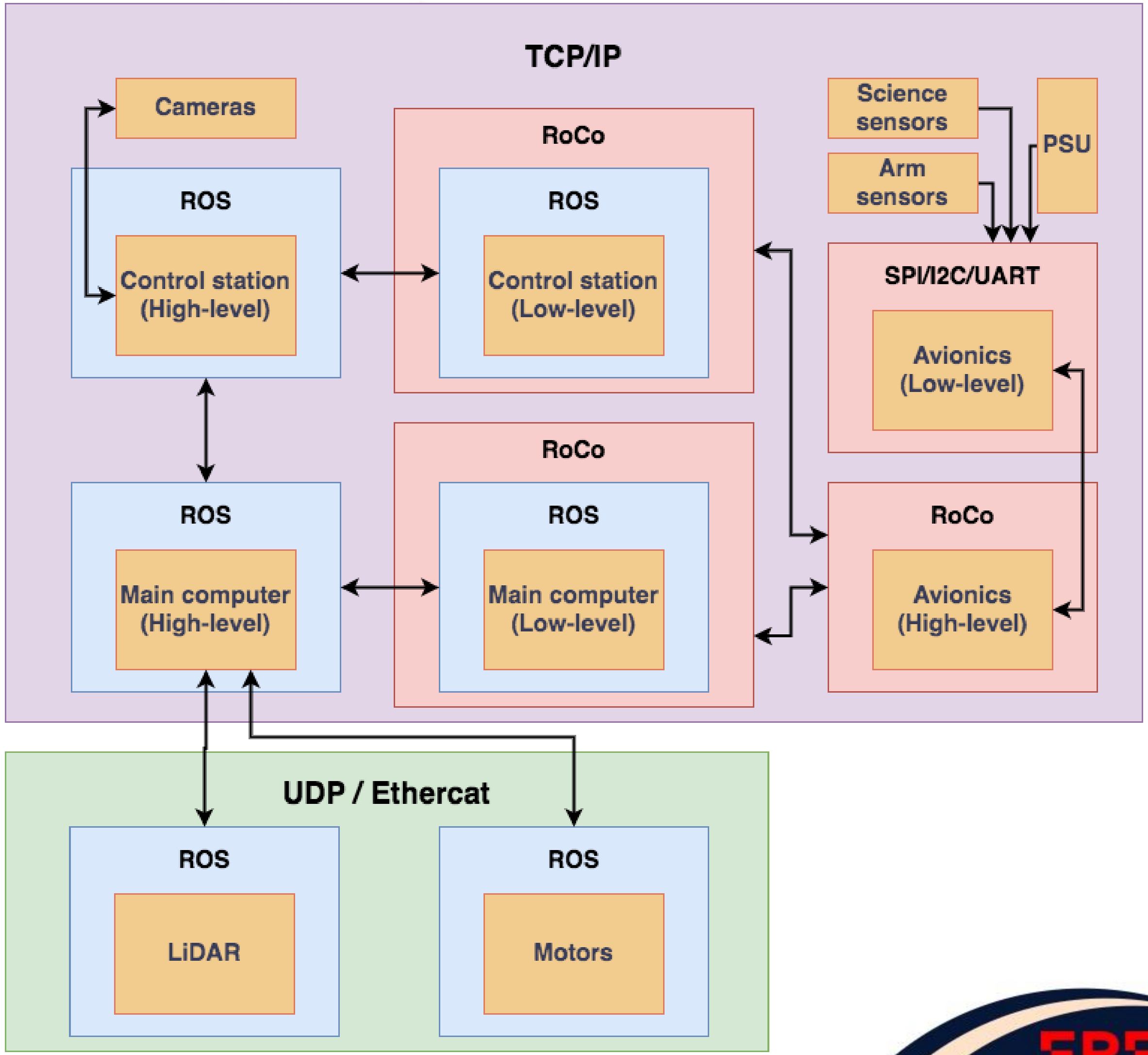
- Using ROS (Robotic Operating System) nodes for high-level communication
- Using RoCo (custom protocol) for low-level communication

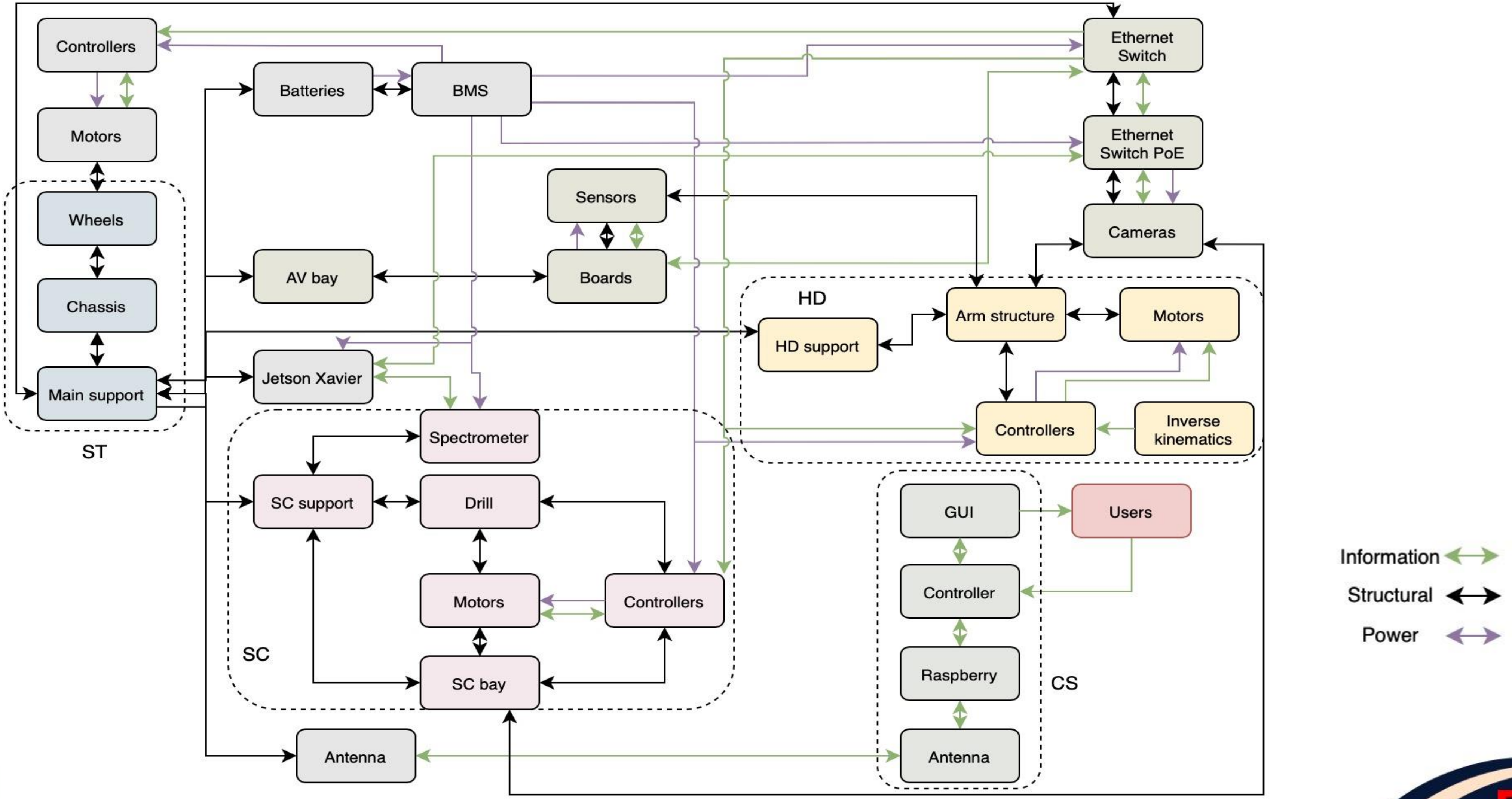
Advantages

- Modular
- Seamless software integration

Disadvantages

- Protocol nesting increases risk of failure
- Development time dedicated to interfacing ROS and RoCo




Controllers
Motors
Wheels
Chassis
Main support
ST
Batteries
BMS
AV bay
Jetson Xavier
Sensors
Boards
Ethernet Switch
Ethernet Switch PoE
Cameras
HD
HD support
Arm structure
Motors
Controllers
Inverse kinematics
Spectrometer
SC support
Drill
Motors
Controllers
SC bay
SC
GUI
Users
Controller
Raspberry
Antenna
CS
Antenna
Information
Structural
Power

	Issue	Possibilities	Decision	Consequences
Number of wheels	How many wheels should the rover have ?	4 or 6 wheels	6 wheels	Higher stability, greater step-climbing ability but a bit heavier
Material for the structure	Which material to choose for the chassis and the structure ?	Full aluminium structure and chassis or combine aluminium and carbon fibre for structure and chassis	Under discussion, depends on the total mass of the rover and the available time for the manufacturing	Alu is easy to manufacture but heavier Carbon fibre is light but anisotropic and complex to manufacture
Surface sampling mechanism	How to recover the surface samples ?	Use the arm from handling device or develop a specific mechanism	Use the existing arm	Heavier but avoids spending time and resources on developing another mechanism
Core boards	Which core boards should we use ?	Homemade PCB or COTS board	COTS board	Gain of time, guarantee that the board is functional, addition of a routing board
Type of chassis	Which type of chassis should we implement ?	Shrimp or Rocker-bogie	Rocker-bogie	No steering of the wheels, easier to control, more compact
Communication bus	Which type of bus should we use to communicate ?	CANbus or Ethercat	Ethercat	PoE camera and motors connected by Ethernet, Ethernet switches No Canbus redundancy
Gripper	How the 2 rotations of the gripper should be implemented?	Differential mechanism or 2 pivots in series	Differential mechanism	Compact mechanism, identical motors, bevel gears

Xplore Implementation	Technology Readiness Level (TRL)
Testing on manufactured Rover	**TRL 9** •Actual system "flight proven" through successful mission operations
	TRL 8 •Actual system completed and "flight qualified" through test and demonstration (ground or space)
	TRL 7 •System prototype demonstration in a space environment
Testing within subsystem	**TRL 6** •System/subsystem model or prototype demonstration in a relevant environment (ground or space)
Testing of advanced prototype under relevant environment	**TRL 5** •Component and/or breadboard validation in relevant environment
First prototype and preliminary testing	**TRL 4** •Component and/or breadboard validation in laboratory environment
Development, modeling and analysis	**TRL 3** •Analytical and experimental critical function and/or characteristic proof-of-concept
Concept and ideas studies	**TRL 2** •Technology concept and/or application formulated
Task definition	**TRL 1** •Basic principles observed and reported

References:
Nasa: https://www.nasa.gov/pdf/458490main_TRL_Definitions.pdf
Nasa: https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_accordion1.html

Risk Table

Probability \ Consequence	None 0	Very low 1	Low 2	Medium 3	High 4	Very high 5
Very low 1		1	2	3	4	5
Low 2		2	4	6	8	10
Medium 3		3	6	9	12	15
High 4		4	8	12	16	20
Very high 5		5	10	15	20	25

Risk	R≥20	Risk requires priority actions and aggressive risk response strategies.
	20>R≥10	Risk requires priority actions and aggressive risk response strategies. Implement risk response if risks moves to the above category or if time allows.
	10>R≥5	Risk requires actions and risk response strategies.
	5>R>1	Risk not critical. Documented for periodic review.
	R=1	Risk not critical. Documented for periodic review.

Strategies	Avoid	Eliminate threat by eliminating cause (relax objectives, clarify requirements, improve communication)
	Mitigate	Reduce probability or impact of threat (reinforce test plan, build prototype)
	Transfer	Make another party responsible for risk (purchase insurance, outsource work)
	Accept	**Active** acceptance (involve creation of contingency plans and reserves to be implemented if risk occurs ≠ passive acceptance leaving actions to be determined of risk occurs)

References:
Nasa: https://ntrs.nasa.gov/citations/20050123548, Malone, Roy W., Jr., Moses, Kelly
BOBST: A. Pauchard – L.Badet, Groupd R&D, EPFL, 01-02.10.2020

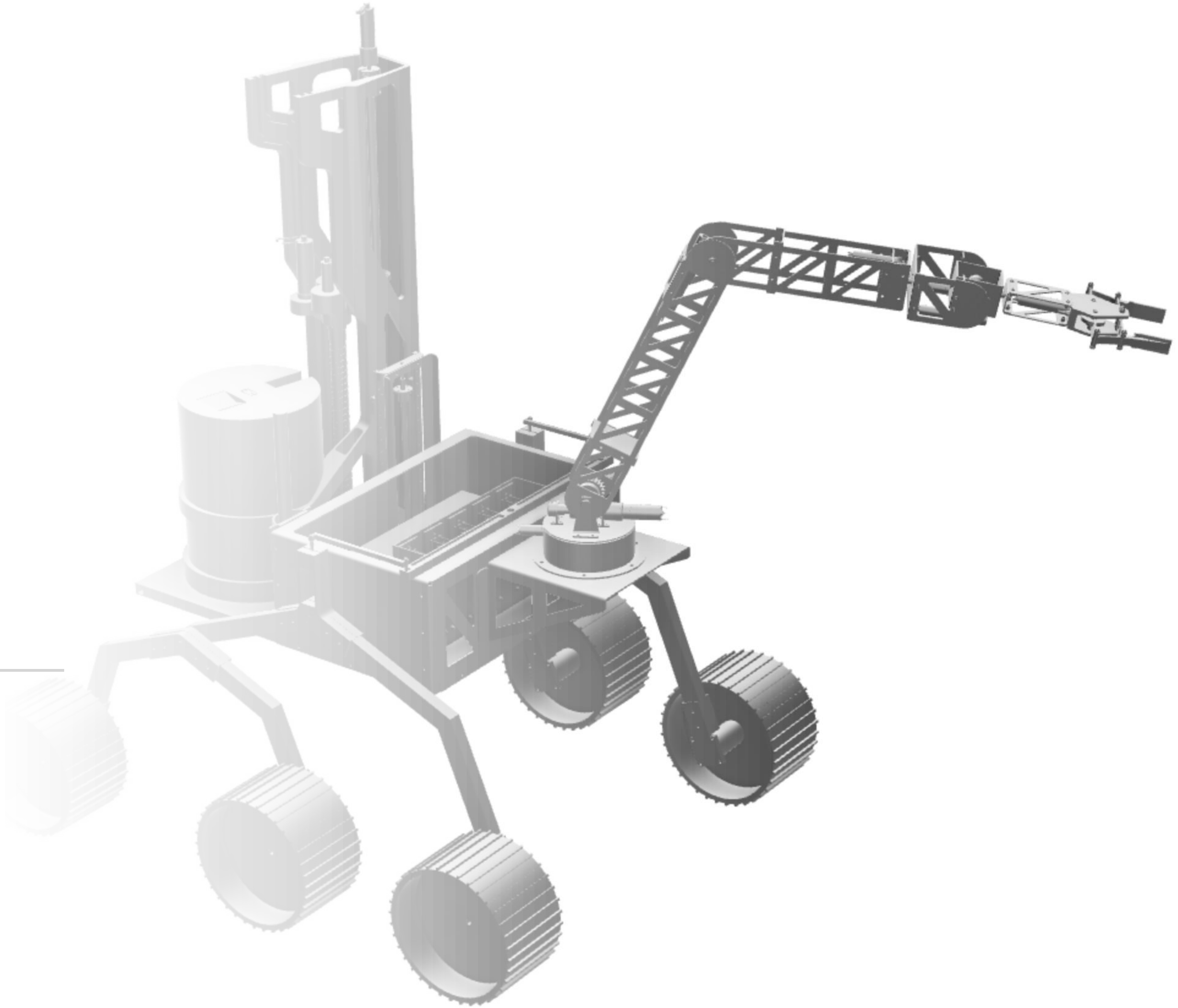
Document	**General Risk Analysis**

Ref / ID	Risk	Consequence	Probability	Impact	Risk	Strategy	Risk Response
XP_SE_RA_N001	Difficulties to find sufficient fundings (CHF 100'000) given the current pandemic situation	Inability to finance the project	**High**	**Very high**	20	Mitigate	Constantly search for foundings. Have multiple sources of foundings. Develop prototypes to show (also helps for testing).
XP_SE_RA_N004	Manufacturers unable to deliver on time given the current pandemic situation (multiple months to ship)	Manufacturing delay: Failure to meet the manufacturing timeline	**High**	**Very high**	20	Avoid	Order as many parts as possible right after PDR and absolutely before Christmas.
XP_SE_RA_N008	Based on uncertainties regarding the manufacturers shiping delays (1 to 2 months delay because of the pandemic situation), the assembly and therefore the testing of the Rover may be delayed	Rover not completely tested	**High**	**Very high**	20	Mitigate	Order as many parts as possible right after PDR and absolutely before Christmas. Manufacture as much as possible on campus. Increase the testing phase during the summer.

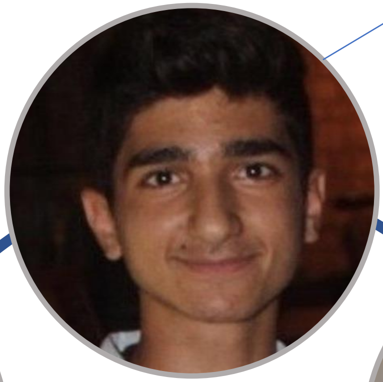
Q&A Session (10 minutes)

Structure

Chassis
Differential
Wheels
Avionics & Navigation bays



Structure Team



Ray Al Dayem

Structure Team Leader

Giovanni Vittorio Boba

Mechnaical Engineer

Alexis Cogne

Mechanical Engineer

Emile Charles

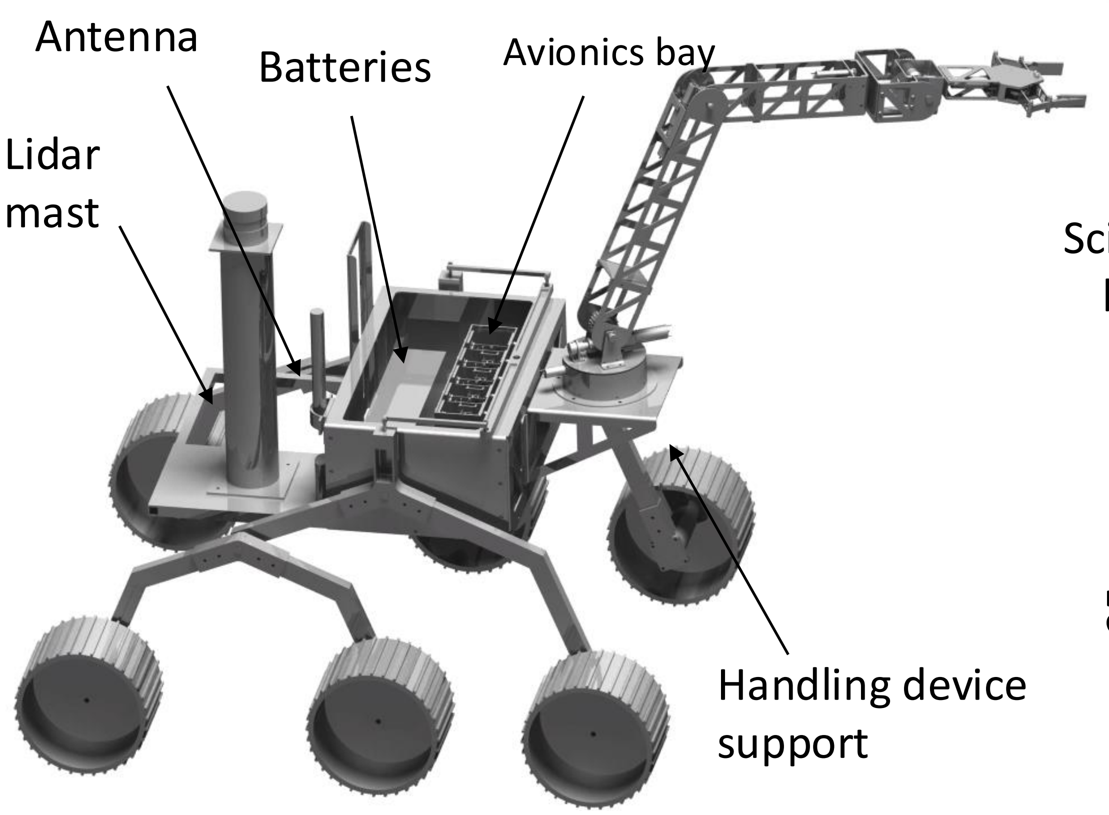
Mechanical Engineer

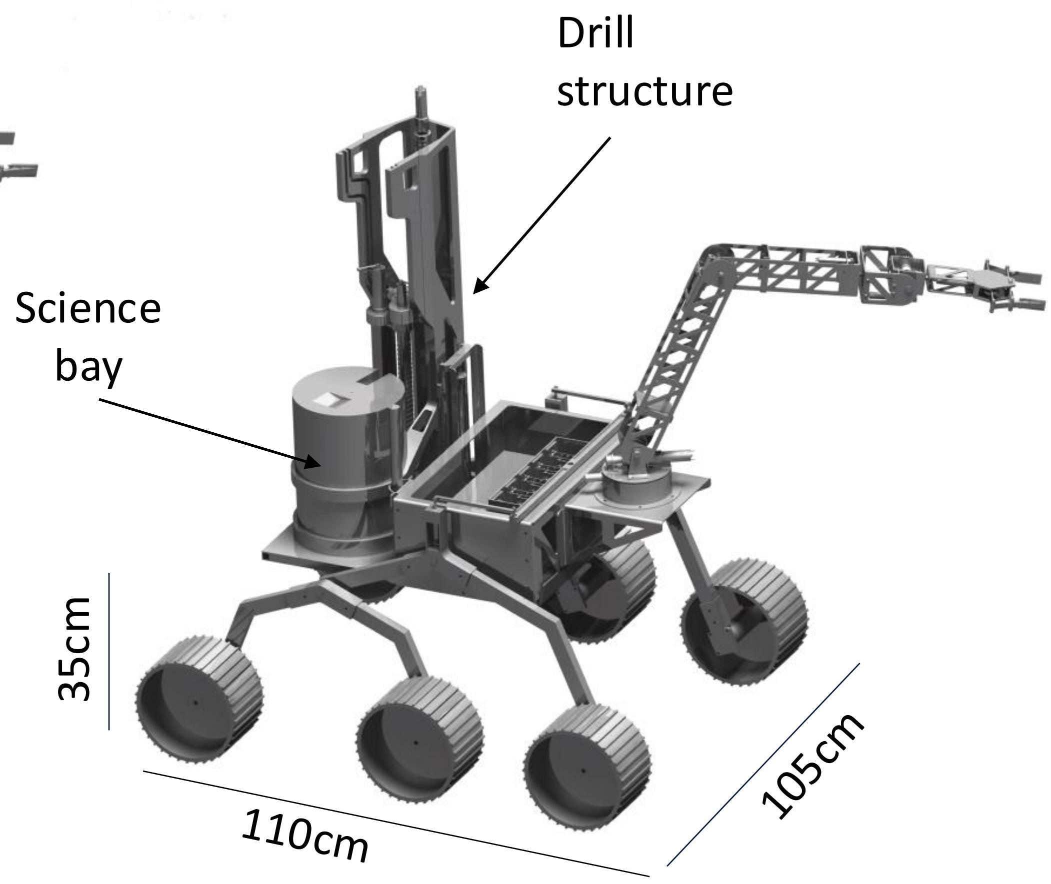
Mickael Grindoz

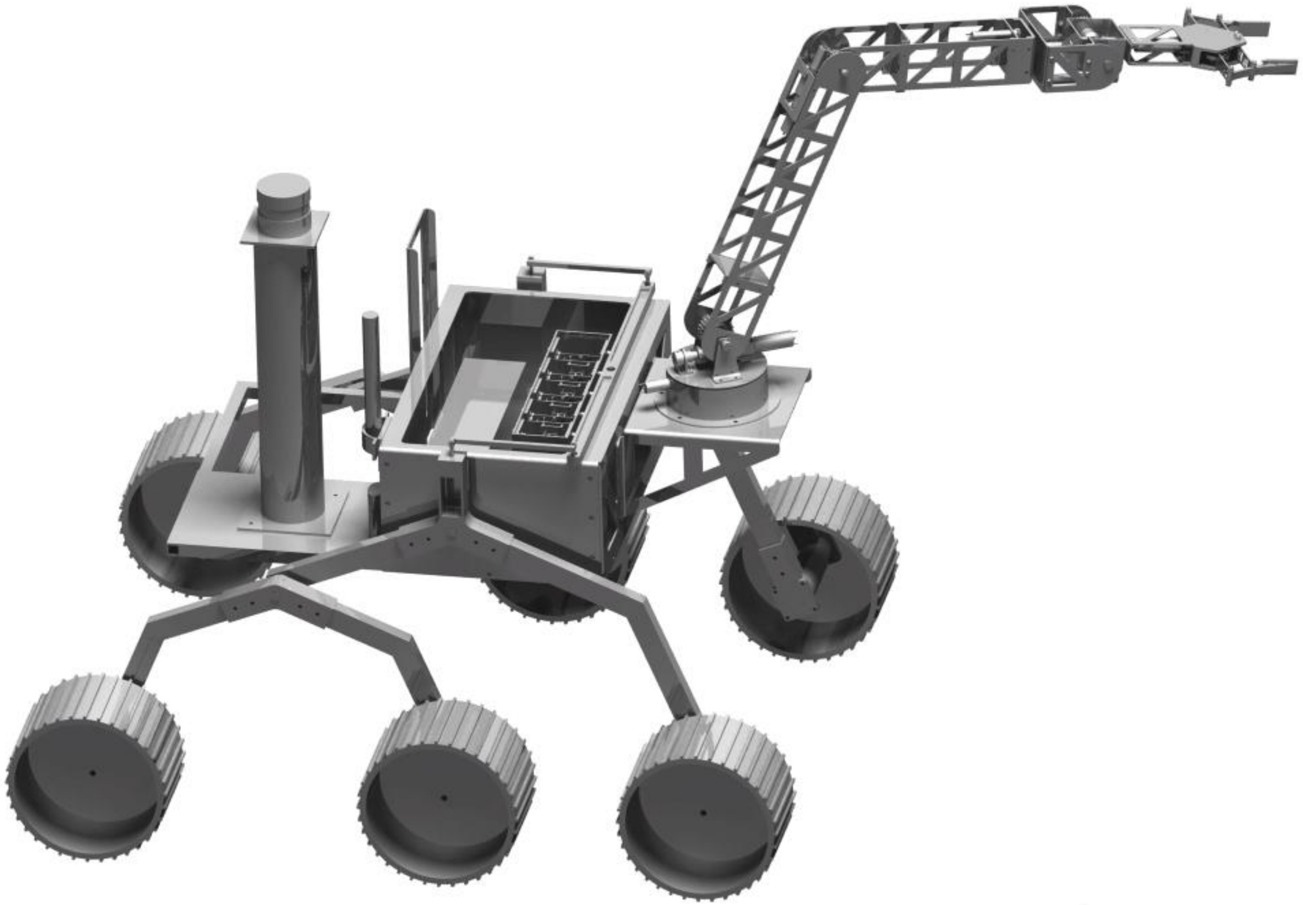
Mechanical Engineer

Document	Structure Requirements

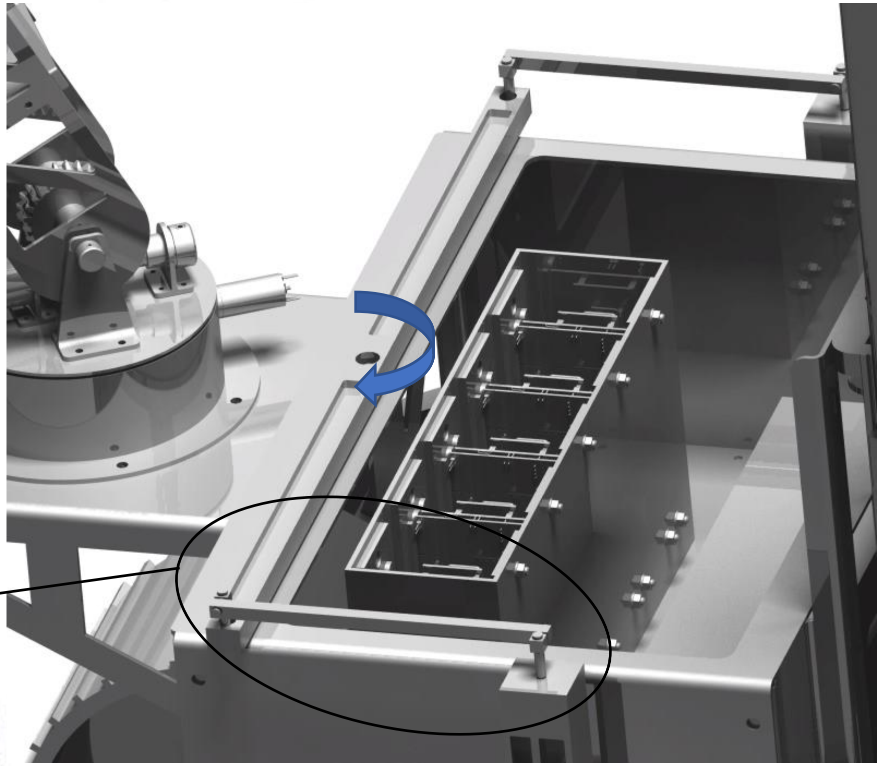
ID	Description	Verification method
EPFL_XP_AV_ST_003	The rover shall be able to climb slopes of {20}°	Test
EPFL_XP_ST_009/010	The wheels/chassis shall damp vibrations	Analysis Test
EPFL_XP_SE_ST_001	The ST subsytem shall not weigh more than {9.6} kg	Test Review-of-design
EPFL_XP_ST_004	The rover shall be equipped with a 4 compartments detachable container	Test
EPFL_XP_SC_ST_001	The SC bay and the cache container should be removable	Test Review-of-design


