ROBOTIC ARM AND GRIPPER END-EFFECTOR FOR MARS ROVER TESTBED

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ABSTRACT

This paper proposes a solution for the kinematic chain and necessary control electronics for a robotic arm and its respective gripper end-effector, which shall serve as testbed for the fetching operations in the upcoming Mars Sample Return (MSR) mission [1]. This manipulator is to be integrated into the Martian Rover Testbed for Autonomy (MaRTA), the latest rover testbed at ESA's Planetary Robotics Lab. The Perseverance rover from the MARS2020 mission is currently collecting Martian soil samples and storing them in tubes. Some of these sample tubes are being dropped onto the ground to later be retrieved by a future European Space Agency (ESA) rover. The robotic arm, gripper, and MaRTA will mimic the key operations of this sample tube retrieval. This operation simulation can be divided into three phases: 1) The physical approach of MaRTA and the robotic arm to a sample tube, 2) The process of grasping the tube with the gripper, 3) and the manipulator motion to properly store the sample tube on-board MaRTA.

1. INTRODUCTION

One of the crucial steps for the success of the Mars Sample Return mission is the retrieval of the samples by ESA's Sample Fetch Rover [2]. These samples are stored in titanium tubes for a later retrieval and subsequent launch into Mars orbit, before finally returning to Earth. The tube retrieval from the Martian surface will be performed by a set of a robotic arm and gripper that are specifically designed for this purpose.

In order to have a tailored design, a specific flow of operations is in place. The grasping process starts with the positioning of the rover in an optimal sample tube pick-up position, which is done by using the relevant locomotion and navigation methods integrated into the rover. This is followed by the robotic arm motion towards the sample tube. The gripper attached to the robotic arm then secures the tube acting upon the data obtained from the on-board sensors. This initial grip is made close to the geometric center of the tube and