Antenna
Batteries
Avionics bay
Lidar mast
Handling device support

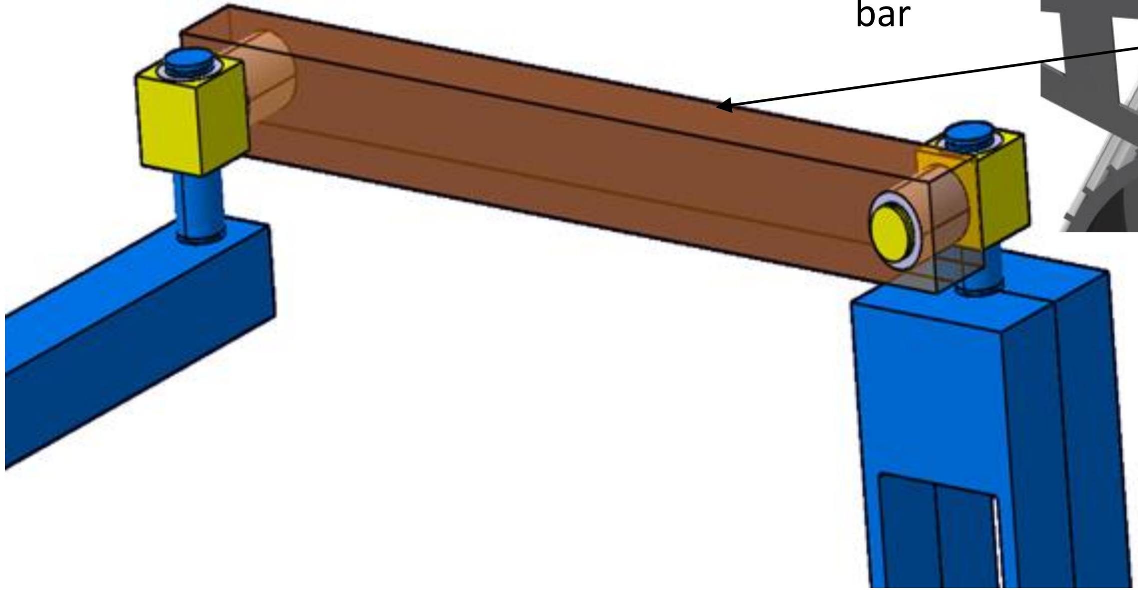

Drill structure
Science bay
35cm
110cm
105cm



Rocker-Bogie Architecture



Differential
bar

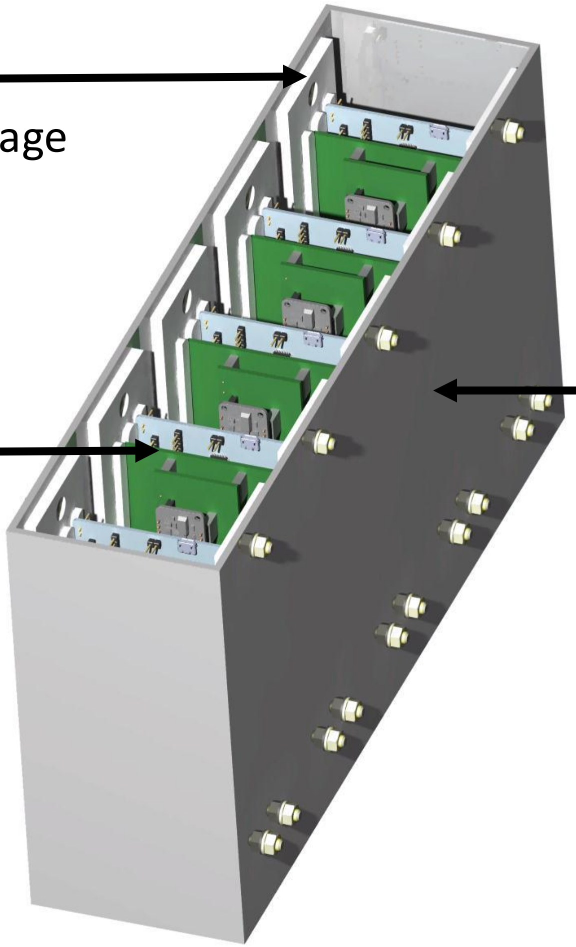


Differential
Structure

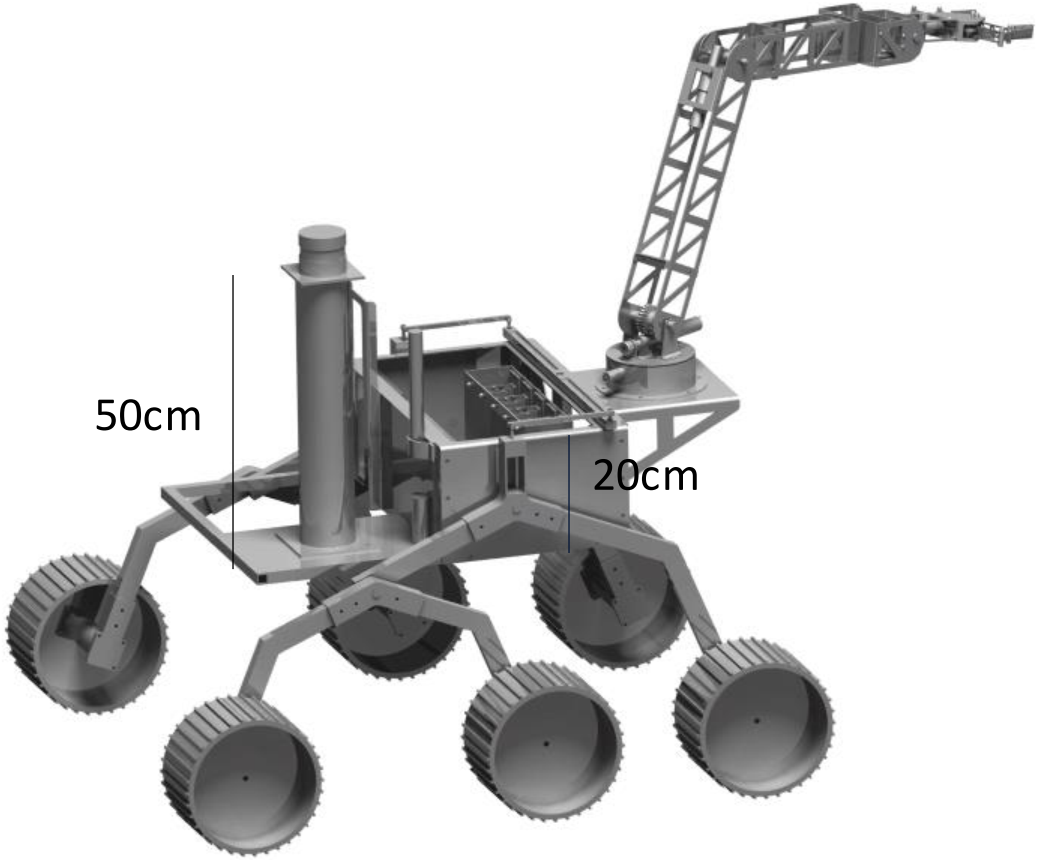
Structure

3D printed rails
➔ Easy boards storage

Avionics boards



MDF/Plywood sheets assembly
➔ Low density
➔ Good machinability

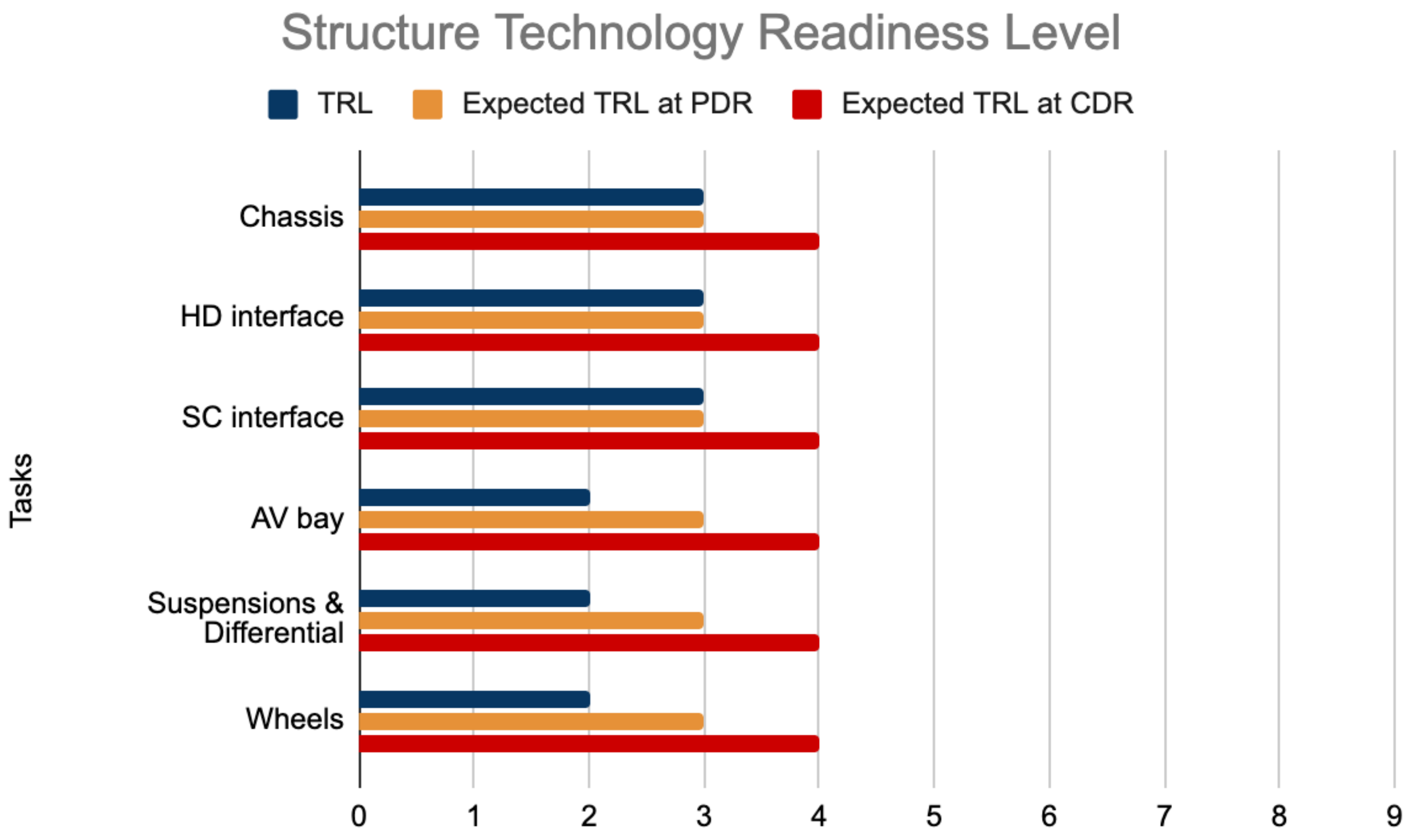


1 Lidar and 2 cameras to mount :

- Required Lidar position : height 50cm
- 1 Camera on the same mast
- 1 Camera for drilling view: bottom of structure

Document	Structure Risk Analysis

Ref / ID	Risk	Consequence	Probability	Impact	Risk	Strategy	Risk Response
XP_ST_RA_N001	Given that the rover shall be able to overcome slopes of 20°, there is a possibility of being blocked or disabled by obstacles with a higher slope.	Rover not able to move	**Medium**	**Very high**	15	Avoid	Conduct advanced tests on the chassis and its response to numerous kinds of obstacles. See with Navigation that they don't send the rover on slopes with higher angles than 20°. Conduct advanced test on the obstacle avoidance algorithms


Structure Technology Readiness Level
TRL
Expected TRL at PDR
Expected TRL at CDR
Tasks
Chassis
HD interface
SC interface
AV bay
Suspensions & Differential
Wheels
0
1
2
3
4
5
6
7
8
9

Next Step

Developp wheel design and its interface with the chassis

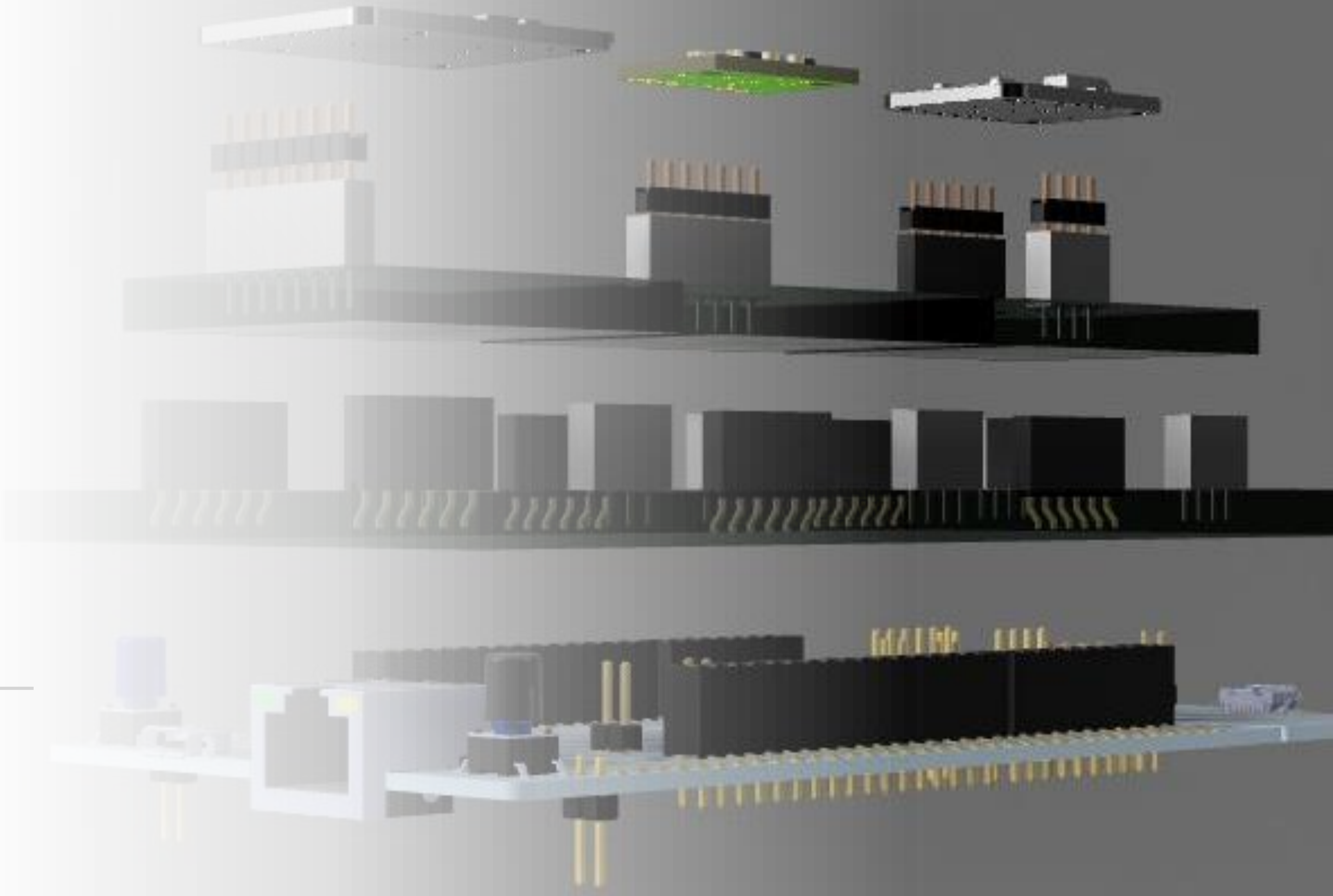
Optimize the structure design to minimize weight (especially rear end)

EPFL

Q&A Session (10 minutes)

Avionics

PCB design
Sensors



Avionics Team

Théo Schäfer

Avionics Team Leader

Pierre-Louis Gaultier

Hardware Engineer

Myriam Rihani

Software Engineer

Léo Litrico

Software Engineer

Josef Thomas

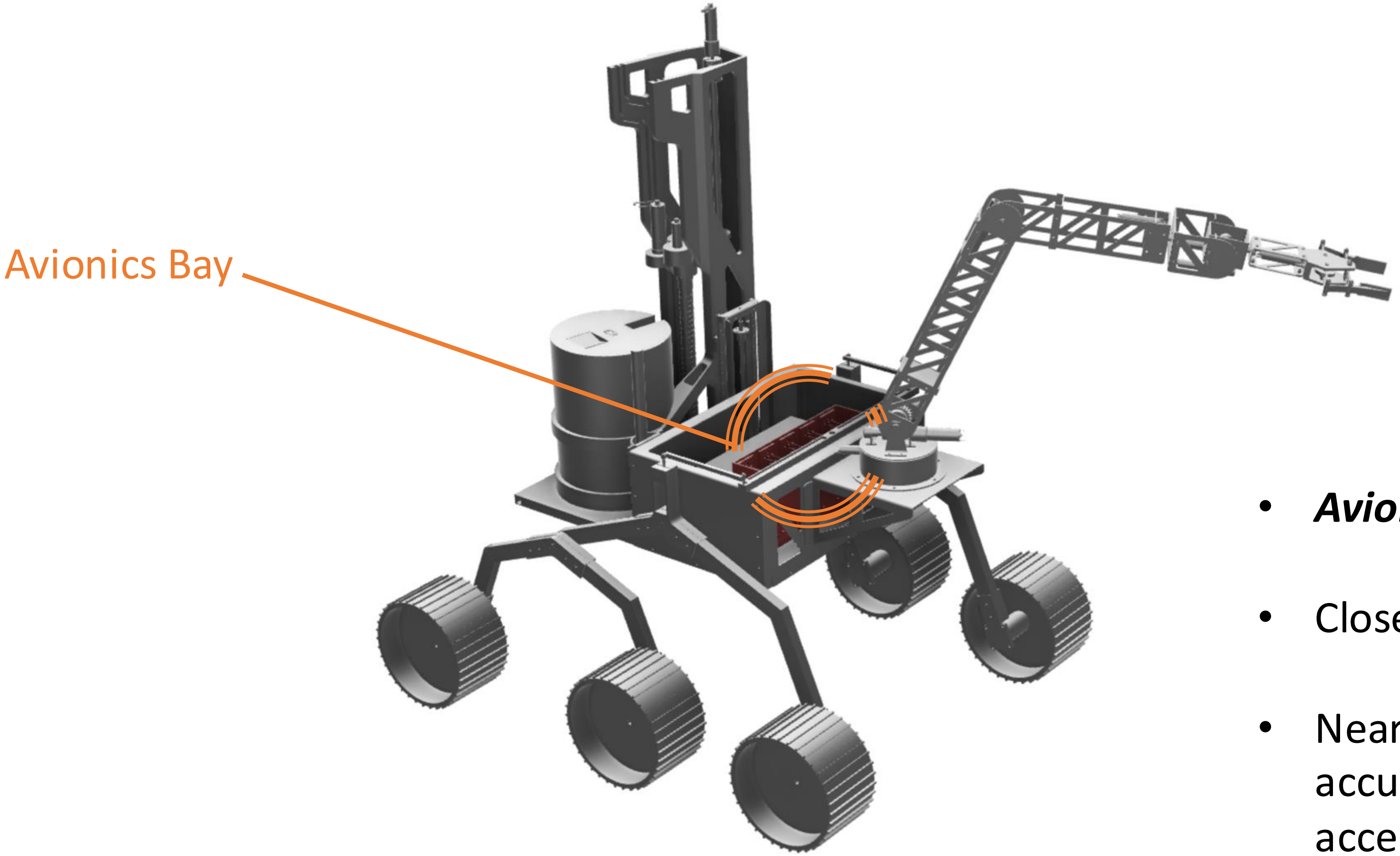
Software Engineer

Omar El Maki

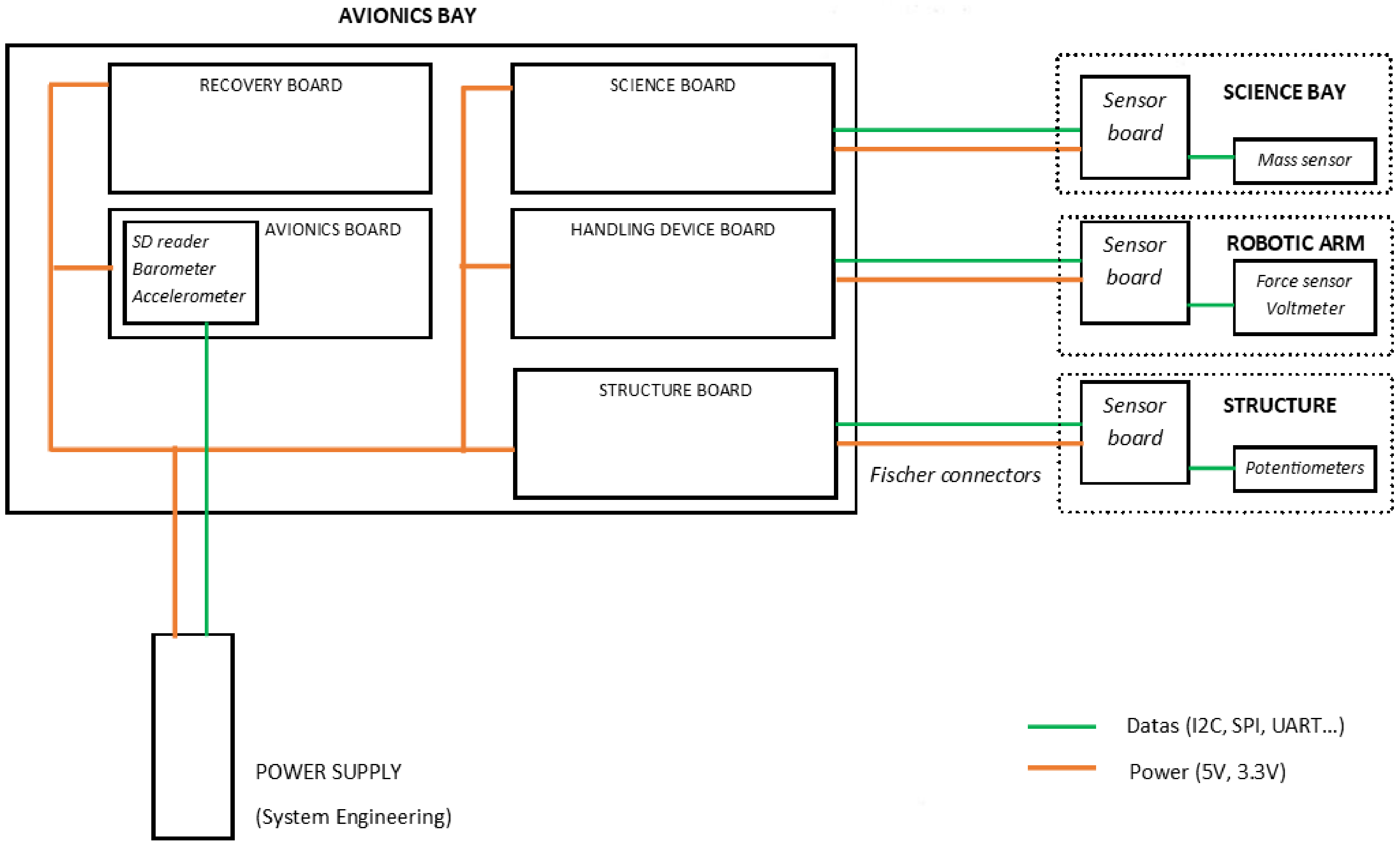
Software Engineer

Document	Avionics Requirements

ID	Description	Verification method
EPFL_XP_AV_001	The rover shall be able to travel 100m from the starting point	Test
EPFL_XP_AV_CS_002	The operator shall be aware of the situation of the rover	Test
EPFL_XP_AV_007	The motors shall be connected by Ethernet	Review-of-design
EPFL_XP_AV_SE_004	The batteries shall provide at least {300} Wh	Review-of-design

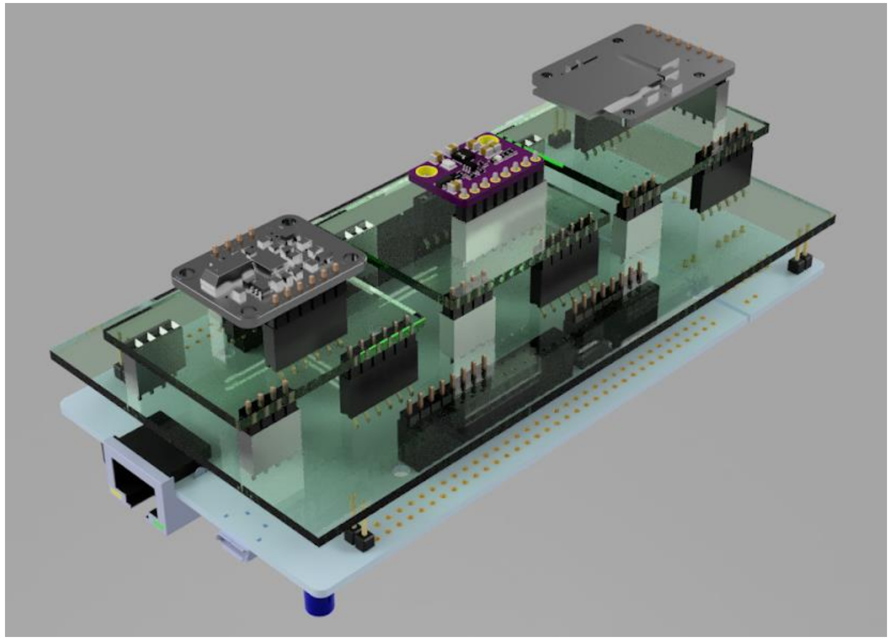


- ***Avionics bay***
- Close to the power supply
- Near the center of mass for more accurate datas acquired by accelerometers

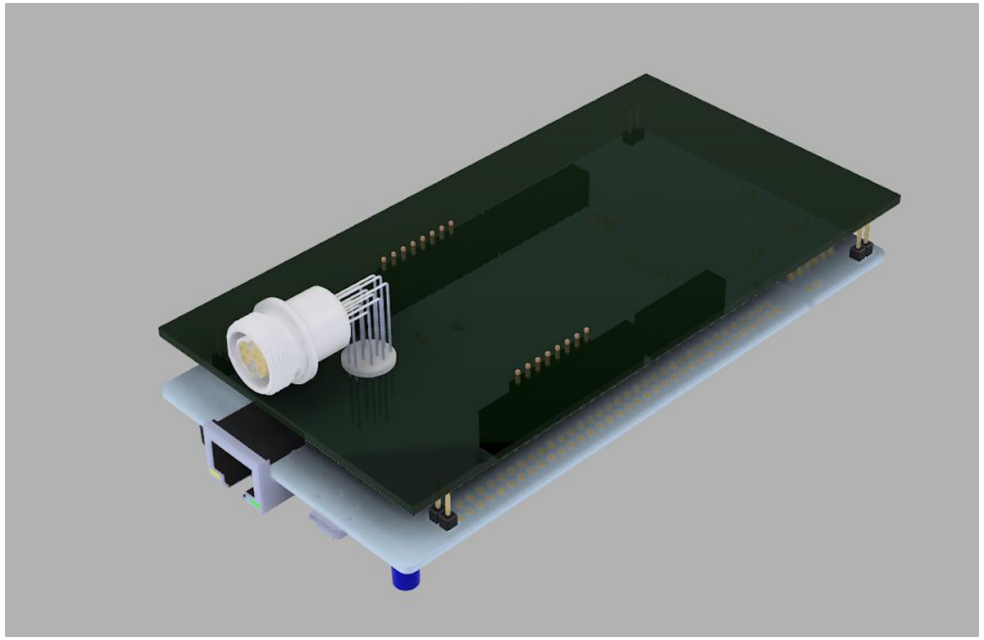


Avionics Architecture

Avionics Board

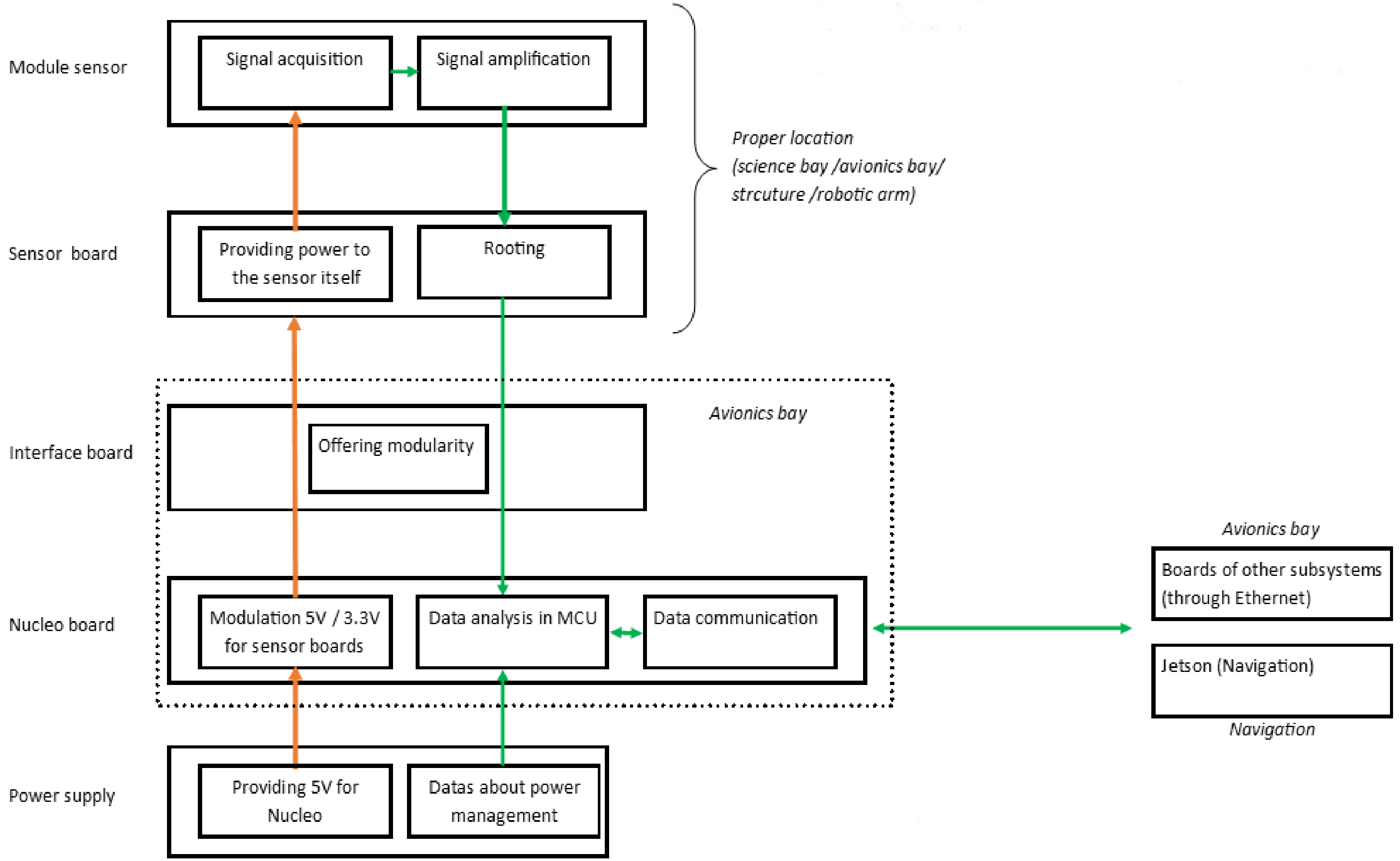


Handling Device and Science Boards

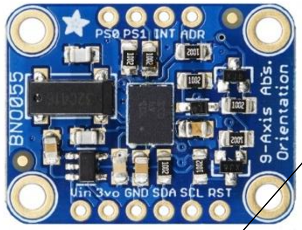


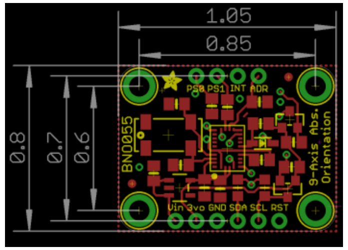
- **Best modulatrity** thanks to **universal connectors** (Xplore standards) on the boards
- **Compatible** with I2C, SPI and UART without any change in design thanks to premade rooting to µC pins
- **Multi-layers design** for easier change in overall design, or instant remplacement of broken sensors
- **Clean implementation** without wires

Boards Design

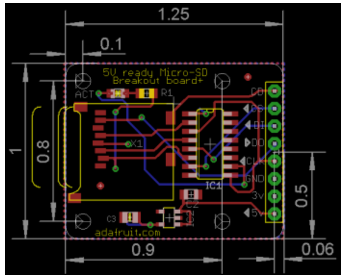


Boards Design



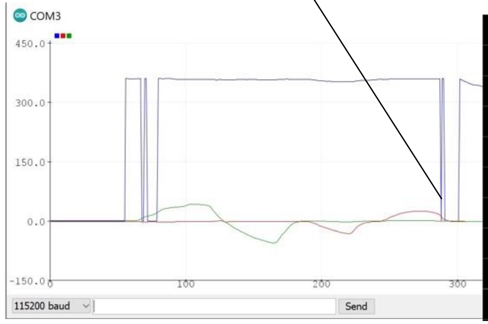


BNO055

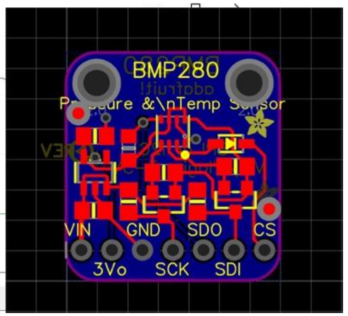


SD Card

Sensors

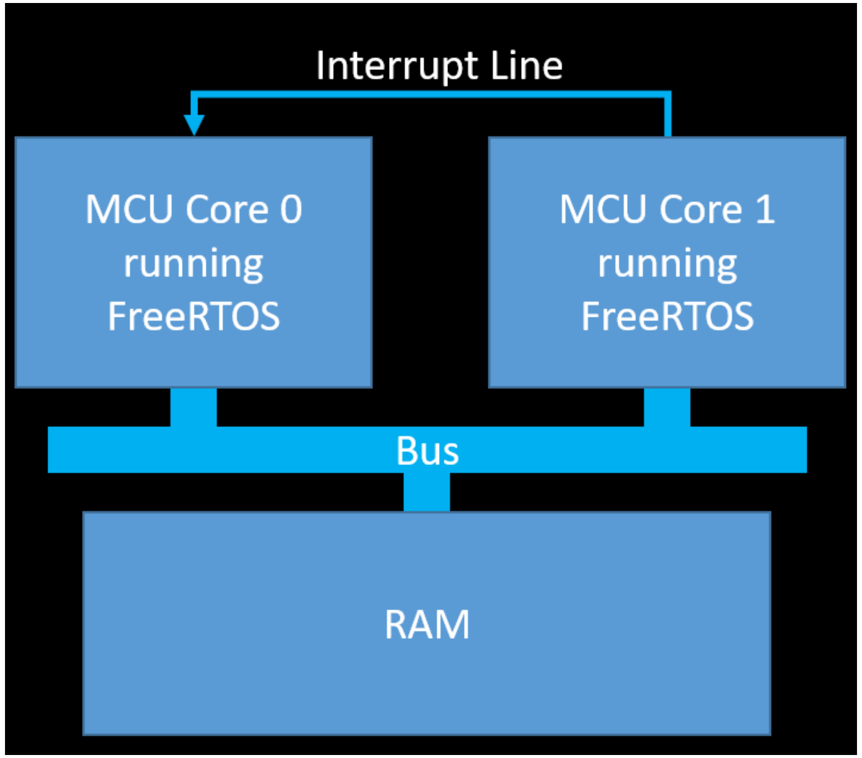


BMP280 datas



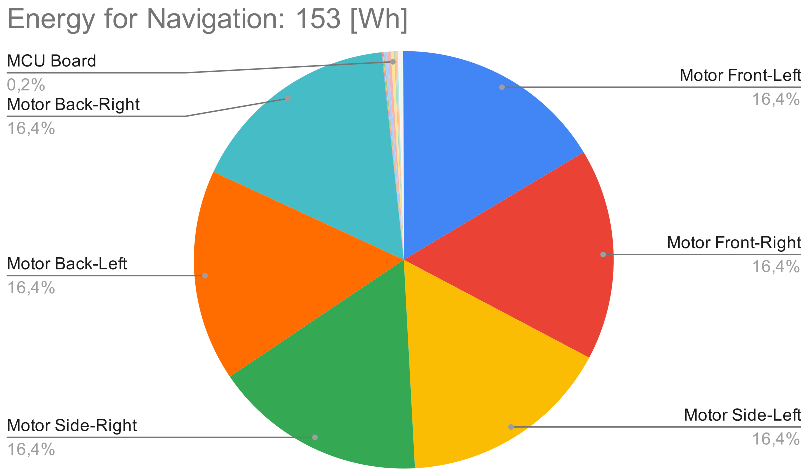
BMP280

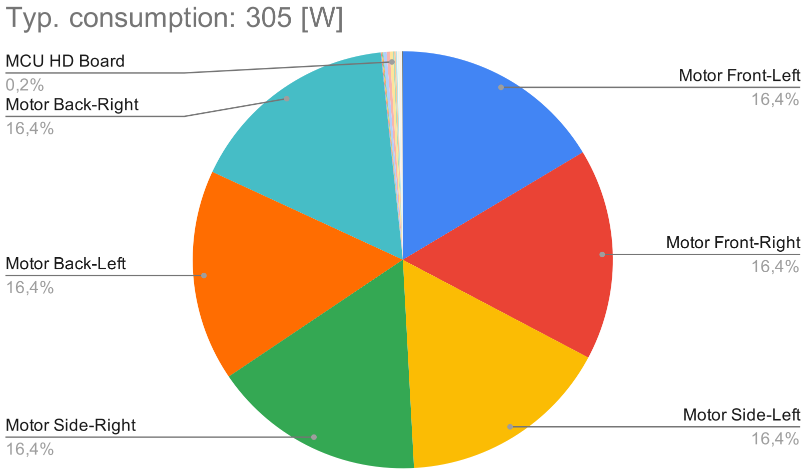
freeRTOS Multicore Architecture



Avionics power budget

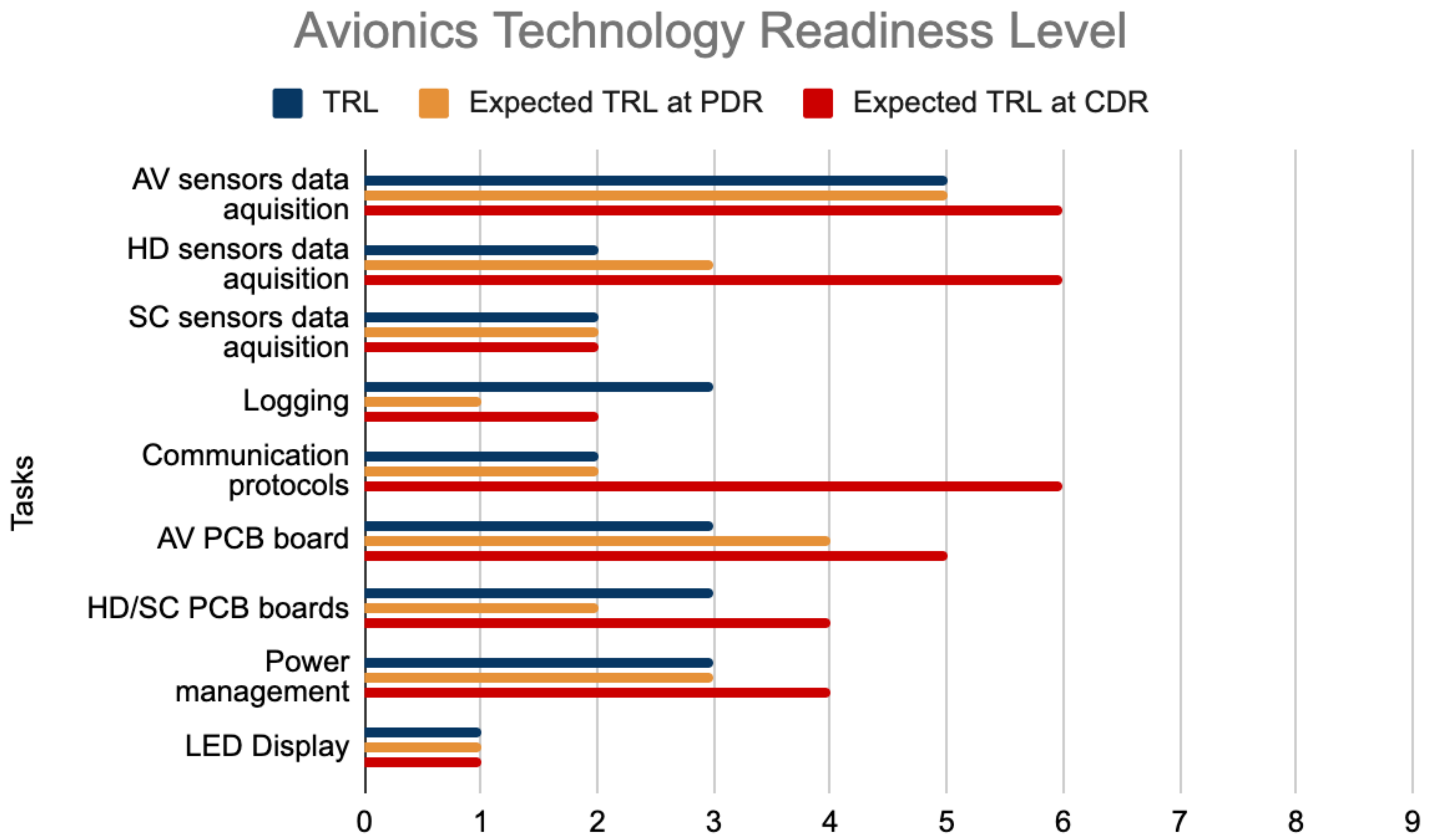
Maximum energy consumption is **153Wh** for Navigation task
Nominal power in full operation: **305W**



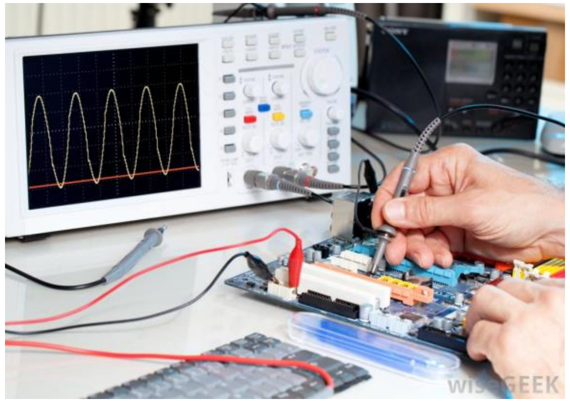


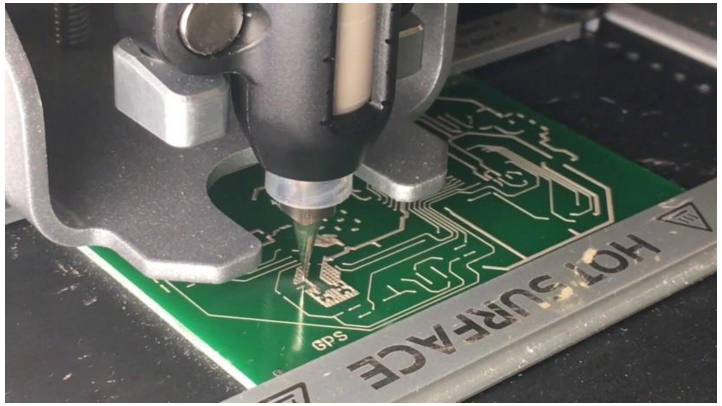
Document	Avionics Risk Analysis

Ref / ID	Risk	Consequence	Probability	Impact	Risk	Strategy	Risk Response
XP_AV_RA_N007	Given that there is a lot of data to load, there is a possibility that we will run out of storage.	Overriding and loss of data, leading to corruption	**Medium**	**Medium**	9	Mitigate	Implement functions to handle limit cases and document the code, Have extra sd cards onhand
XP_AV_RA_N008	Given that the RAM is relativaly small compared to the flow between the two cores, there might be a possibility of the RAM filling up or overload	Leading to miscommuntion between the two cores which relates to data logging problems.	**Medium**	**Medium**	9	Mitigate	Implement a function that would reset the RAM and save the data elsewhere
XP_AV_RA_N009	Given that there are many threads running at the same time, there is a possibility that each thread conflicts and causes timing related problems	Leading to slower communication/processing and a possible backup of data/commands	**Low**	**High**	8	Accept	Extensive planning and testing of different thread priorites within freeRTOS
XP_AV_RA_N011	PCB may become unplugged due to severe vibration of the rover	No more connection between the boards and no data transmitted by the sensors	**Medium**	**Very high**	15	Avoid	Good contact and welding in the header + solution with the pole structure in order to reinforce the attachments
XP_AV_RA_N012	PCB RISK : short (Electrical), warping, cracking, breaking (Mechanical), delamination (Thermal), contamination (Environmental)	No more connection between the boards and no data transmitted by the sensors	**Low**	**Very high**	10	Avoid	Have our designs verified by the ACI lab before production, test a lot


Avionics Technology Readiness Level
TRL
Expected TRL at PDR
Expected TRL at CDR
Tasks
AV sensors data aquisition
HD sensors data aquisition
SC sensors data aquisition
Logging
Communication protocols
AV PCB board
HD/SC PCB boards
Power management
LED Display
0
1
2
3
4
5
6
7
8
9

- **Prototyping** of the PCBs in the EPFL PCB Lab
- **Implementation** of the sensor modules
- **Testing** of the software on our PCB





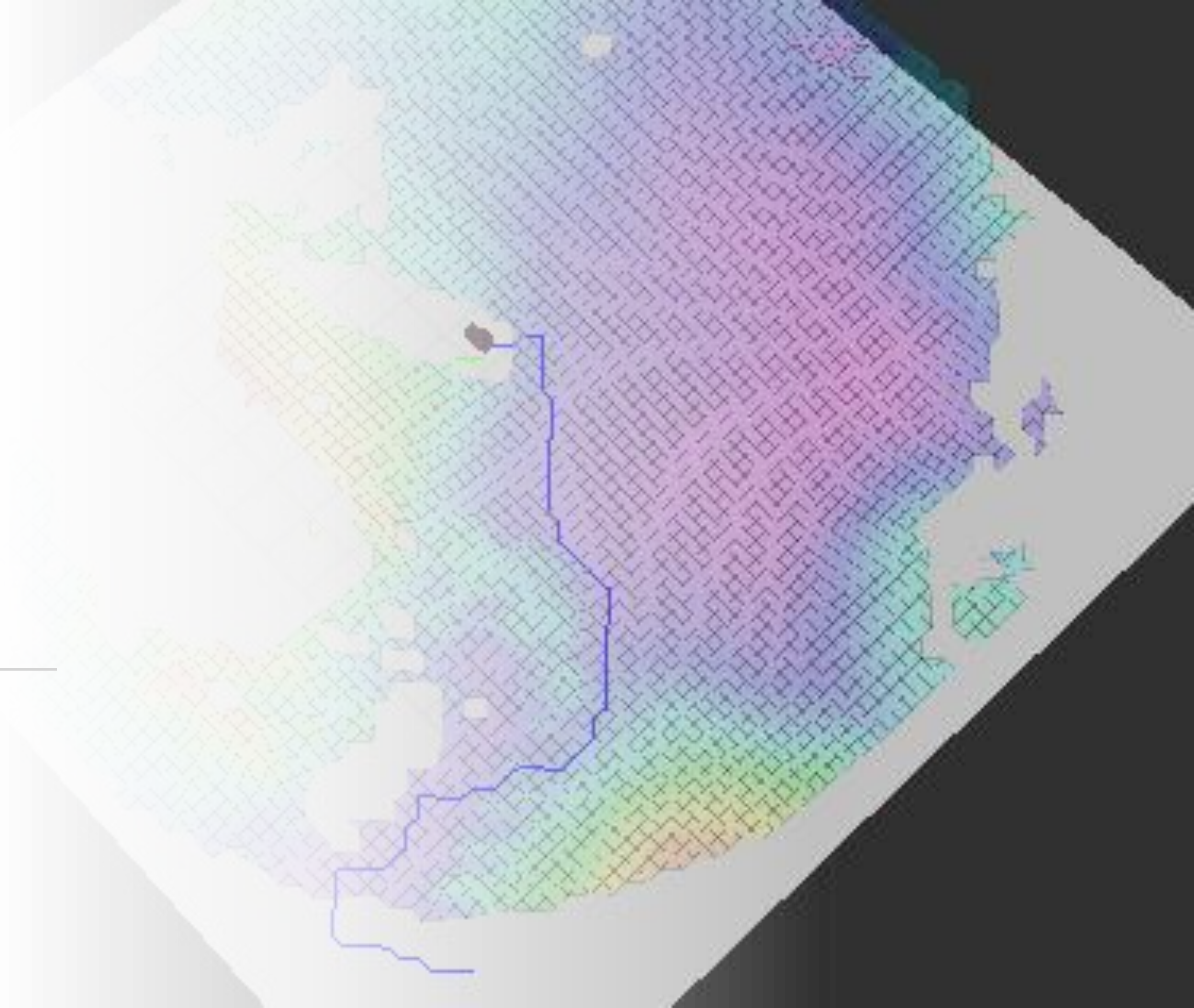
Next Step

EPFL

Q&A Session (10 minutes)

Navigation

Elevation Map
Path Optimization
Localization
Motors control



Navigation Team

Etienne Salimbeni

Navigation Team Leader

Noureddine Gueddach

Software Engineer

Samuele Lanzanova

Software Engineer

Harsh Jaiswal

Software Engineer

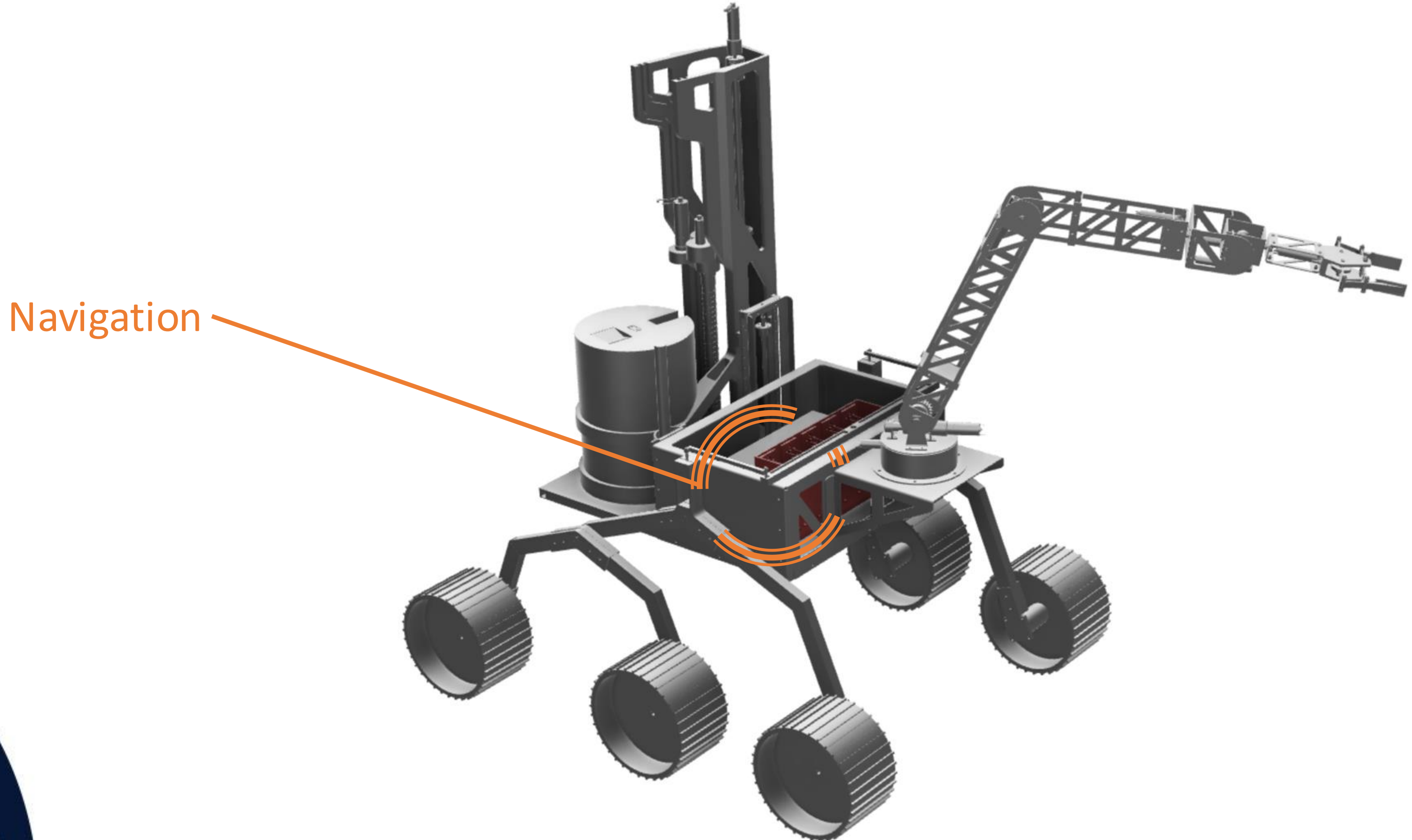
Bastien Darbellay

Software Engineer

Document	Navigation Requirements

ID	Description	Verification method
EPFL_XP_NA_00[1-7]	The rover shall be able to enter the state idle/start/working/wait	Test
EPFL_XP_NA_009	The rover shall be able to report its localisation with an accuracy below 5% of to the traveled distance	Test
EPFL_XP_NA_012	The rover shall be able to navigate semi-autonomously from A to B (i.e. with no visual assist for the operator but only position and orientation data)	Test
EPFL_XP_NA_014	The system shall be able to plan an optimal path based on a given map and waypoint coordinates	Test

Navigation



Rover position

AT-tag detection

1. Surroundings Scan
LiDar & Stereo Cam

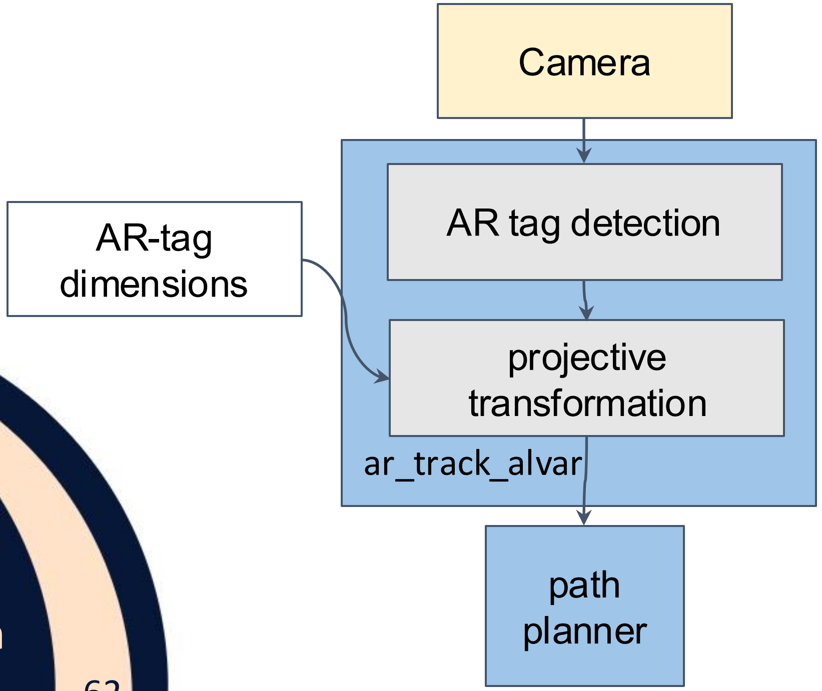
2. Elevation Map
Scan parsing

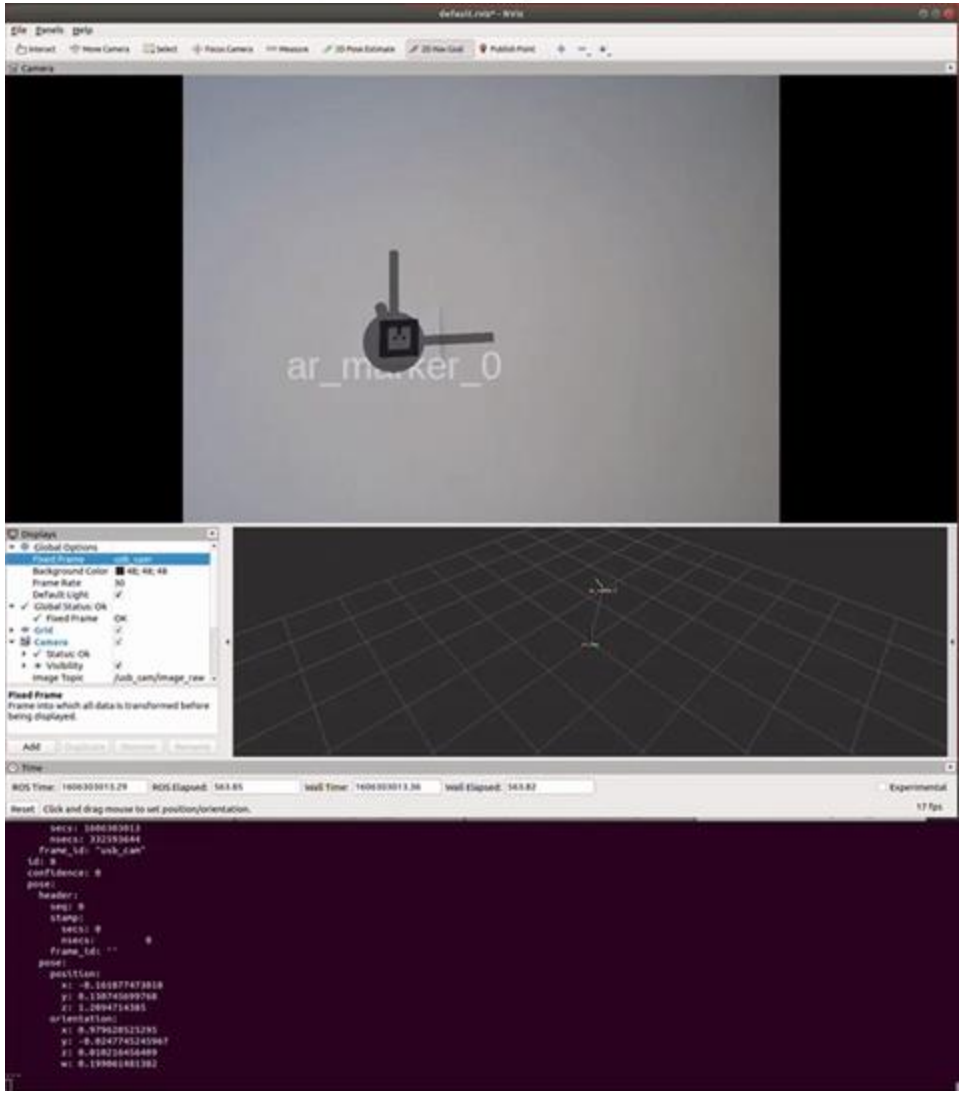
3. Path Planner
Target update

4. Moving towards target
Signal sent to motors

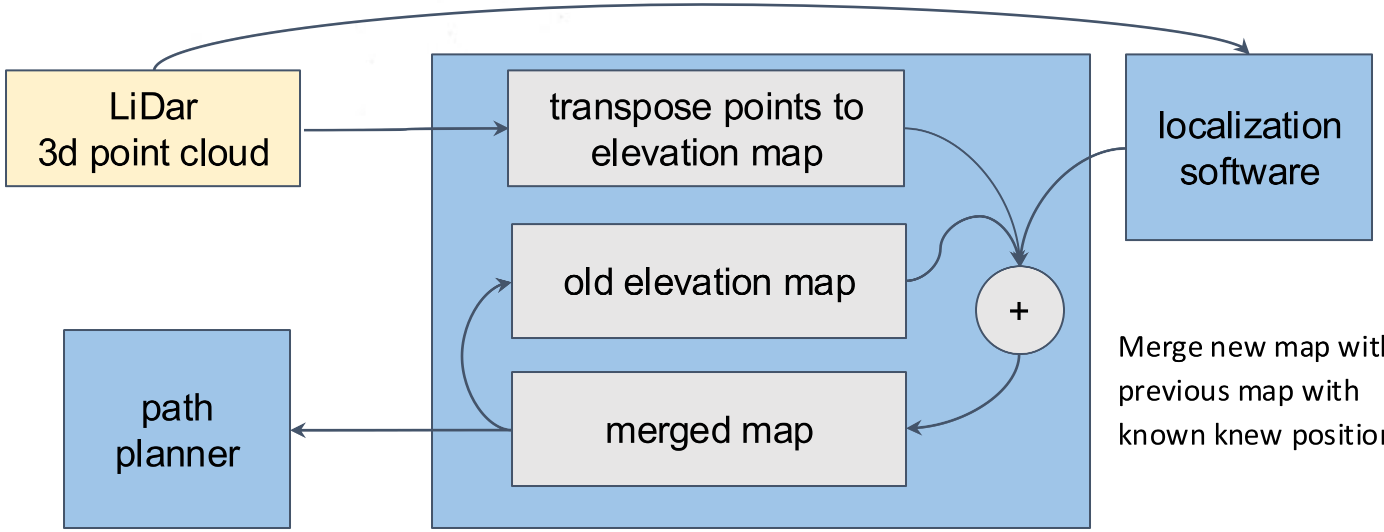
AR tag detection with camera

- with known dimensions of AR-tag, we compute its position and orientation in space relative to the camera



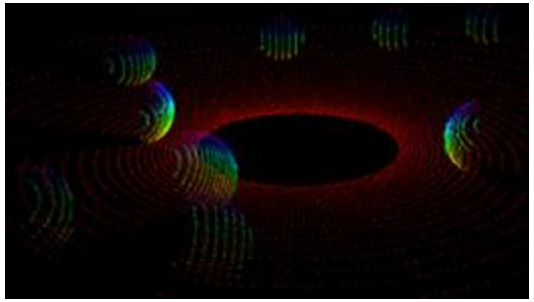


elevation map generated from ouster **OS1 LiDar** point clouds

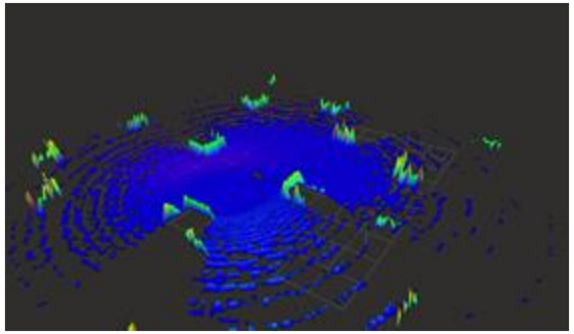


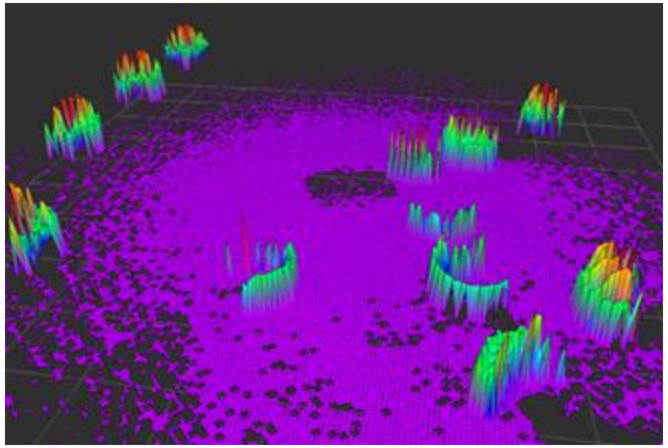
Merge new map with previous map with known knew position

3D point cloud

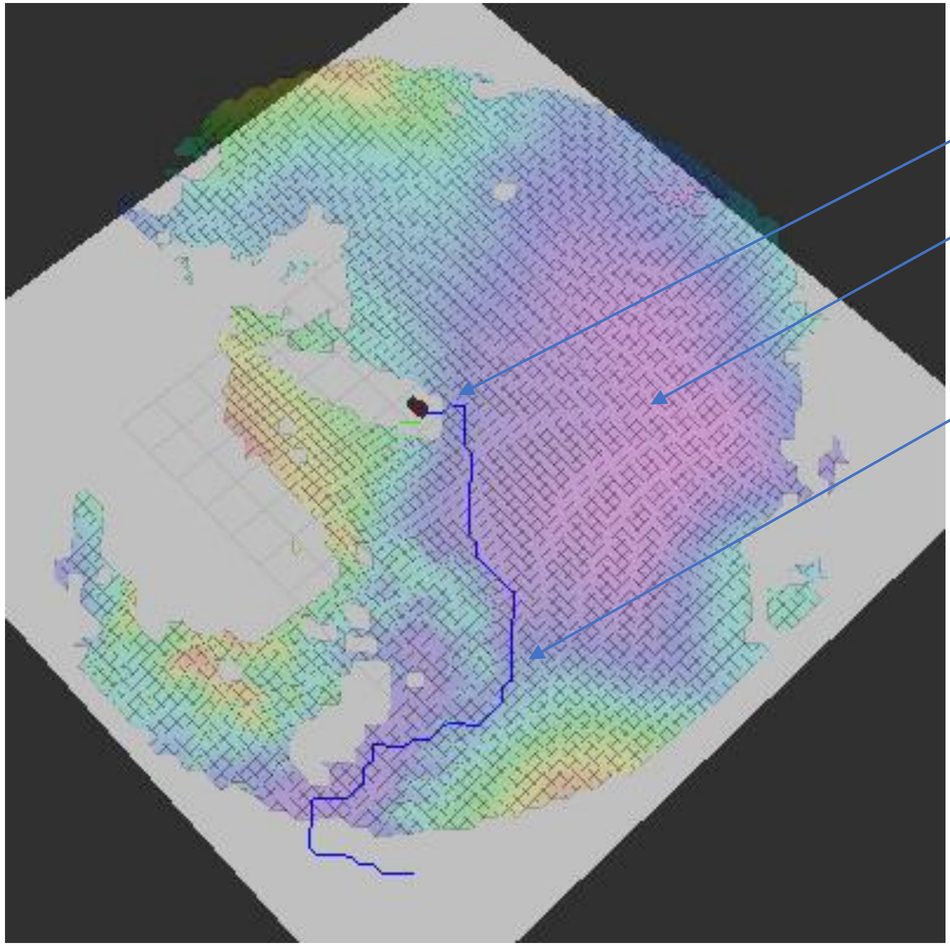


merged elevation map





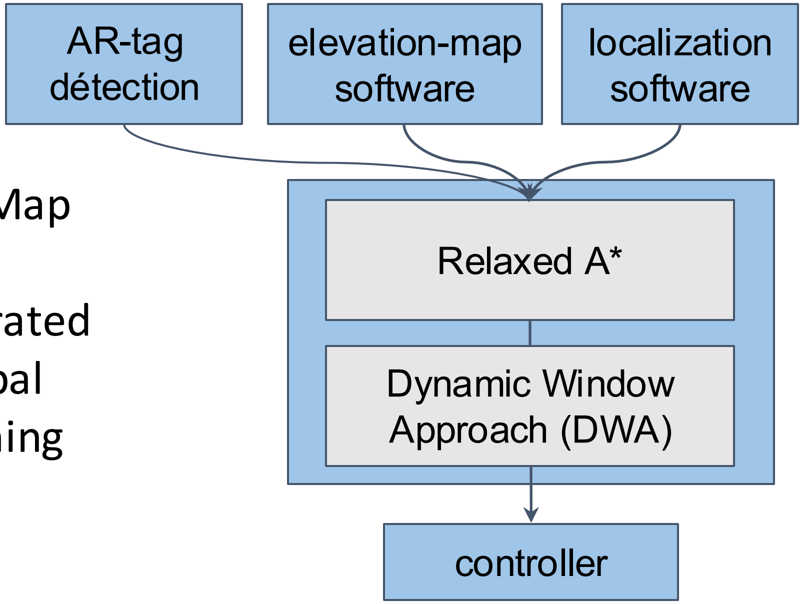
Navigation



Rover

Elevation Map

Path generated by the global path-planning algorithm



Global planning (RA*) : Very efficient and quasi-optimal global path planning

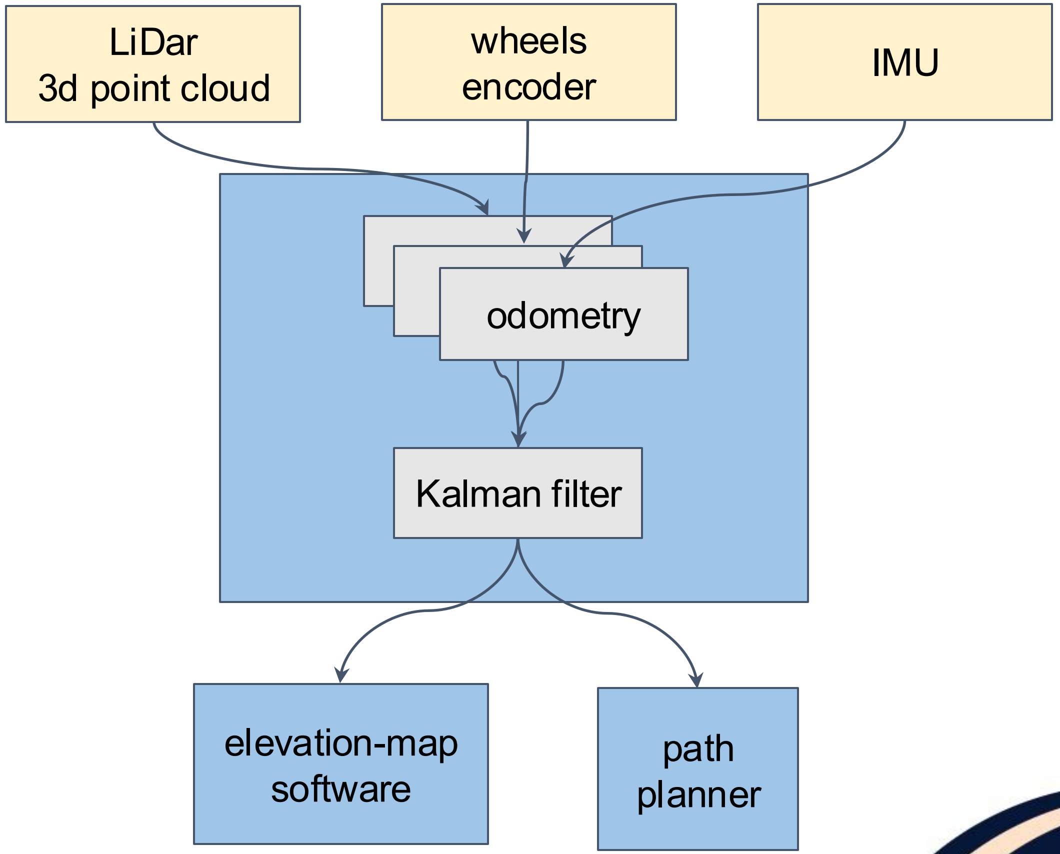
Local planning (DWA) : Collision detection and path smoothing

Cost function : based on motor power consumption per terrain inclination

Sensors are noisy and the real world is uncertain (eg. measurement errors, wheels slip etc).

The **extended Kalman filter** and the **particle filter** are used to fuse sensor data.

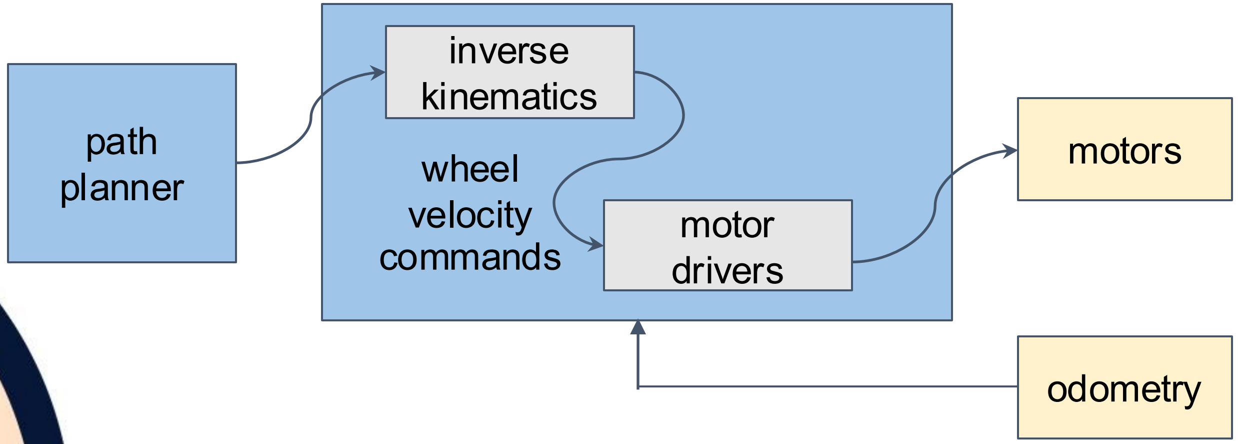
Implementation in ROS



Motors Control

- An **inverse kinematic model** based on the chassis specifications is needed to compute the necessary **wheel velocities**

- Motor drives were chosen to accounts for **low-level motor control** (fig.2)



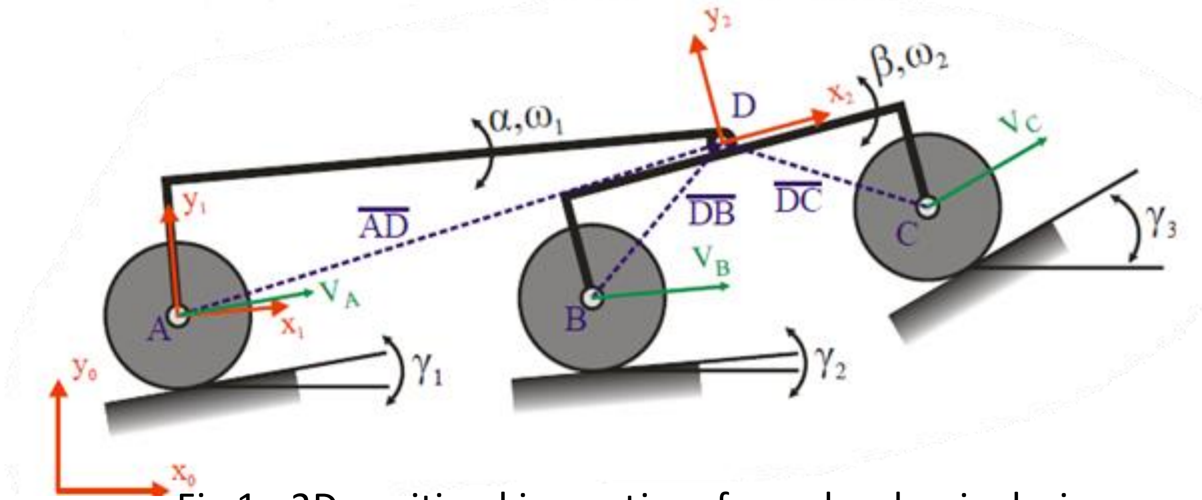
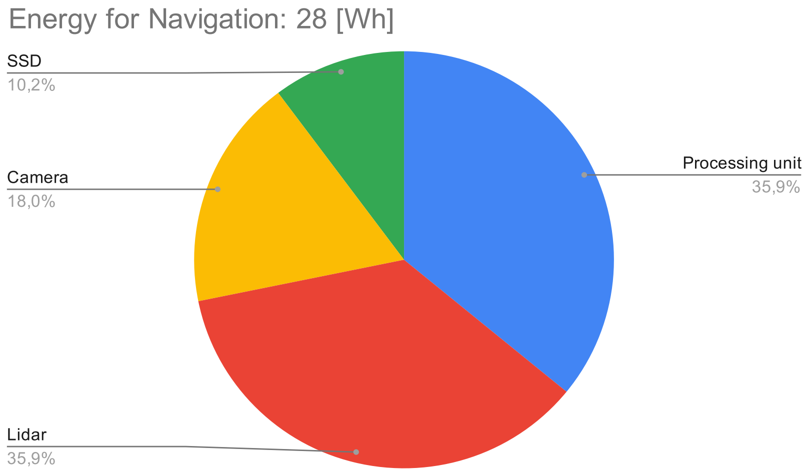


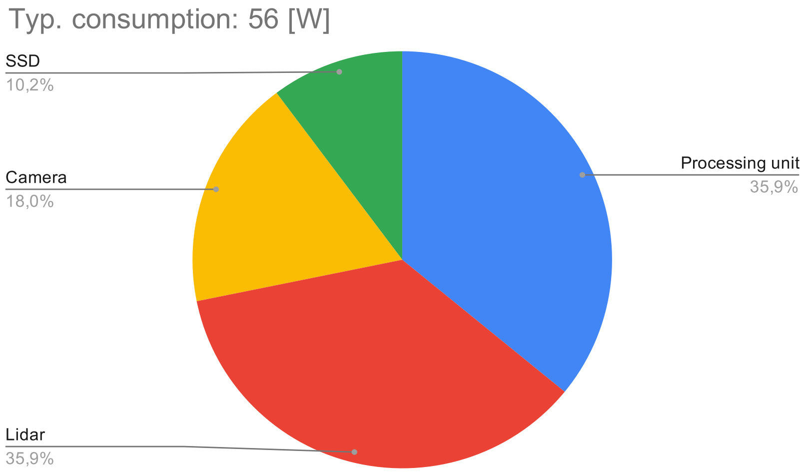
Fig.1 - 2D position kinematics of a rocker-bogie design

Fig.2 - EPOS4 3-axes

Navigation power budget

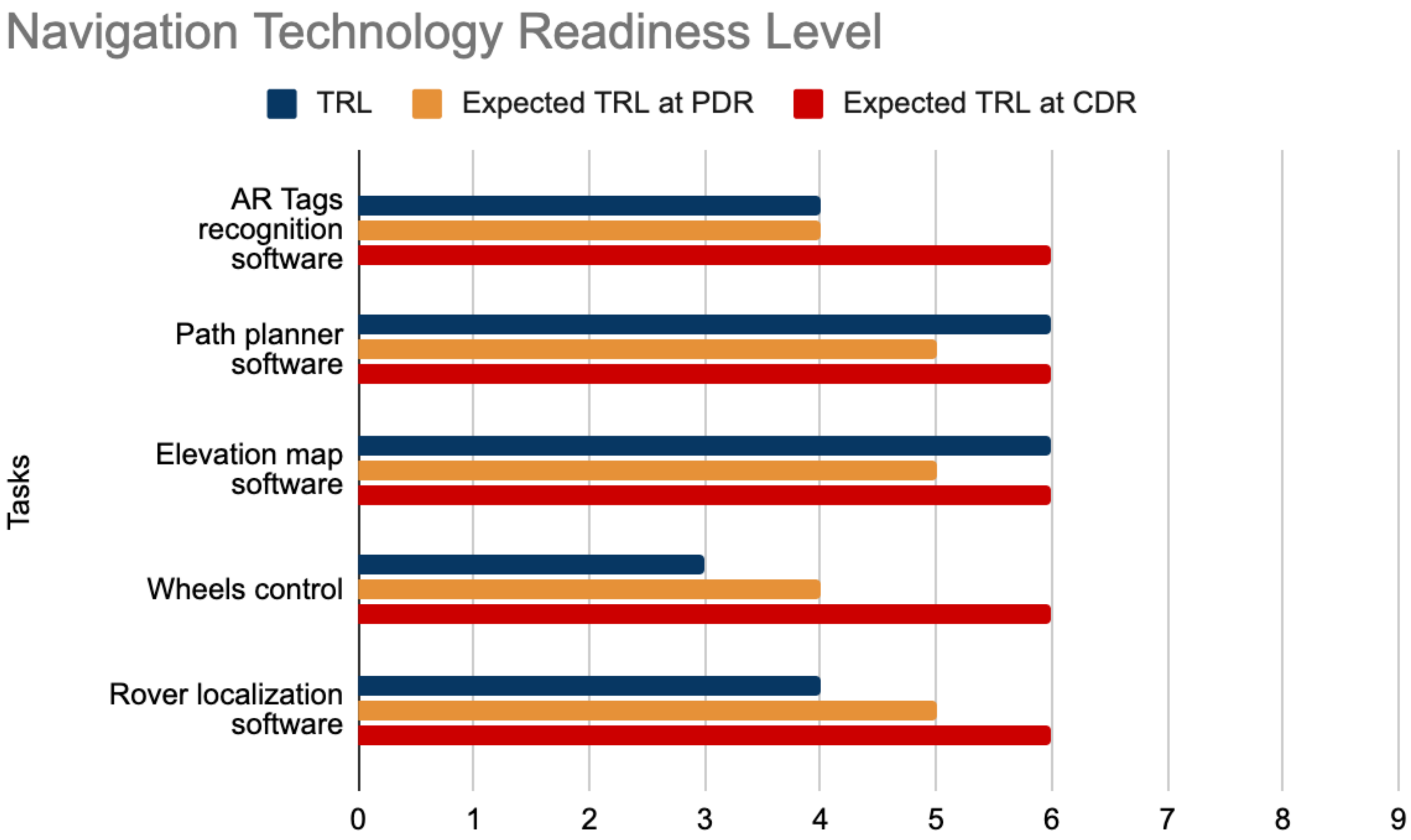
Maximum energy consumption is **28Wh** for Navigation task
Nominal power in full operation: **56W**





Document	Navigation Risk Analysis

Ref / ID	Risk	Consequence	Probability	Impact	Risk	Strategy	Risk Response
XP_NA_RA_N001	LiDar does not perform well on a shiny reflective environment , rain and smog	Avoidance of non existing obstacles	**Low**	**High**	8	Avoid	Use the cameras
XP_NA_RA_N002	Given that the LiDar has a min range of 1m, there is a possibility of missing close range obstacle	Crash on nearby obstacles	**High**	**High**	16	Mitigate	Keep track of previous LiDar scans to interpolate the unknown areas
XP_NA_RA_N003	Path optimiser over or underestimate the rover capabilities	Waste of resources and potential shutdown	**Medium**	**Medium**	9	Mitigate	Take into account as many parameters as possible like battery consumption, max slopes, etc ...
XP_NA_RA_N004	Stereo cannot detect AR-Tag (ex: occlusion , reflections , etc ..)	The rover can't finish the task	**Medium**	**Medium**	9	Mitigate	Tradeoff with false positive, reducing the algorithm sensitivity

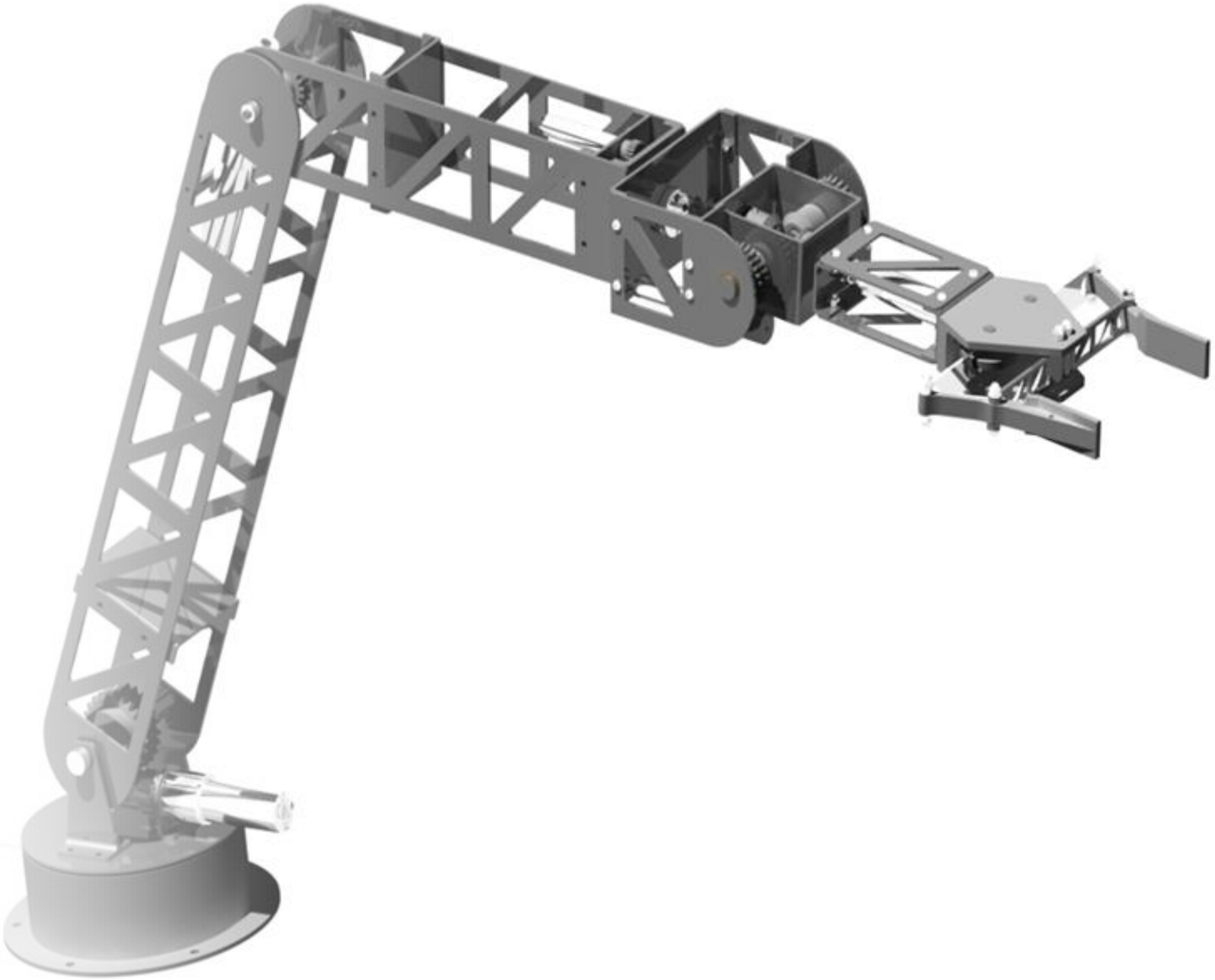

Navigation Technology Readiness Level
TRL
Expected TRL at PDR
Expected TRL at CDR
Tasks
AR Tags recognition software
Path planner software
Elevation map software
Wheels control
Rover localization software
0
1
2
3
4
5
6
7
8
9

Testing (from sim to reality) and tuning hyperparameters

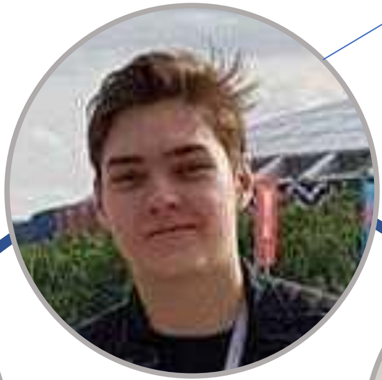
Q&A Session (10 minutes)

Handling Device

Robotic Arm
Kinematics
Image Recognition



Handling Device Team



Daniel Tataru

Handling Device Team Leader

Hugo Bordereaux

Mechanical Engineer

Sami Bouziri

Software Engineer

Lilian Laporte

Mechanical Engineer

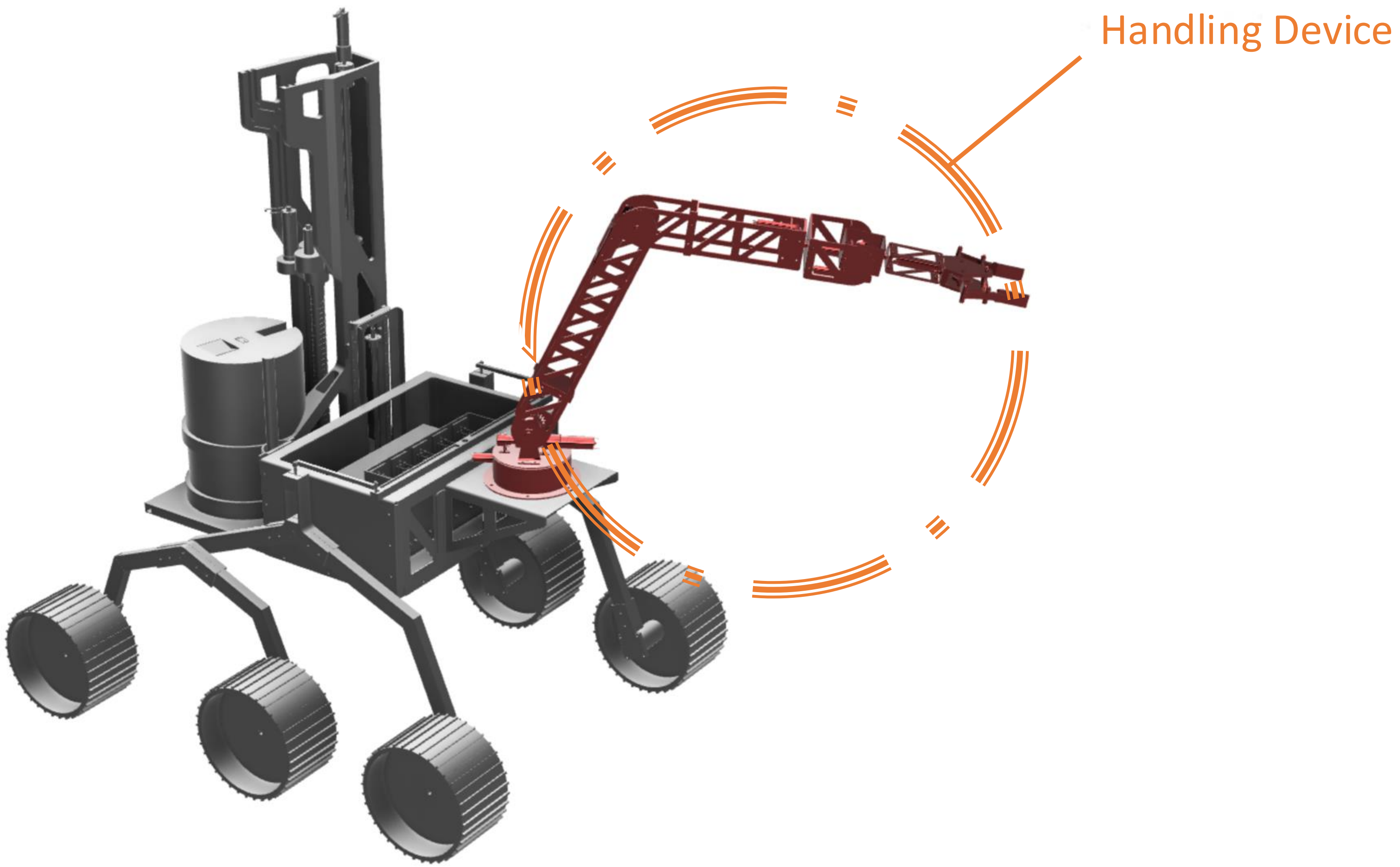
Xavier Servot

Deep Learning Engineer

Document	Handling Device Requirements

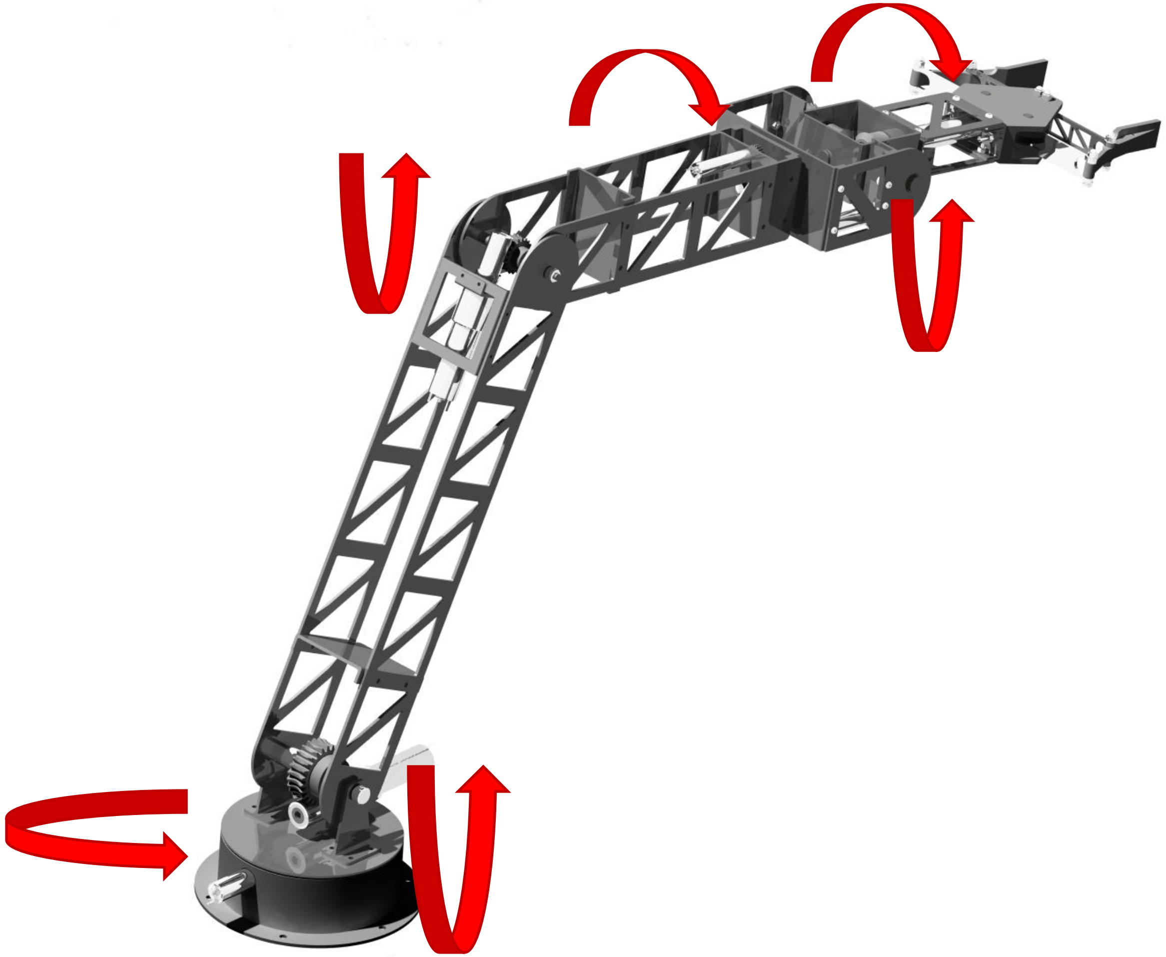
ID	Description	Verification method
EPFL_XP_HD_008-010/041-045	The arm shall be able to flip switches, turn knobs, pick up objects, grasp and insert plugs in sockets.	Test
EPFL_XP_HD_ST_004	The arm shall be able to manipulate the cache container of max {1.5} kg	Test
EPFL_XP_HD_054	The minimum accuracy in translation of the arm at the end of the gripper shall be +/- {2e-3} m	Test
EPFL_XP_HD_035	The arm shall have a range of {0.8} m to reach the SC bay	Review-of-design
EPFL_XP_HD_001-005/011-015	The arm shall be able to recognize and report the positions of various sockets, buttons and knobs of the control panel as well as their orientation	Test

Handling device



Handling device objectives:
- Manipulate switches
- Move and collect objects up to 1.5kg
- Collect soil samples and place them in the designated containers
- Detect control panel elements/cache objects

Arm specifications:
- Reach of 1.1 m
- Weight of 5.5 kg
- 6 DOF
- Max. gripper aperture of 130 mm

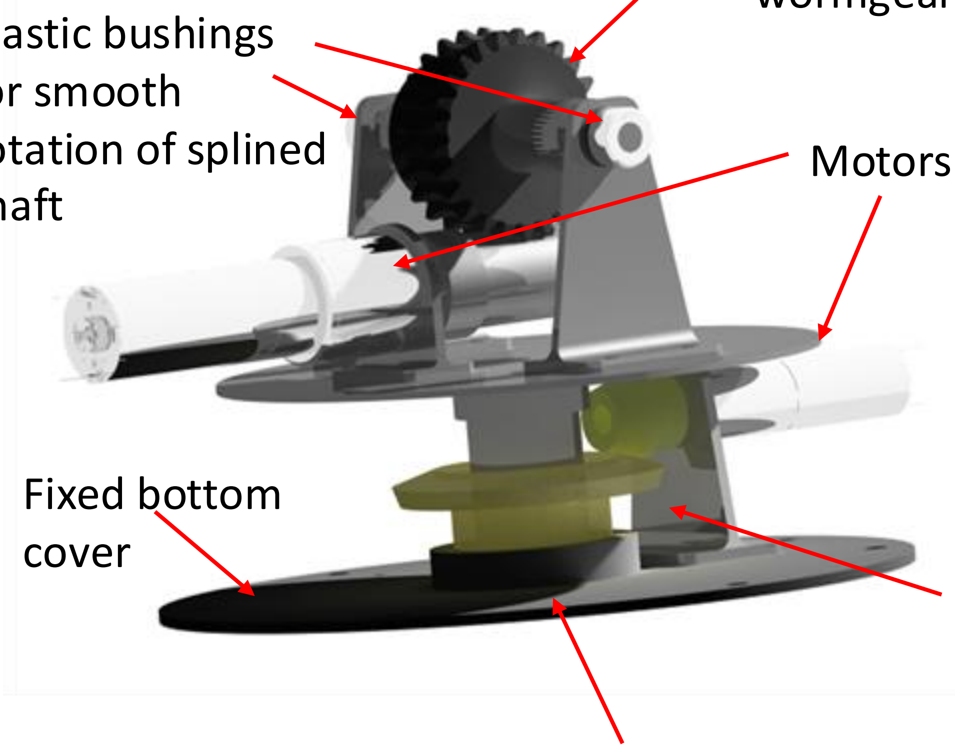


- **Allows 2-axis rotation:**
  - **Arm elevation**
    - Steel wormgear paired with plastic wormwheel provide necessary torque
  - **Arm vertical rotation**
    - Plastic bevel gears for compactness

- **Combination of plastic and aluminium**

- **Motor specifications:**

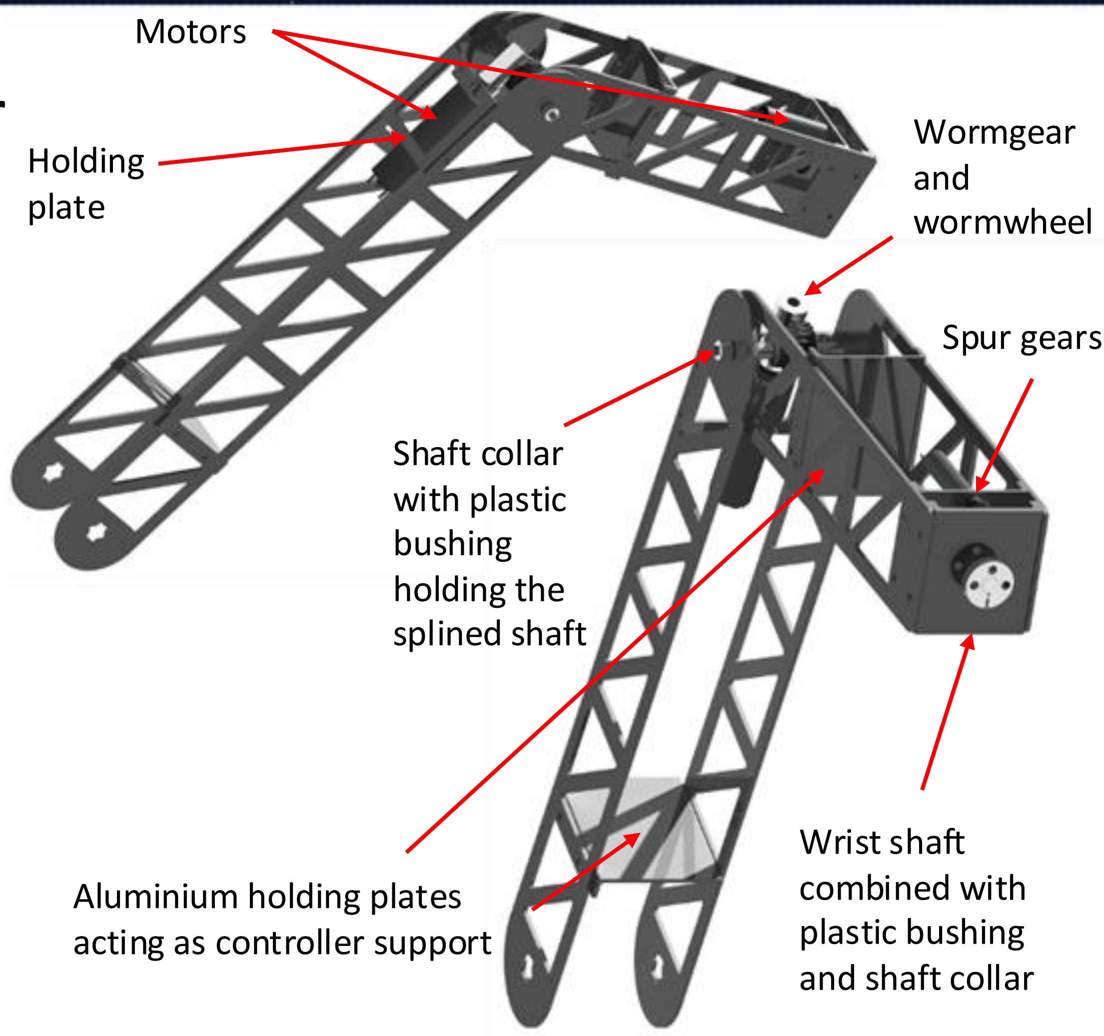
	Desired Torque (Nm)	Desired speed (rpm)	Reduction ratio	Motor Torque (Nm)
Motor 1 (base rotation)	2,59	5	3	1,38
Motor 2 (arm elevation	46,75	5	30	3,34



Handling device

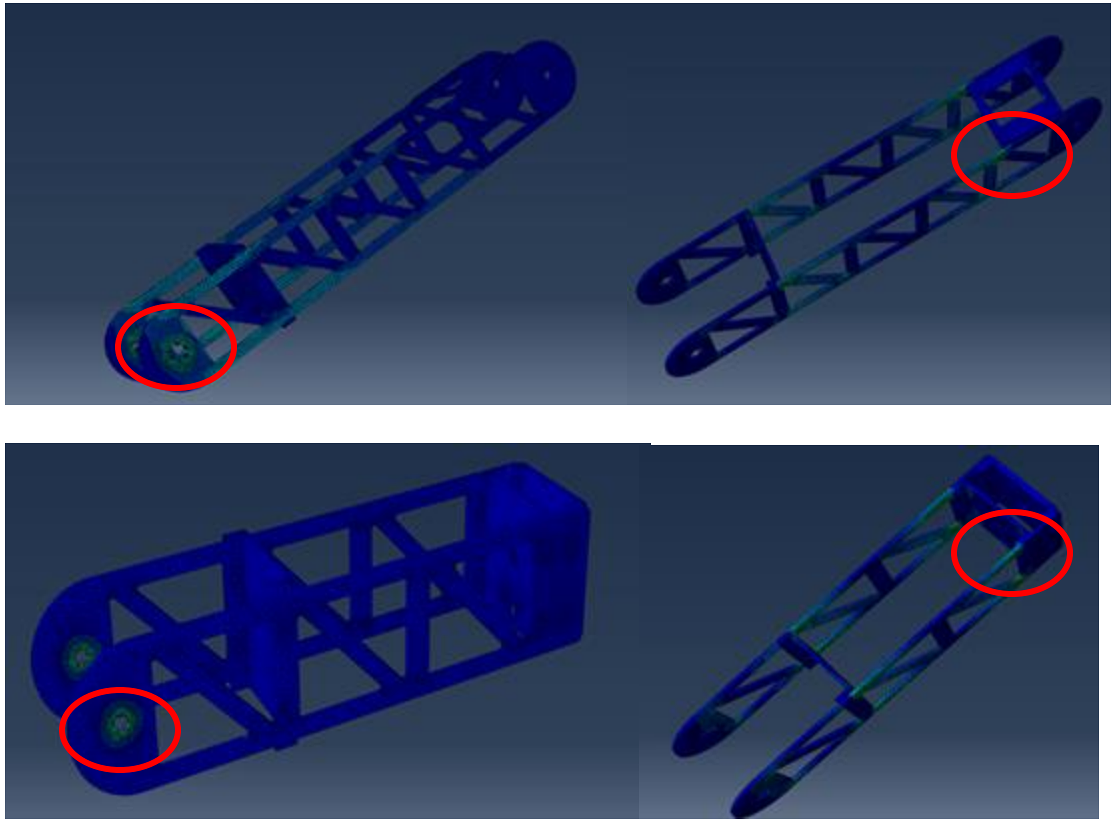
- **3 mm aluminium sheets with holding plates for rigidity**
- **Elbow elevation:**
  - Steel wormgear paired with plastic wormwheel to provide necessary torque
- **Elbow rotation:**
  - Plastic spur gears for low weight
- **Motor specifications:**

	Desired Torque (Nm)	Desired speed (rpm)	Reduction ratio	Motor Torque (Nm)
Motor 3 (elbow elevation)	22,63	5	30	1,62
Motor 4 (elbow rotation)	0,40	5	3	0,13



	Load Type	Magnitude	Maximum stress [MPa]	Maximum displacement [mm]
Base arm	Bending	65 N	110	0.4
	Torsion	8 Nm	103	0.3
	Sideway bending	**65 N**	**72**	**4.2**
Front arm	Bending	50 N	132	0.3
	Torsion	8 Nm	103	0.6
	Sideway bending	**50 N**	**86**	**2.6**

Most critical displacement occurs in sideway bending (can be improved by adding small holding plate in the middle)



FEA results for both arm parts in bending (left) and sideway bending (right) with a deformation scale factor of 1 (maximum stress highlighted)

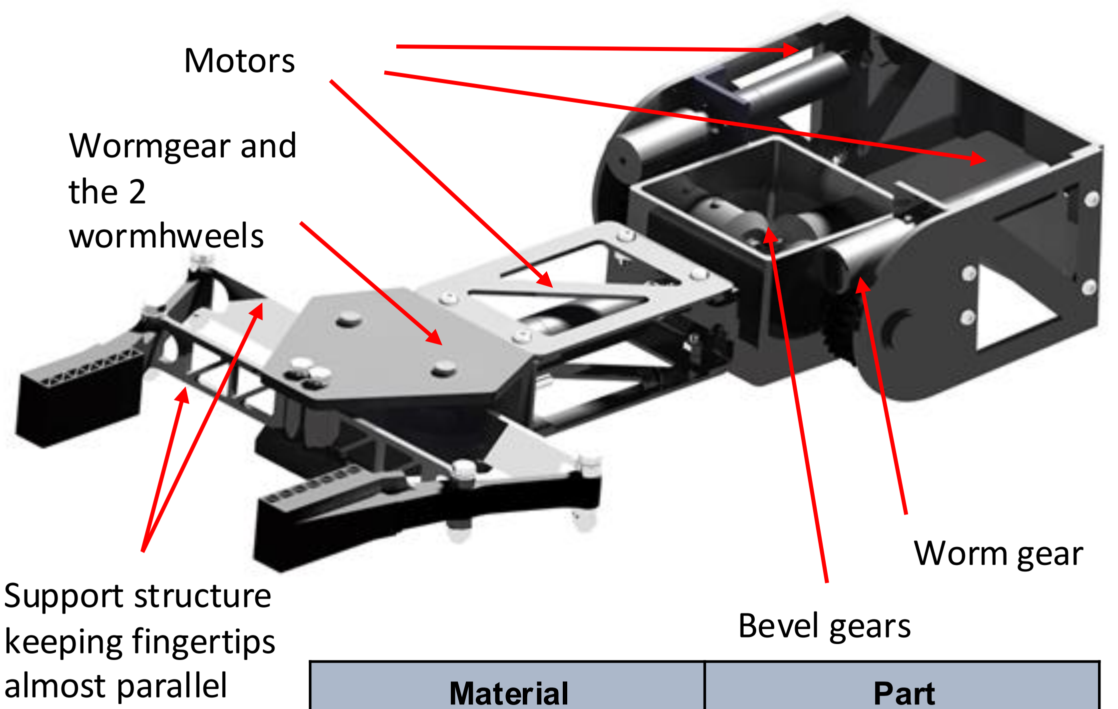
Arm FEM Analysis

- **Differential-like system for the wrist:**
    - Wormgear and wormwheel combination for power transmission
    - 4 bevel gears allowing elevation and rotation around main axis in a compact size

- **Wormgear paired with 2 wormwheel for grasping**
    - Centered motor
    - High torque transmission
    - Optimization of the grips for better **grasping.**

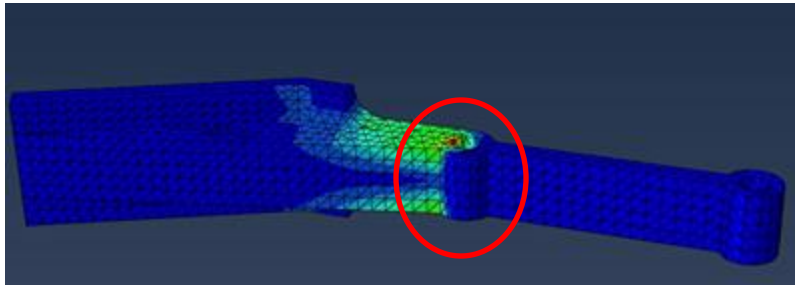
- **Motor specifications**

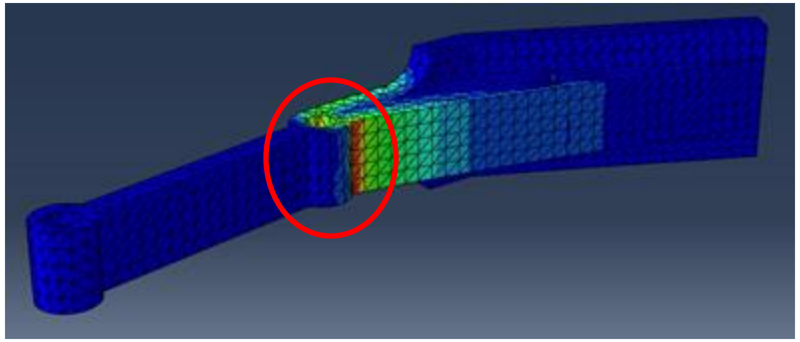
	Desired Torque (Nm)	Desired speed (rpm)	Reducti on ratio	Motor Torque (Nm)
Motor 5/6 (wrist)	3,33	5	25	0,30
Motor 7 (gripper)	14,72	5	25	1,26

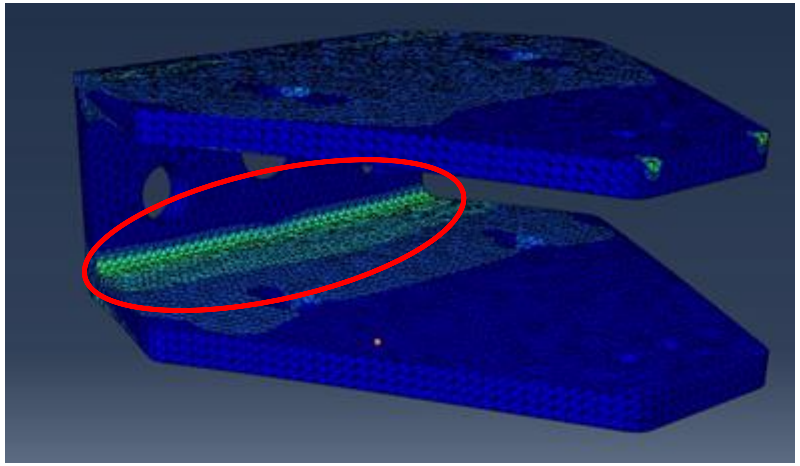


Material	Part
Aluminium	Main structure
Polymer (e.g. PLA, POM …)	Gripper crankcase and fingers of the gripper
Flexible 3D printing or rubber	Grips

	Load cause	Magnitude	Maximum stress [MPa]	Maximum displacement [mm]
Fingers	Mass (1)	15 N	6.2	0.2
	Force on an object (2)	123 N	55	4.5
Base	Mass (3)	15 N / 1,2 Nm	6	0.4


(1)


(2)


(3)

FEA results for finger, (1) and (2), and base parts (3)

Gripper FEM Analysis

Two methods of Control:

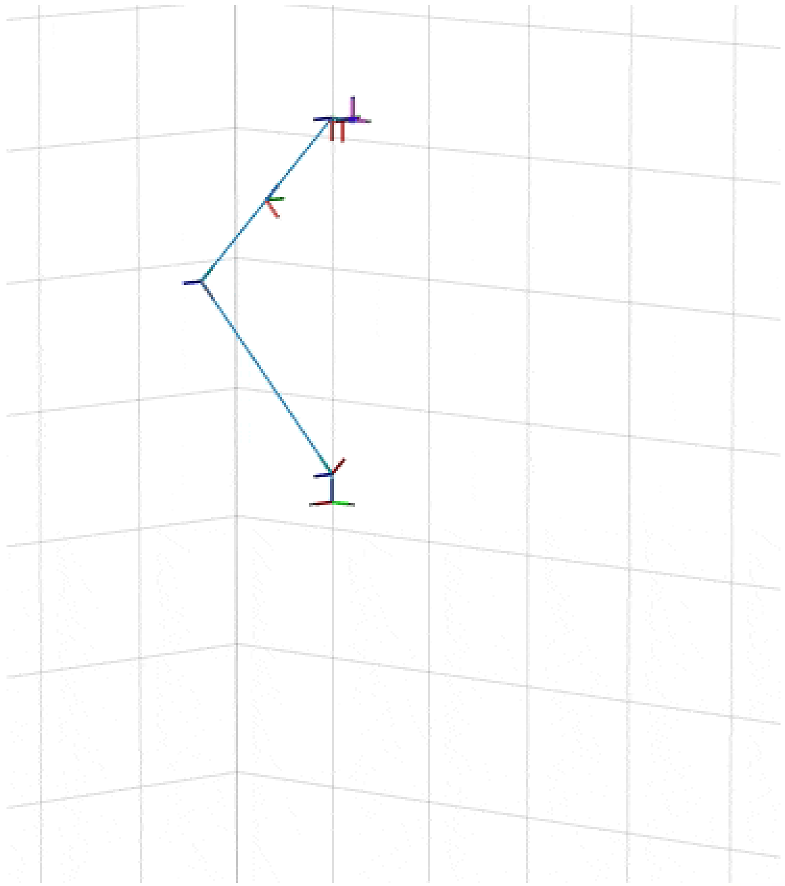
1. By giving the final joints values (direct kinematics)
1. By giving the coordinates of the point you want to reach and three angle of rotation along the three axis (inverse kinematics)

Two path planning method were implemented :

1. Path in the task space
1. Path in the joint space

Quintic functions were used to generate trajectories and interpolate them between the start and end point

Maxon's motors already have PID controllers so we will just have to tune them

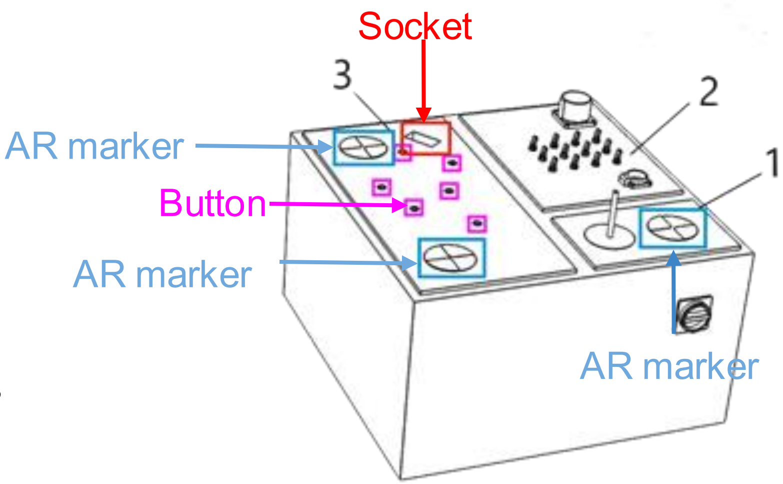


What do we have to detect?

1. Buttons
2. AR markers
3. Socket

Why?

1. It's cool
2. It gets us a lot of points

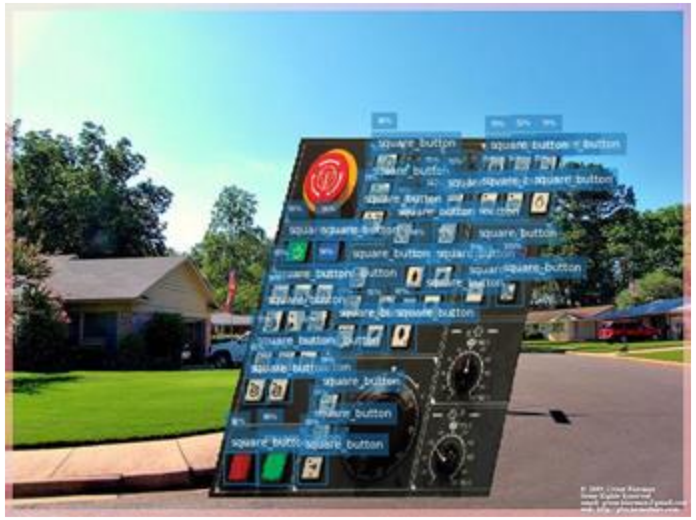


The model

1. PifPaf, a deep learning model developed at EPFL by the VITA lab.
2. Training on SCITAS, the EPFL computer cluster.

The dataset

1. Recreate the control panel (optional)
2. Take pictures of it
3. Annotate them (CVAT)
4. Do data augmentation:
   - Apply perspective transforms
   - Overlay on backgrounds from the COCO dataset (330k+ images)
   - Apply additional transforms



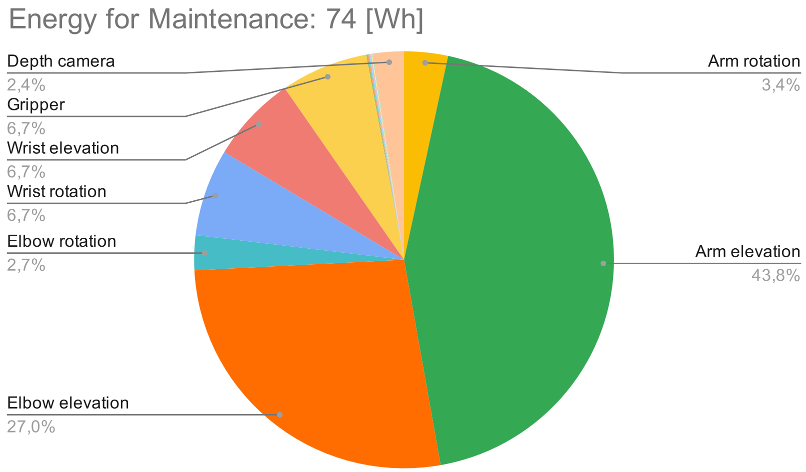
Risk analysis

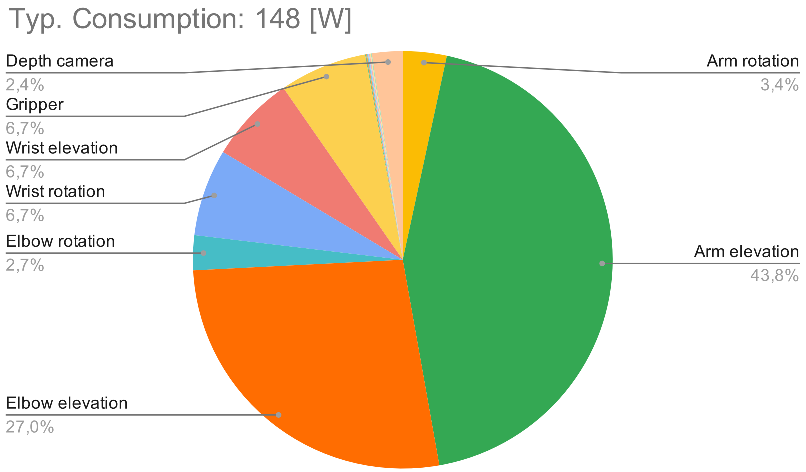
Only risk: Model fails to detect

1. Can be countered by testing the model.
2. Small probability of failure given strong accuracy.

Handling device power budget

Maximum energy consumption is **74Wh** for Maintenance task
Nominal power in full operation: **148W**



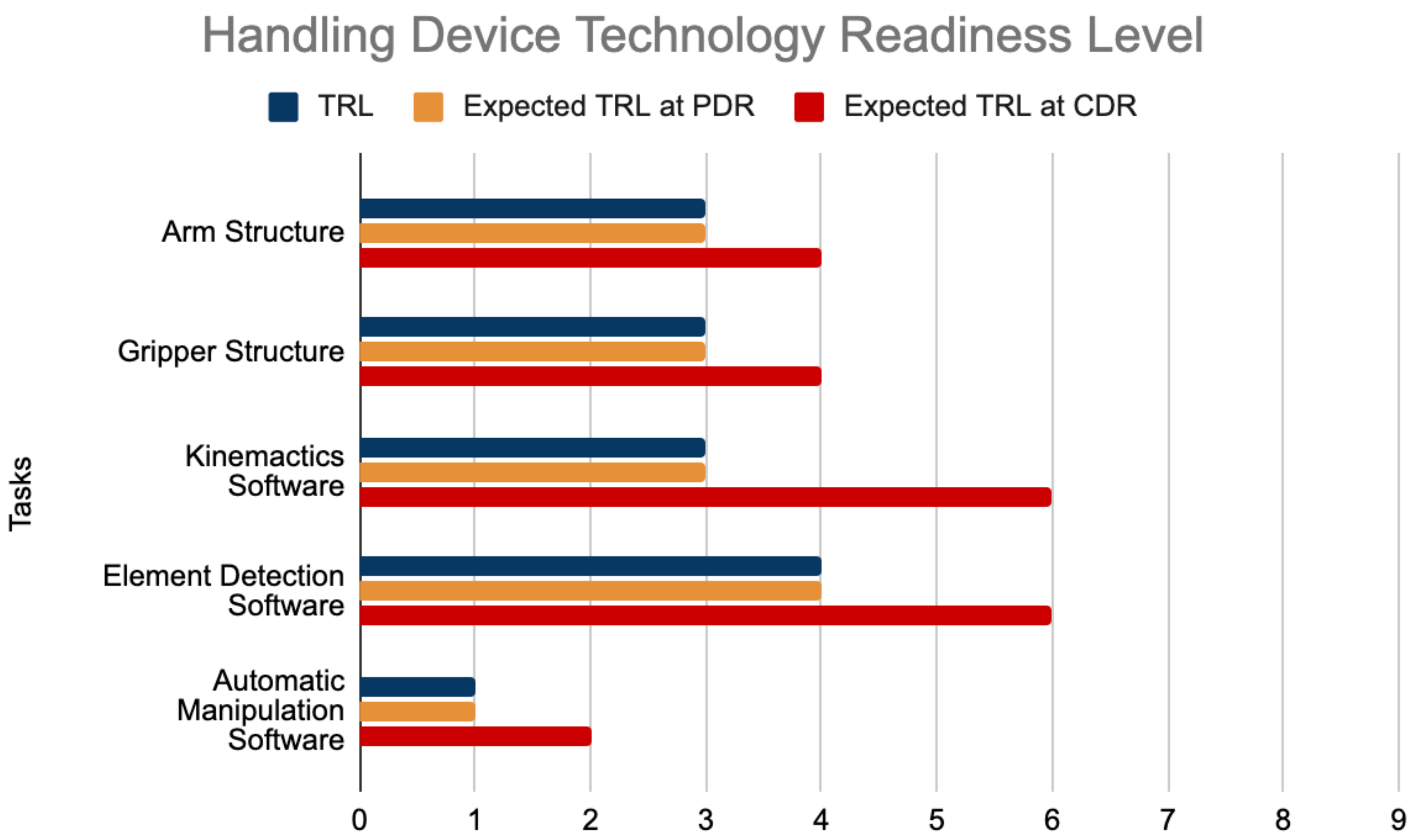


Document	Handling Device Requirements

Ref / ID	Risk	Consequence	Probabilty	Impact	Risk	Strategy	Risk Response
XP_HD_RA_N001	Given that the arm is 1.1 m long and weighs 5.5 kg, there is a possibility of the arm not being strong enough to support the required loads leading to a breakdown of the arm	**Structural failure of the arm**	**Low**	**Very high**	10	Avoid	Perform FEM analysis, design review, extensive testing, adapted material choice
XP_HD_RA_N002	Given the weight of the arm and the maximum object weight, there is a possibility that the chosen hardware is unable to perform the required tasks	**Inability to perform load carrying tasks**	**Low**	**Very high**	10	Avoid	Adapted safety factors in calculations, testing
XP_HD_RA_N003	Given the length of the arm, the motor accuracy and the control software algorithm precision, there is a possibility that the arm isn't able to perform all required actions	**Failing to perform precise actions**	**Low**	**High**	8	Mitigate	Perform extensive software testing, choose appropriate encoders, fine-tuning motor control, increase arm stiffness
XP_HD_RA_N006	Given the arm's size and length compared to the rover, there is a possibility of wobbling leading to damage in the arm structure and instability of the rover	**Loss of balance and potential structural failure**	**Low**	**High**	8	Mitigate	Arm stowing during navigation, lower as much as possible center of gravity

Risk Analysis

Handling device



End of semester:

- **Finish arm design and advance software**
  - Mitigate any structural issues
  - Increase stiffness and strength as well as weight (optimization)
  - Validate preliminary motor choices
  - Finish element detection software
  - Finish and optimize arm control software
  - Solve problems related to the generation of path.
  - Elaborate a control architecture

Spring semester

- **Create a dynamic and static model.**
- **Tune PID controllers**
- **Start manufacturing phase**
  - Order necessary parts, materials and motors
  - Manufacture in-house parts at EPFL
  - Assemble the arm
- **Start test phase after manufacturing**
  - Hardware testing
  - Software testing
  - Simulate competition tasks in adapted environment

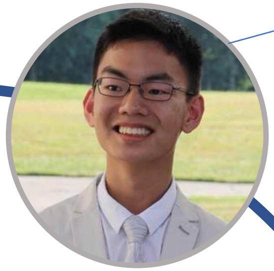
Q&A Session (10 minutes)

Science

Drilling Mechanism
Sampling
Raman Spectroscopy
Science Plan

Science Team

Junyan Qian
Science Team Leader | **Drill**



Jason Huang
Science Co-Team Leader |

Container, suface sampling

Lorenzo Minervini
Mechanical Engineer | **SC bay**

Gloria Mellinand
Scientist | **Science plan**

Jehan Corcelle
Mechanical Engineer |

Raman housing

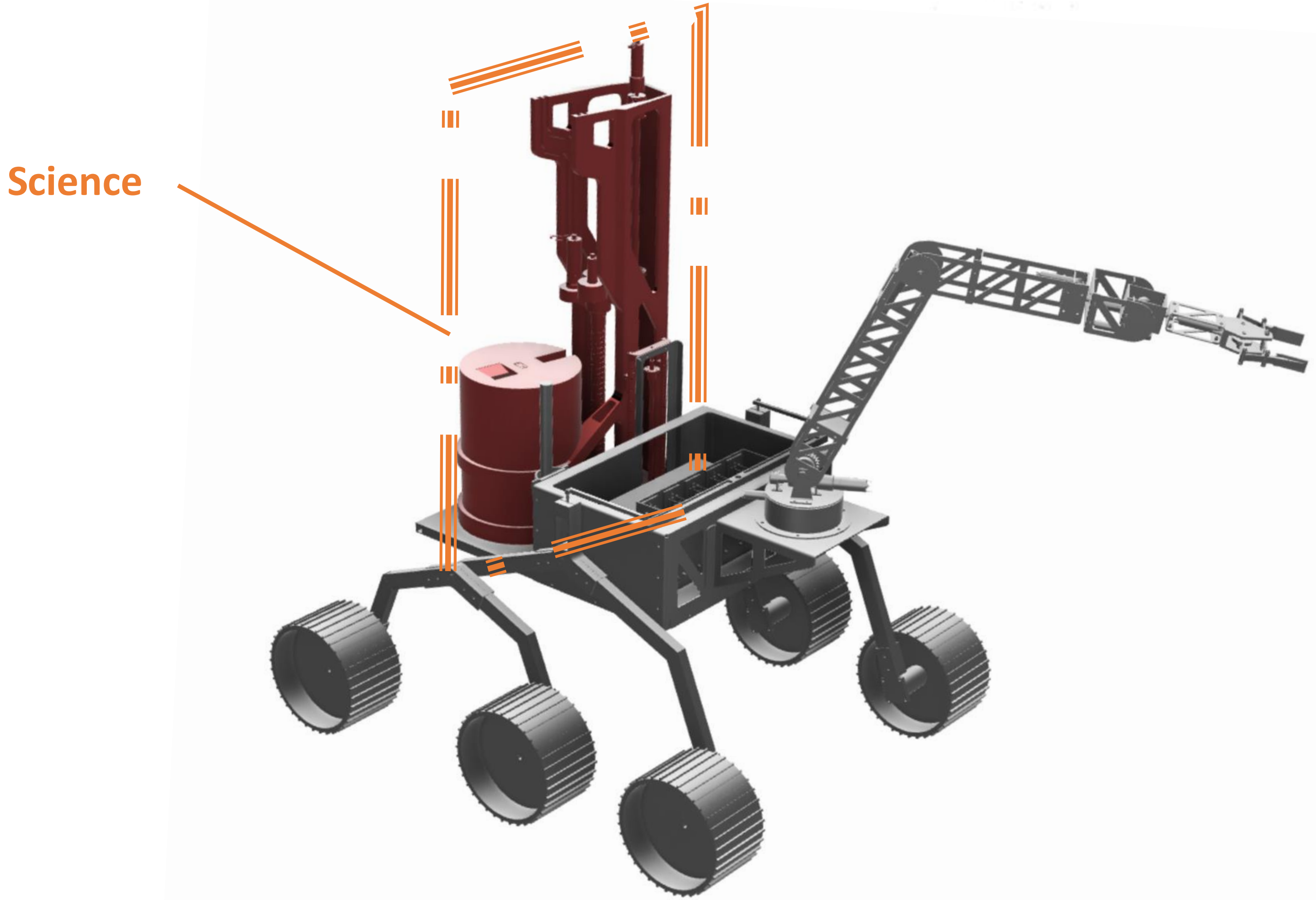
Pierre Amadio
Scientist | **Science plan**

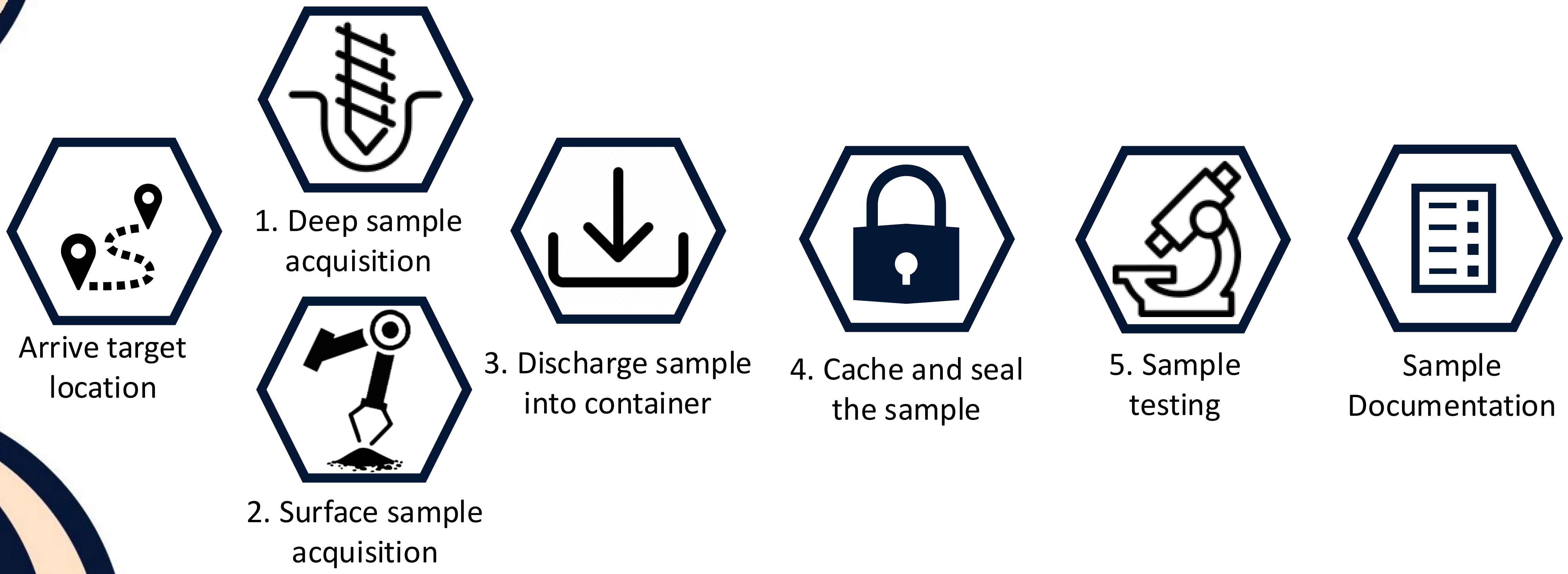
Loris Castagnolo
Mechanical Engineer | **SC bay**

Arthur Vard
Scientist | **Raman specialist**

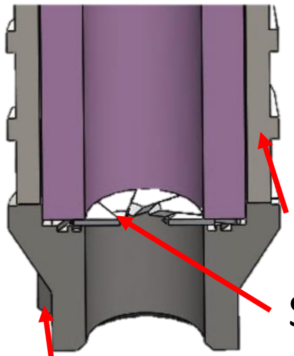
Document	Science Requirements

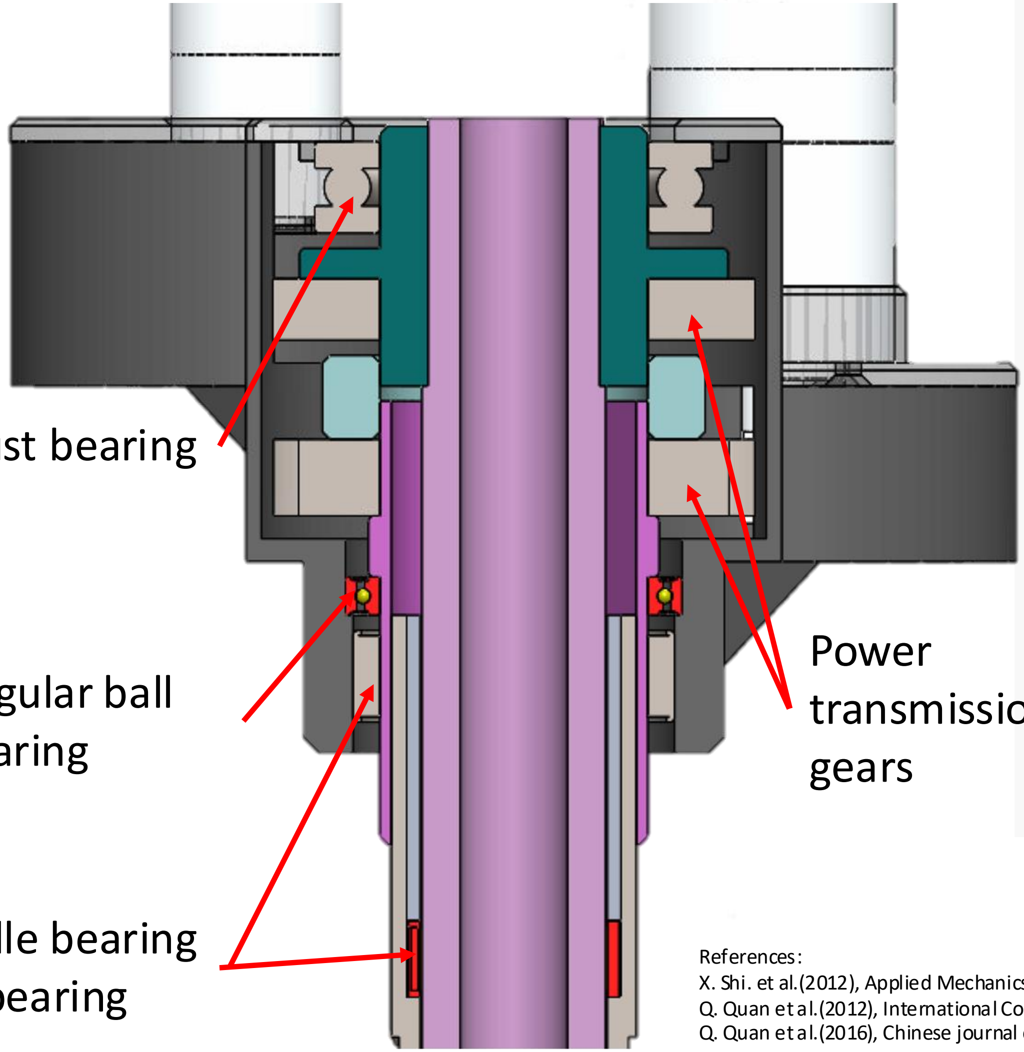
ID	Description	Verification method
EPFL_XP_SC_015	The rover shall be able to extract samples from the subsurface of the soil	Test
EPFL_XP_SC_002	The rover shall be able to extract samples from the surface of the soil	Test
EPFL_XP_SC_024	The mechanism shall put the samples accurately into the container and in a controlled way	Test
EPFL_XP_AV_SC_001	The scientific task shall provide results of measurements	Test
EPFL_XP_SC_049	The Rover shall detect the presence of life (extinct or extant) in the sample	Test


Science

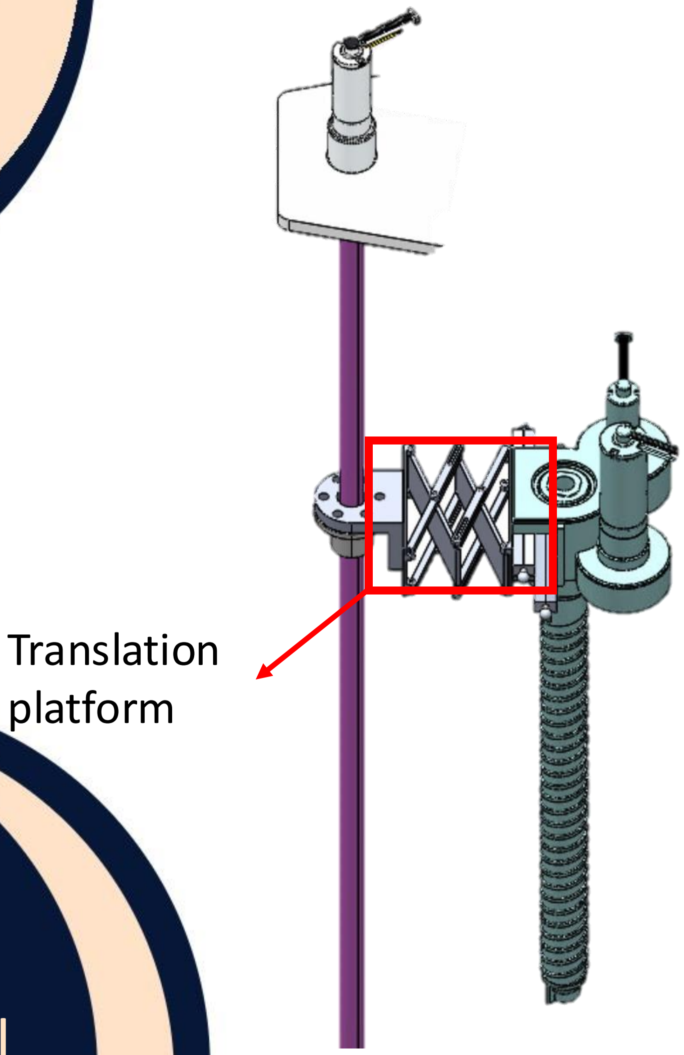


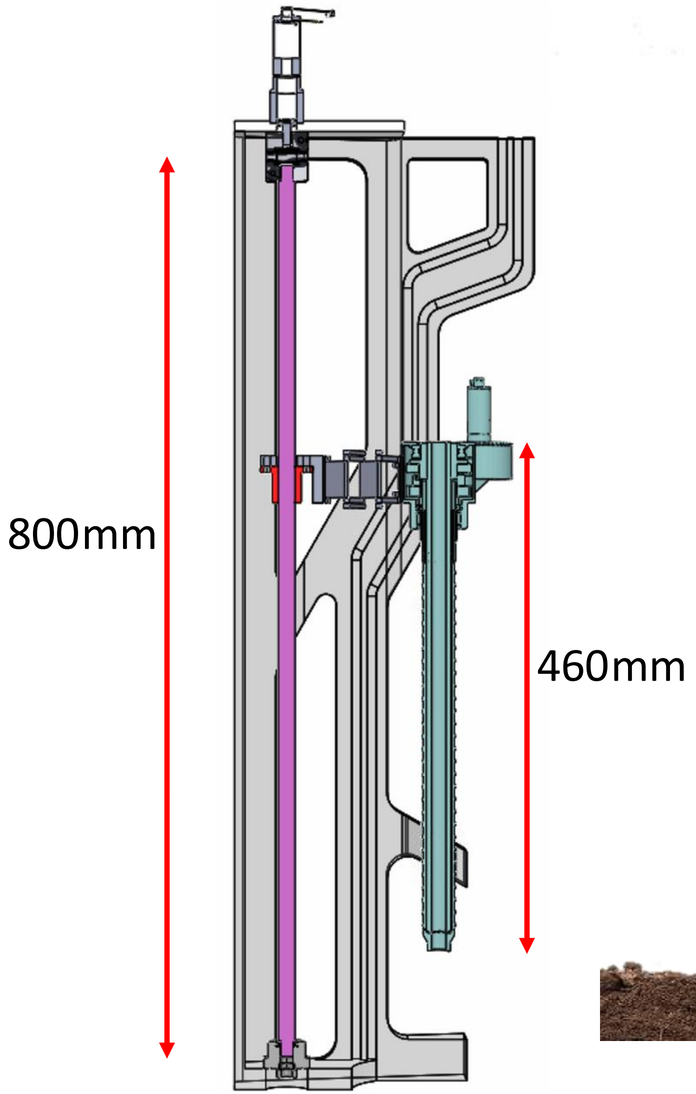
Operating Sequence

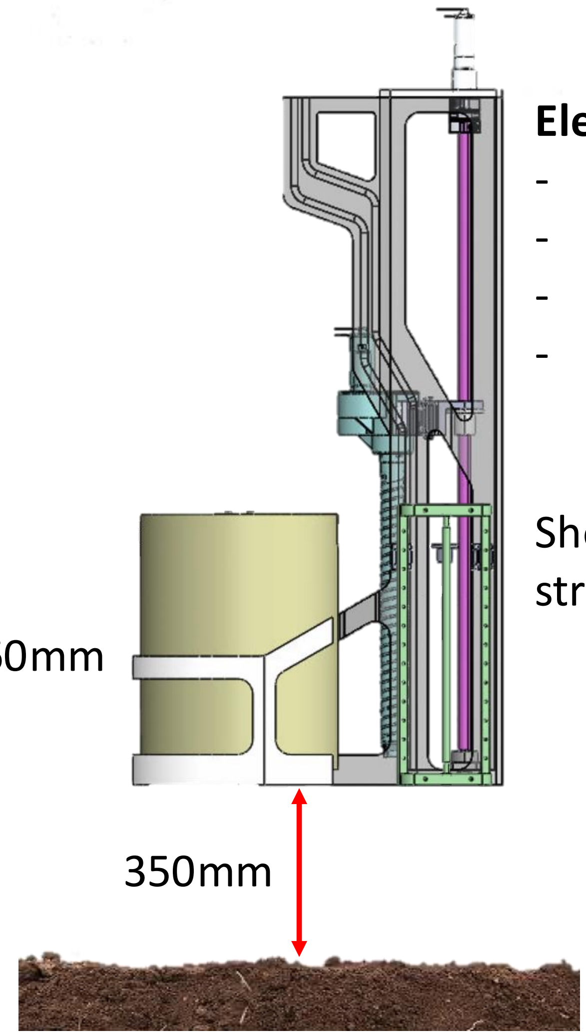




References:
X. Shi. et al.(2012), Applied Mechanics and Materials, 233, 218-223;
Q. Quan et al.(2012), International Conference on Robotics and Biomimetics;
Q. Quan et al.(2016), Chinese journal of areonautics, 30, 434-446;







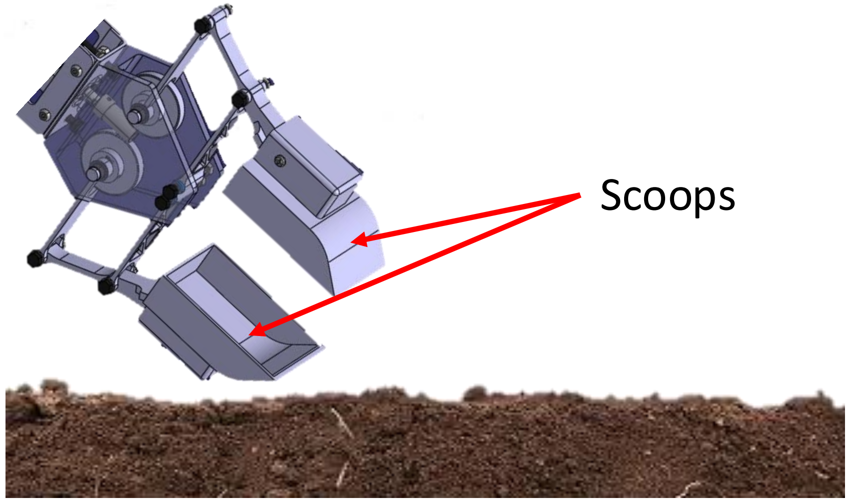
Elevation system
- Lead screw
- Nut
- Motor
- Linear bearing

Shorter auger to avoid structural failure

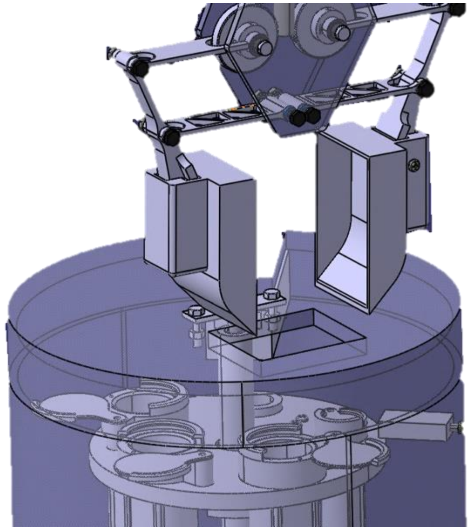
Drill Install

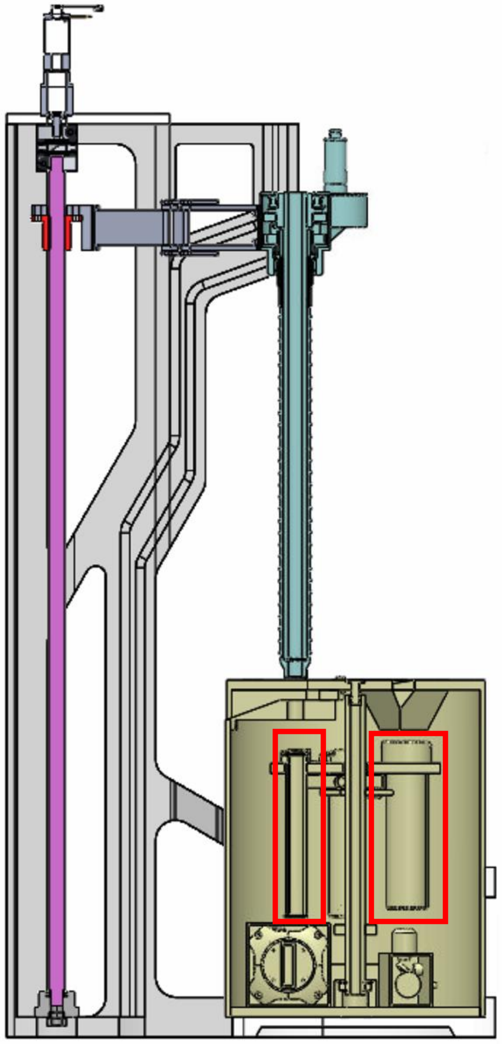
Goal: To collect 150g of surface soil sample at 3 different locations

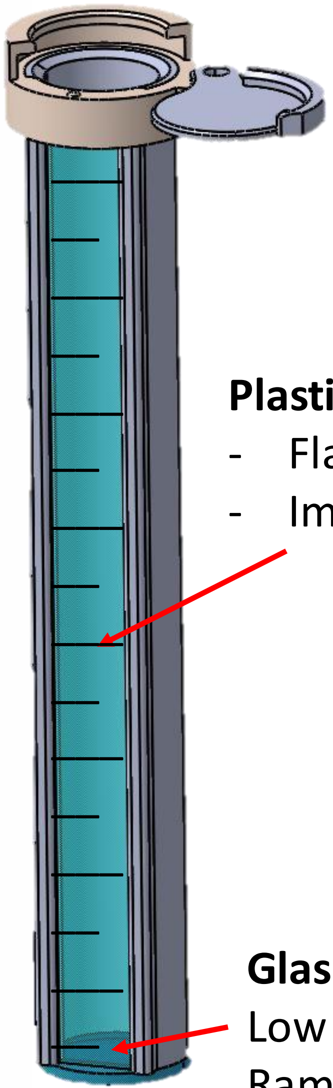
- Implemented with two 3D printed scoops on the end of the handling device.
- Catching operation achieved with the help of the depth camera (D435i) on the arm.



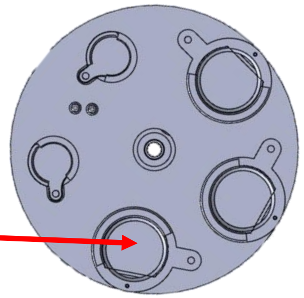
Catching the sample
↓
Transferring with the robotic arm
↓
Depositing the sample in the funnel leading to the container
↓
Sealing the container







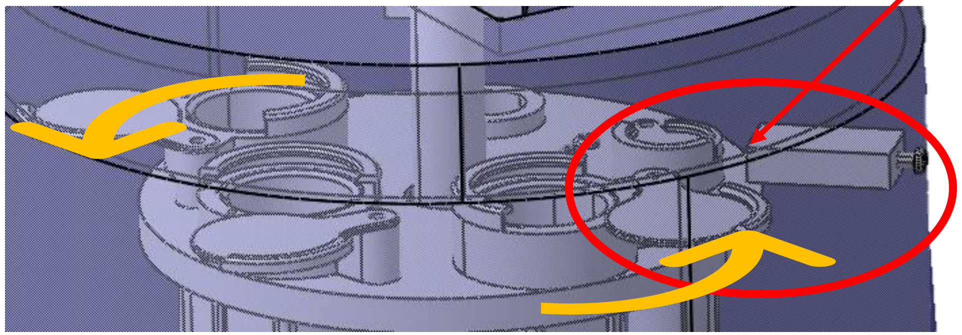
3 types of container:
- Deep (30mL)
- Calibration tube
- Surface (120mL)



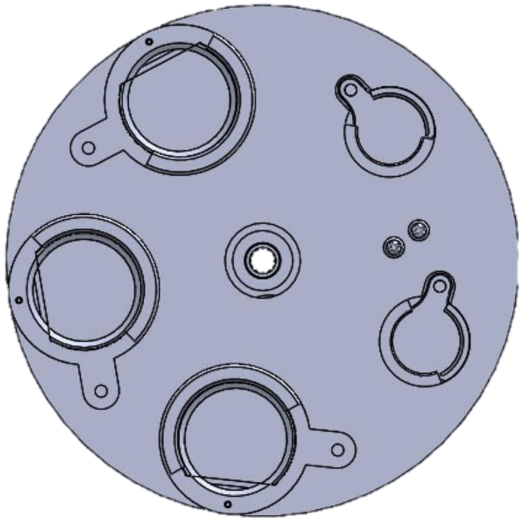
Calibration tube:
- RGB Color chart
- Replace the glass with PET to calibrate spectrometer

Plastic sheet:
- Flat clear view of the sample
- Implement with volume scale

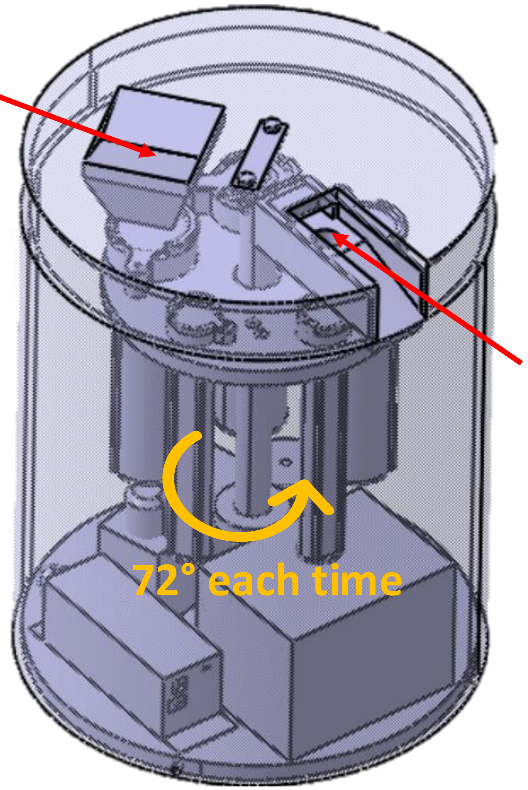
Caching mechanism:
- The cap is shutted when it passes this obstacle



Glass :
Low interference with Raman wavelength

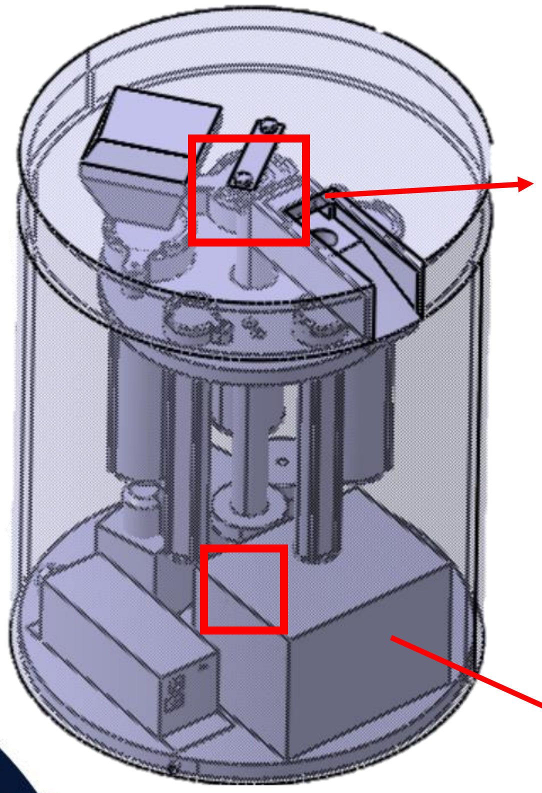


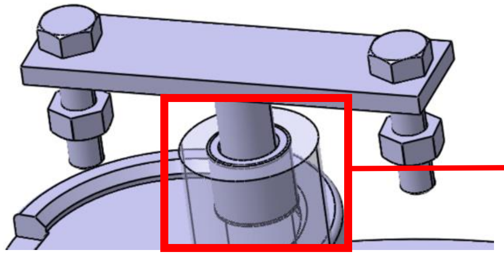
Surface sample entrance



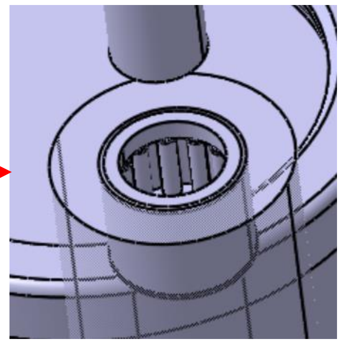
Deep sample entrance

2-points shaft stabilization:

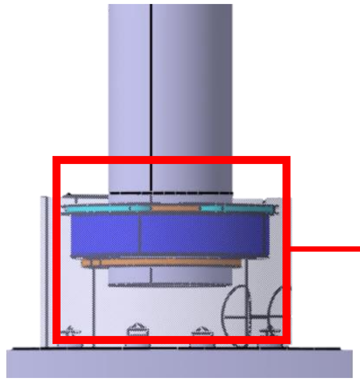




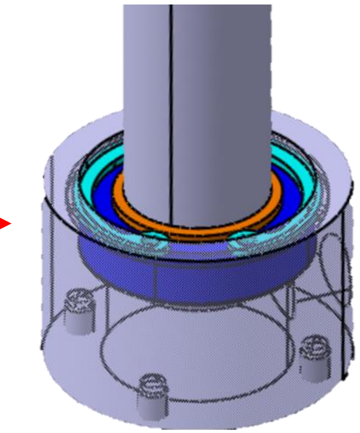
From above



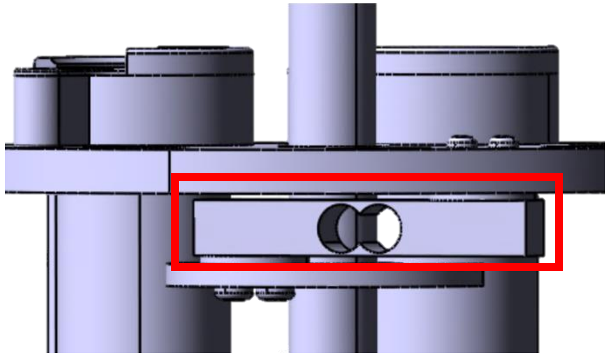
Needle bearing
- Provide radial support to the shaft
- Allows rotation and reduce friction



From below

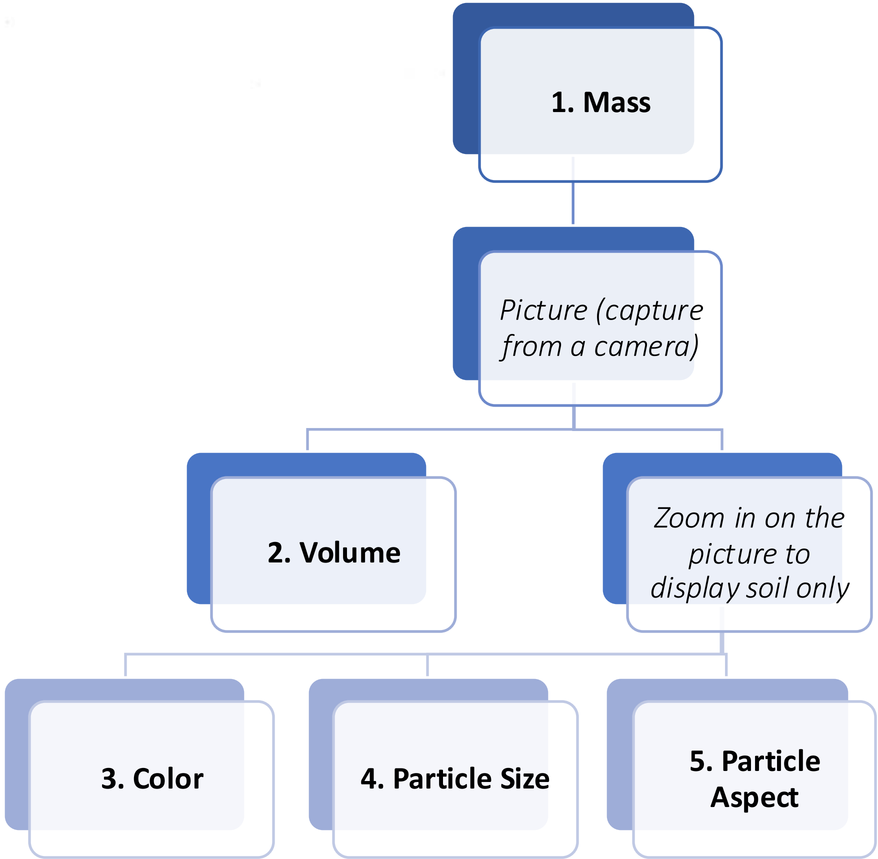


Ball bearing
- Provide axial support to the shaft
- Allows rotation and reduce friction



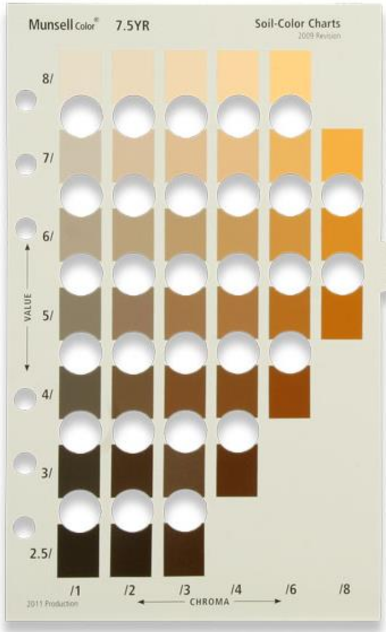
Load cell

Ethernet camera



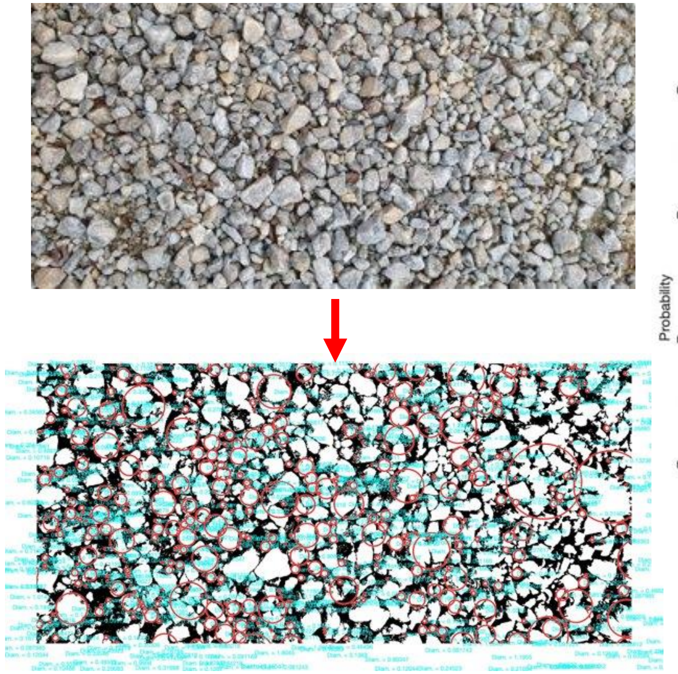
- How :
  - Load cell with HX711 amplifier
  - Image analysis of the sample (volume, particle size, color) relying on Matlab
- Volume :
  - Compare the height of the soil with the scale on the transparent screen
  - Error approximation (3D displayed as 2D)
- Particle Aspect :
  - The magnified picture is directly displayed documented and saved to build a library of soil particles

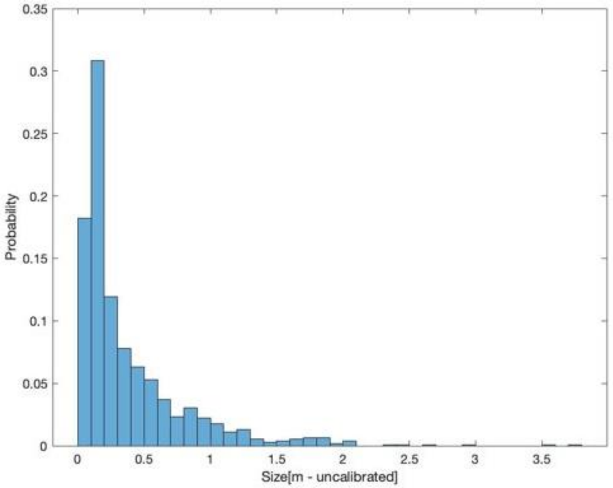
- Mineralogy – color analysis:
  - Define areas of color using either CIE or RGB data
  - Average the values for each ares
  - Convert to Munsell color notation (hue-value-chroma)
  - Identify soil composition using Munsell soil color charts



https://www.torso.de/en/Color-Standards/Munsell-Colors/Munsell-Scientific-Colors/Munsell-Soil-Color-YR-Kit::417.html
https://ucanr.edu/blogs/blogcore/postdetail.cfm?postnum=29670

- Particle size :
  - Convert image to greyscale data
  - Compute diameter of bright spots
  - Display in the form of a histogram, the Probability Density Function of the size





https://ch.mathworks.com/matlabcentral/answers/524362-particle-size-calculation-from-given-image

Raman Spectrometer Artsakh

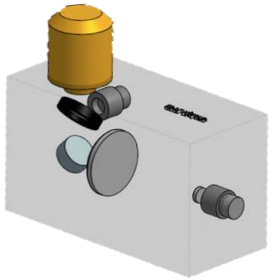
Implemented a 405 nm excitation laser

Laser

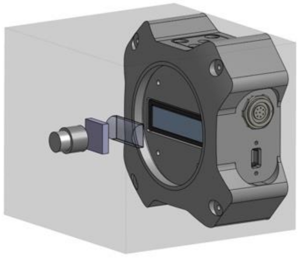
Choosing the wavelength:

1. UV/near UV laser are the ones used to target biomolecules (resonance Raman).
2. Florescence: Main enemy of Raman. Not in the same spectral range if we work in UV/near UV
3. Raman efficiency:

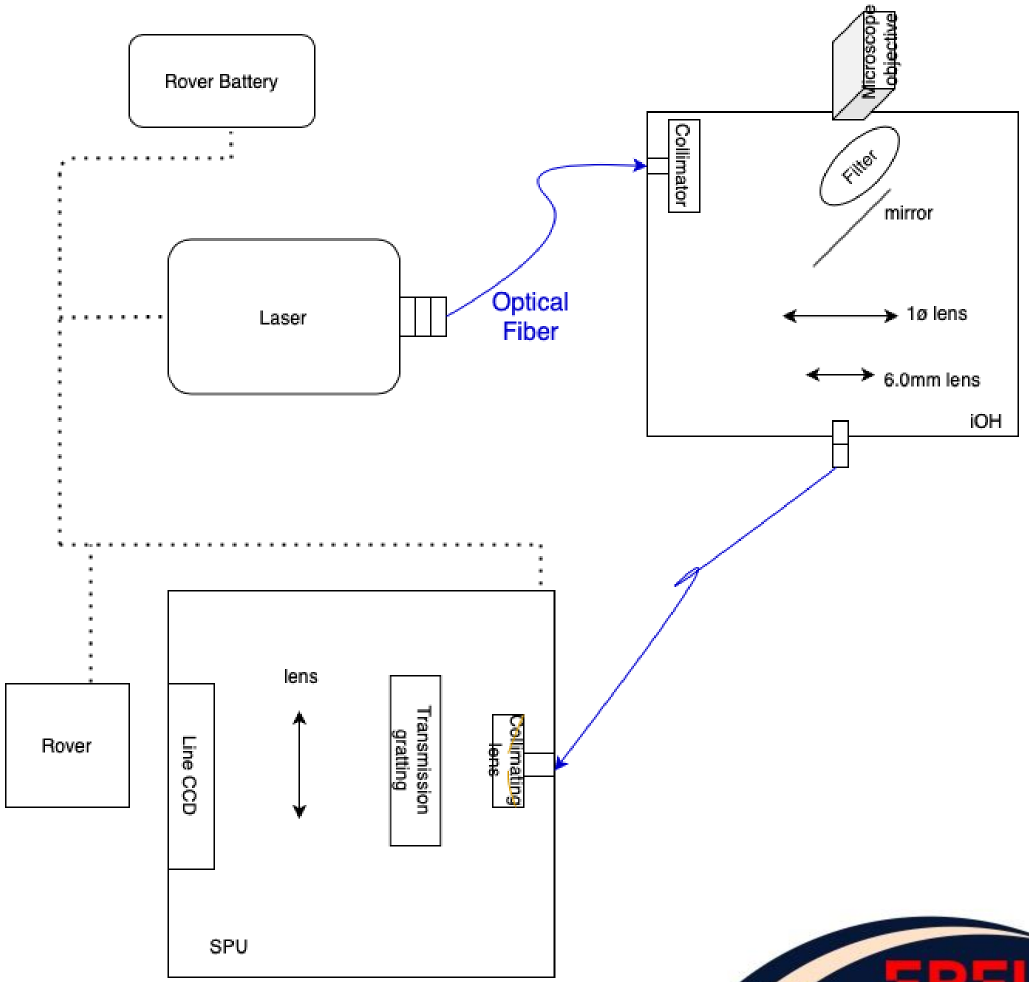
$$I_r \propto (\lambda_0 - \lambda)^{-4}$$



IOH



SPU

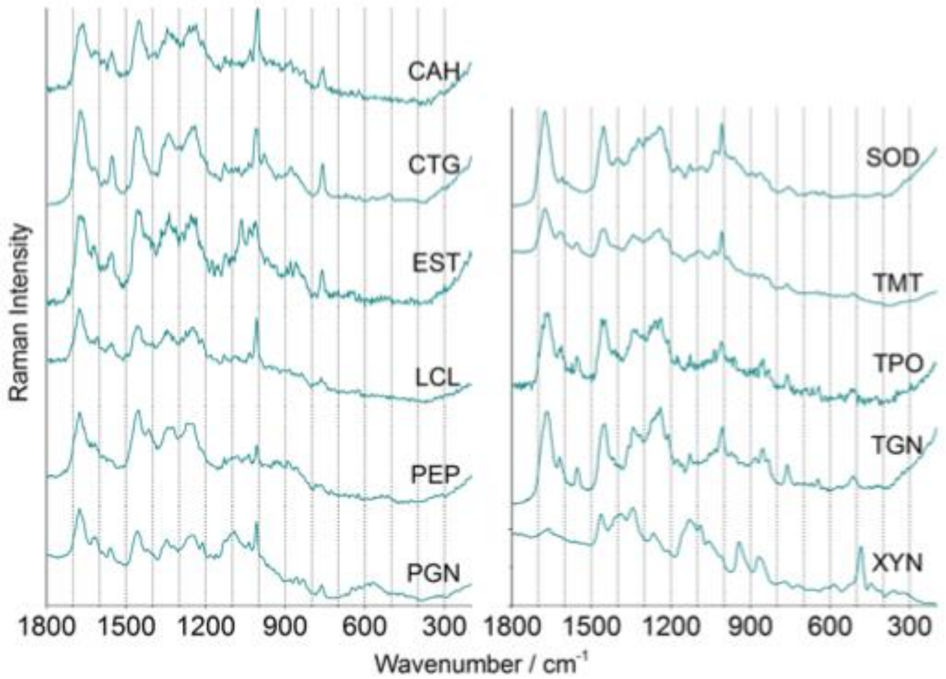


Spectral Range:

Detect the presence of protein and DNA inside soil

$$\Delta\tilde{\nu} = \left(\frac{1}{\lambda_0} - \frac{1}{\lambda_1}\right)$$

- Raman spectra of the DNA display pronounced peaks between 500-1700 cm^{-1}; Similar range for proteins (400-1800cm^{-1})
- As we work with a 405 nm laser, we have to analyse Raman wavelength between 414nm and 436nm

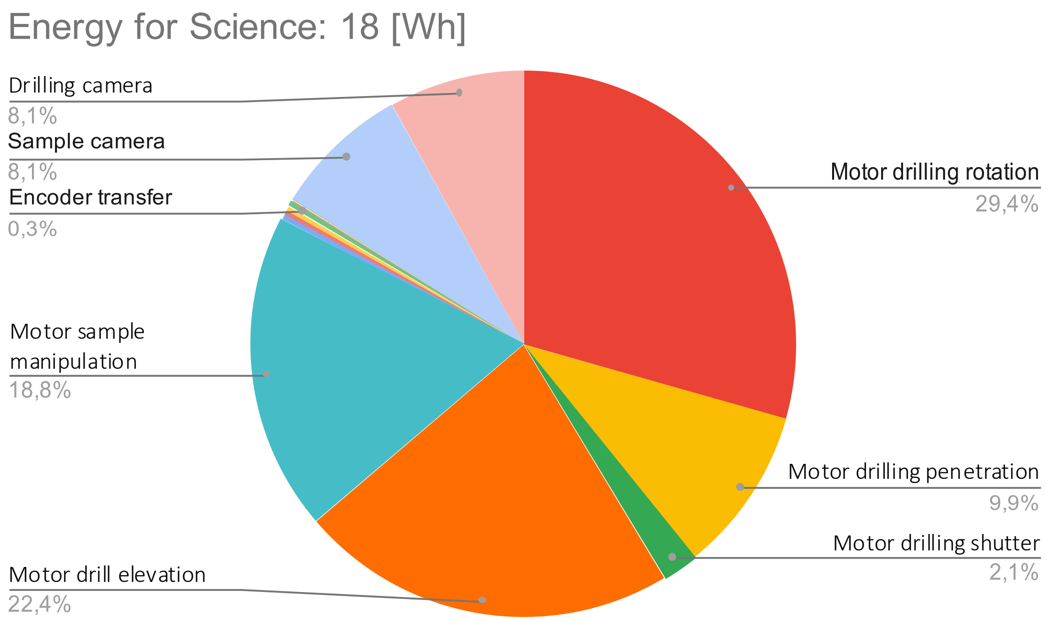


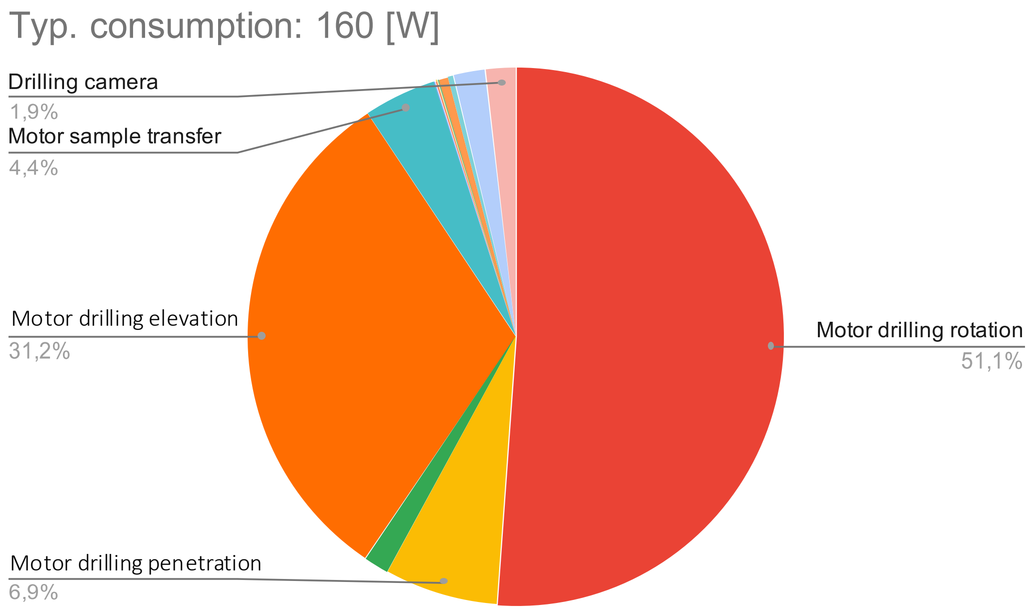
Raman spectra of the β-sheet proteins at 488 nm in the 1800–200 cm^{-1} range.

Source: J. Raman Spectrosc. 2013, 44, 1061–1076

Science power budget

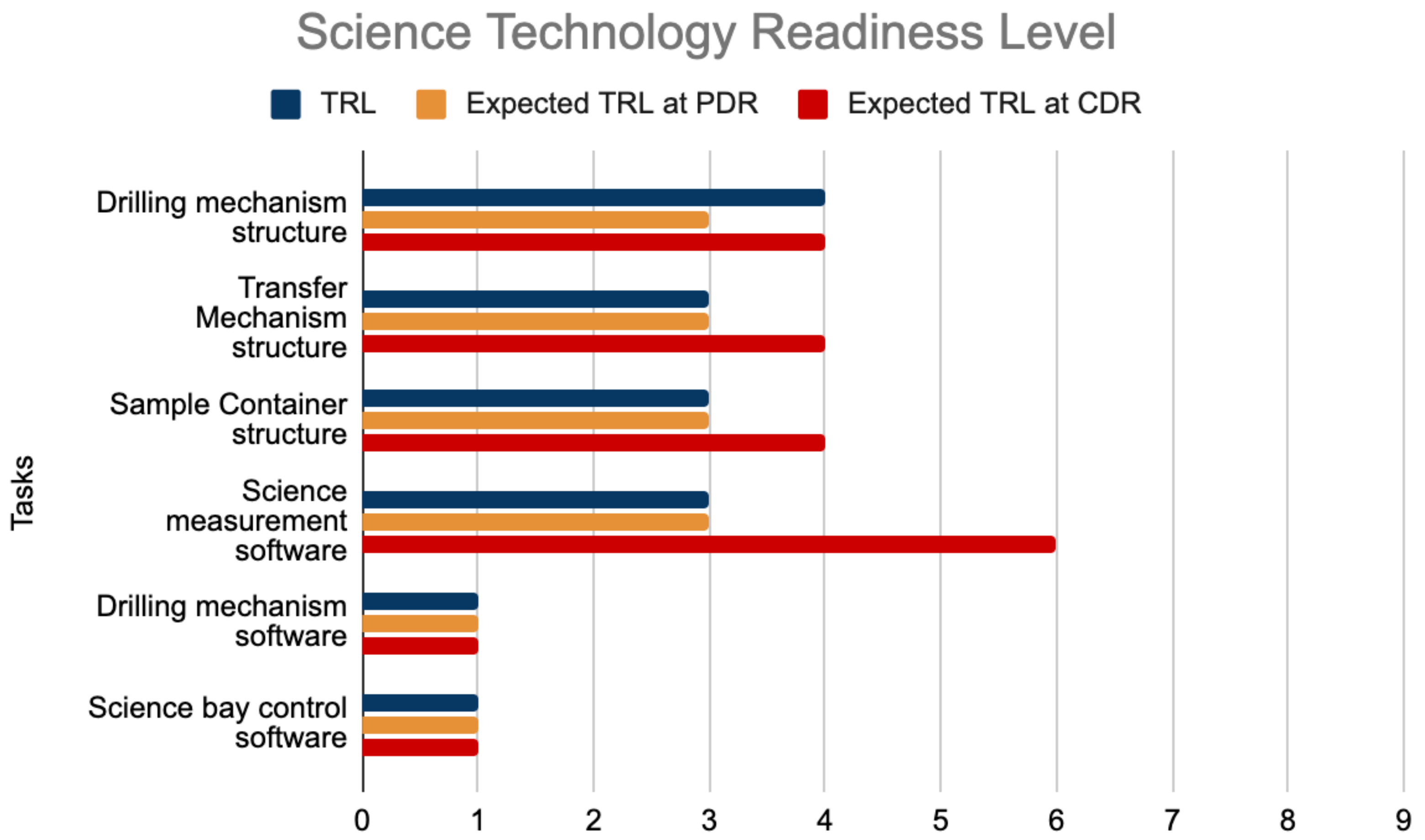
Maximum energy consumption is **18Wh** for Science task
High power for short amount of time: **160W**





Document	Science Risk Analysis

Ref / ID	Risk	Consequence	Probabilty	Impact	Risk	Strategy	Risk Response
XP_SC_RA_N012	Due to the harsh surface condition of the rocky sample, the durability of the scoop for surface sampling may be affected, the scoop may break after certain number of operation.	**Fail to extract surface sample**	**Medium**	**Very high**	15	Mitigate	Reduce the speed when closing the scoops. Have backup scoops to exhange if necessary.
XP_SC_RA_N013	Due to the unknown hardness of the regolith, when penetating the soil it will generate heat on the cutting blade. Which may cause the drill bit to melt down.	**Fail to extract deep sample**	**Medium**	**Very high**	15	Mitigate	Reduce penetration velocity. Monitor the input current to check the status of the drill. Set a threshold of operation current.
XP_SC_RA_N003	The shaft of the science bay may break due to the lifespan of the material or turbulence, the SC bay can no longer rotate.	**Science task failed**	**Medium**	**High**	12	Avoid	Have back up components to fix the science bay.
XP_SC_RA_N001	Given that the length of the drill is about 60cm, if the mass of the drill does not distribute symmetrically, it might lead to a break down of the drill system.	**Fail to extract deep sample**	**Low**	**Very high**	10	Avoid	Descend the drill platform before starting the deep sampling task.


Science Technology Readiness Level
TRL
Expected TRL at PDR
Expected TRL at CDR
Tasks
Drilling mechanism structure
Transfer Mechanism structure
Sample Container structure
Science measurement software
Drilling mechanism software
Science bay control software
0
1
2
3
4
5
6
7
8
9

Spring semester:

- <u>Components fabrication</u>
  - Purchasing the acessaries online
  - Contact EPFL workshop for piece productions
- <u>Hardwear testing and improvement</u>
  - Test drill and scoops in different soil condition(Contact material rock lab for different UCS sample), in order to find the optimum operation point
  - Test the functionality of Raman spectrometer(absorbance of different materials)
  - Optimize the length and height of the system to further reduce the mass
- <u>Softwear programing and testing</u>
  - Write the program for particle and color recognition
  - Data transmission essay
  - Controller programing and testing

Summer vacation:

- <u>Parts assambly and testing!</u>

Next step:

- <u>Implement liquid based test:</u>
  - Enable the test for pH
  - Enable spectrofotometer to determine the component of the soil
  - Optimise Raman spectrometer acquire data in different wavelength

Q&A Session (10 minutes)

Control Station

User Interface
Controls
Telemetry

Control Station Team

Emile Janho Dit Hreich

Control Station Team Leader

Grégoire Lacroix

Hardware Engineer

Aurelio Noca

Software Engineer

Document	Control Station Requirements

ID	Description	Verification method
EPFL_XP_CS_001	The rover shall not use GNSS receivers	Test
EPFL_XP_CS_005	The radio / antenna mast shall be able to communicate at a distance of 150m	Test
EPFL_XP_CS_008	The radio shall be able to work even with obstacles and obstrusions beween the rover and the base station	Test
EPFL_XP_CS_010	The team shall be able to control the rover from the control station without seeing the rover	Test
EPFL_XP_CS_002	An overflow of any communication/interface buffers or broadcast of multiple commands shall be prevented by means of the design	Test

Top-Level

- **src** MVC Template
  - Controller.py (main)
  - Model.py
  - View.py
- **resources**
  - images
  - audio files
  - etc.

Tools:

- Python GTK3
- C++
- RoCo
- ROS Melodic
- Glade
- CSS

ROS
Robot Operating System

Control station

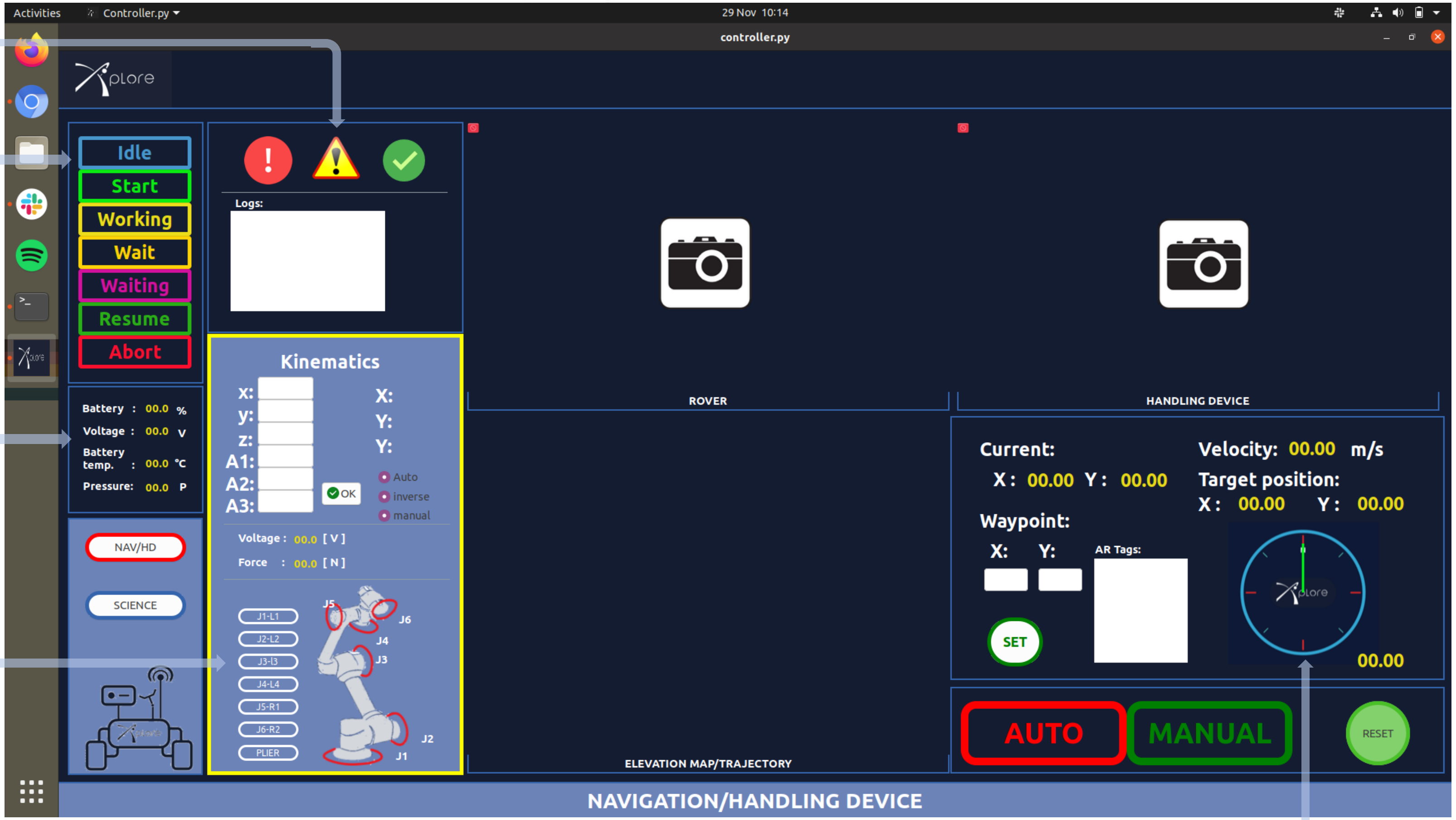
Error/Warning/OK

States

Avionics

Kinematics

Navigation



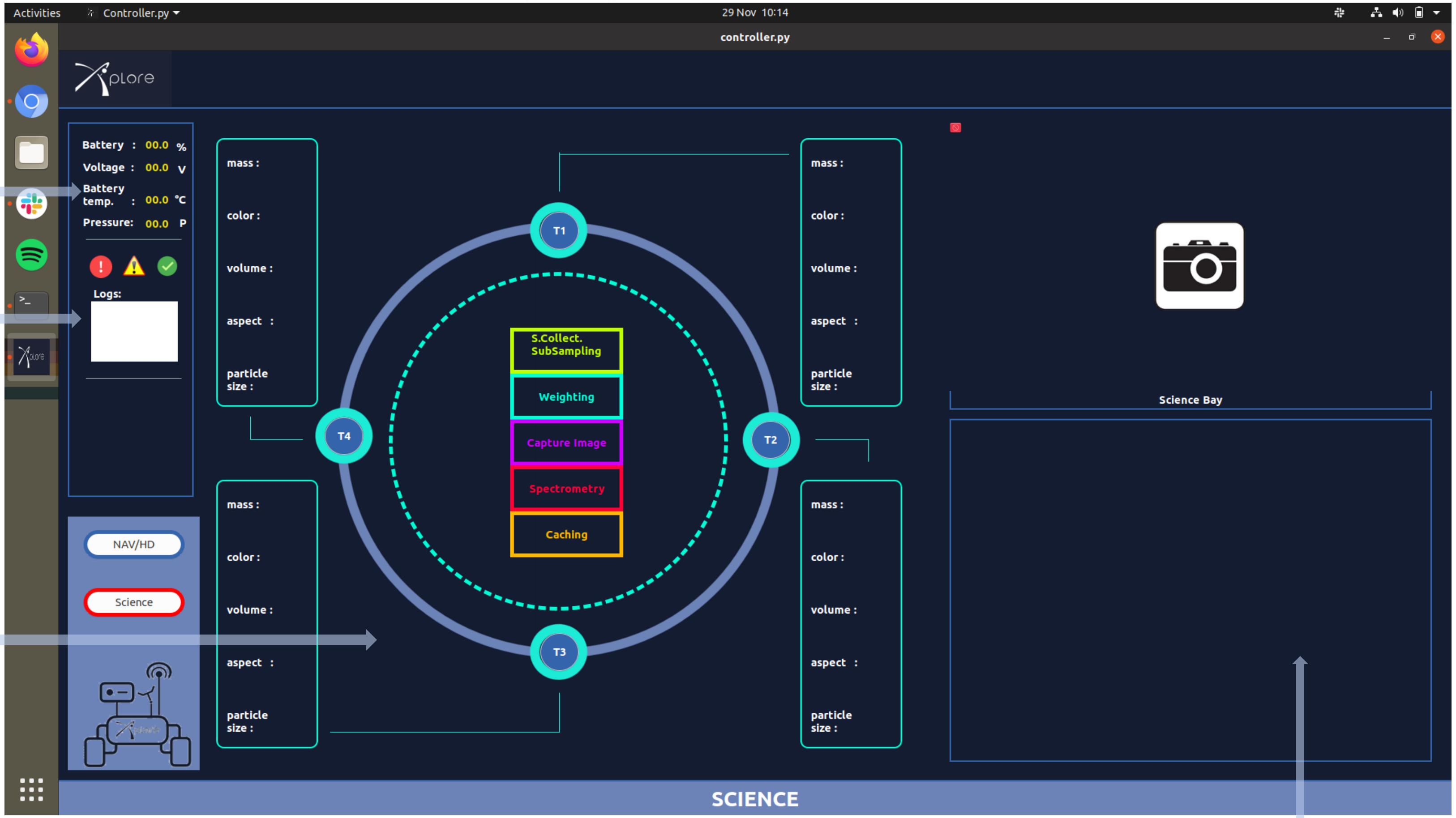
Navigation & Handling Device

Avionics

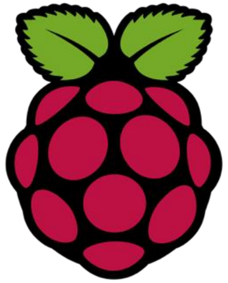
Error/Warning/OK

Tubes information

Experience data and graphs



Hardware Choices:
- Raspberry pi 4B 8 GB RAM with raspberry pi OS
- 128GB SD card
- 24-inch display
- Box
- Mouse + keyboard



Manual Controls:

Rover Navigation :
- X axis - Left Joystick - Directions
- R2 - Forward
- L2 - Reverse

Handling Device :
- △ to open the plier
- □ close the pliers

Direct kinematics:
- 1 joystick axis for all joints

Inverse kinematics:
- X axis - left joystick - movement on the X axe
- Y axis - left joystick - movement on the Y axe
- R2 and L2 - up and down - Z axe

Software choice

Communication with Navigation, Handling device, Science through ROS

- Easy Integration with GUI and Control
- Multi-platform (C++ / Python), ROS Python on Control Station

Communication with Avionics (RoCo + ROS)

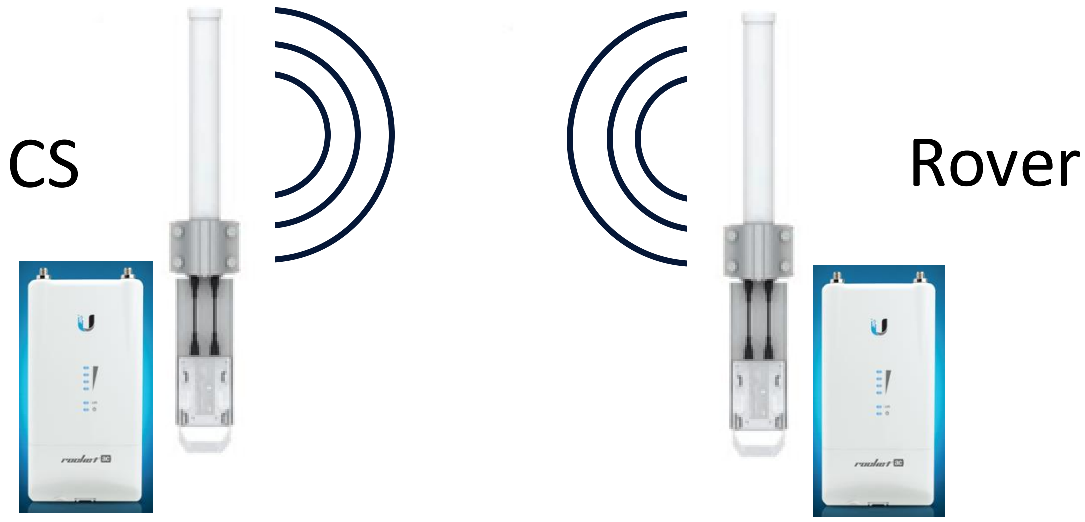
- Combination of RoCo and ROS
- Interface between ROS Python & ROS C++, as RoCo is in C++

Hardware choice

Rocket R5AC-Lite

- 5150 – 5875 MHz, (Channels 10/20/30/40/50/60/80 MHz)
- Within radiated power limits (max 27 < 30 dBm)
- Data rate up to 500 Mb/s (1x80MHz channel)
- Ethernet & power over ethernet (POE)

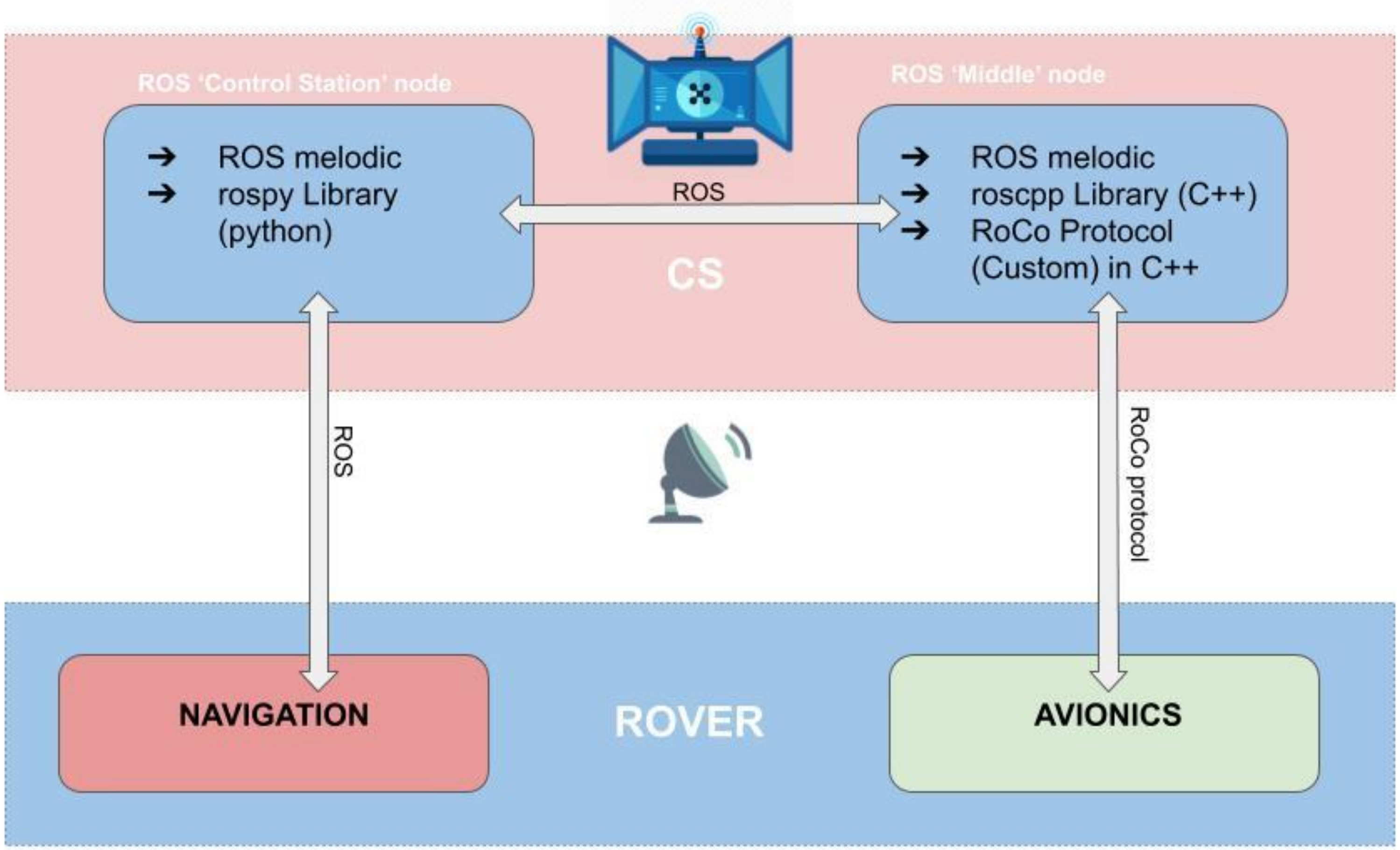
Lightweight : below 1Kg for transceiver + antenna



AirMax Omni MIMO 2x2 AMO-5G10

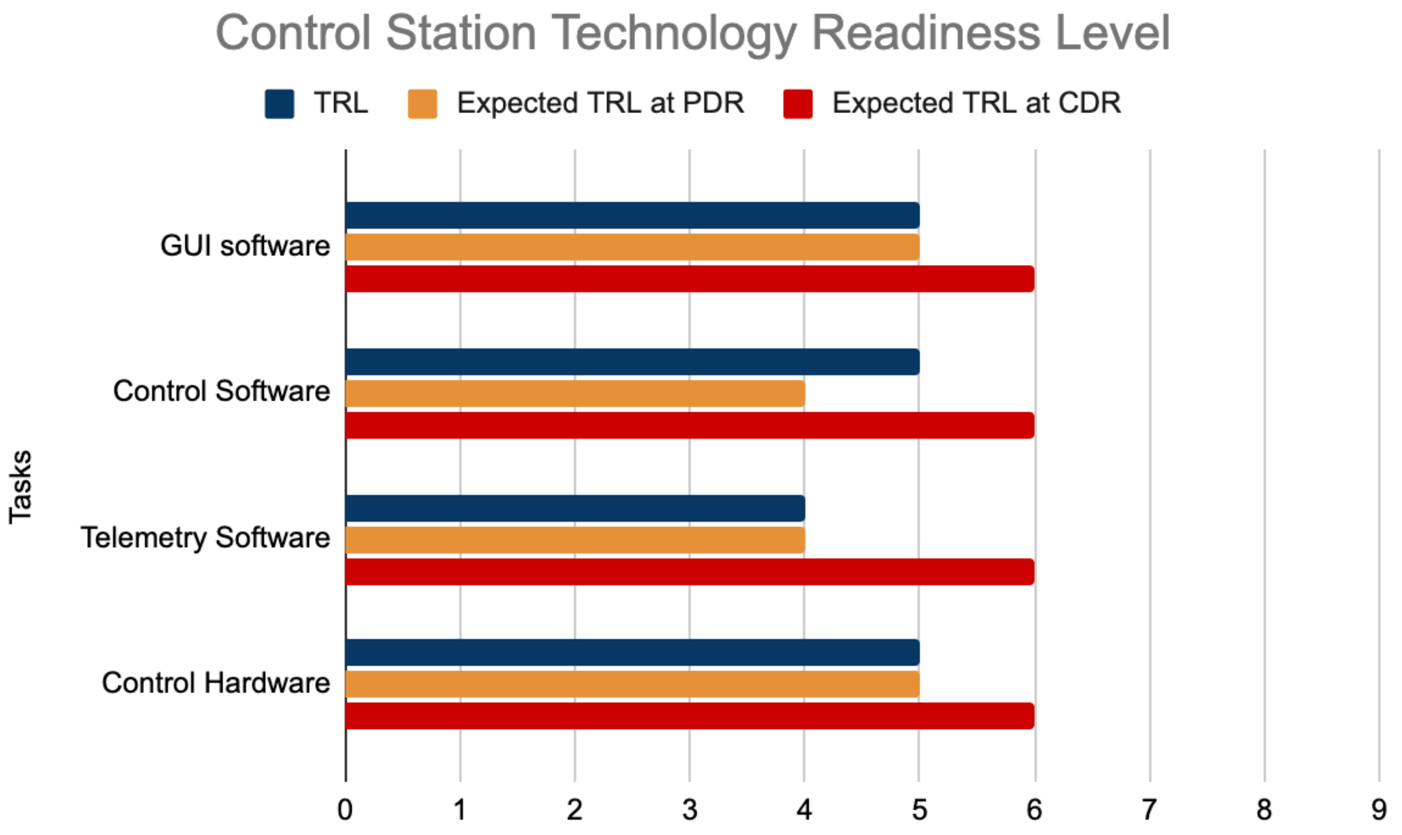
- Omnidirectional
- 10 dBi gain
- Plug & play

Communication Diagram



Document	Control Station Risk Analysis

Ref / ID	Description	Consequence	Probability	Impact	Risk	Strategy	Risk Response
XP_CS_RA_N001	Given that the Global Interpreter lock in python restricts the CPU usage to a single core, there is a possibility of overflow in the main thread	Impacting the rate at which data is received and sent, thereby leading to the interruption of real time communication	**Medium**	**High**	12	Mitigate	Extensive planning and testing of different thread priorites


Control Station Technology Readiness Level
TRL
Expected TRL at PDR
Expected TRL at CDR
Tasks
GUI software
Control Software
Telemetry Software
Control Hardware
0
1
2
3
4
5
6
7
8
9

1. Define ROS topics and packets based on an elaborated communication strategy
2. Test the multithreading in python on IO bound software
3. Study the implementation of multiprocessing in python
4. Assemble the Box and test antennas

Next Step

Q&A Session (10 minutes)

Conclusion

THANK YOU

The EPFL Xplore team wishes to thank you all for attending this presentation.

*Especially, we would like to thank our sponsors Maxon,
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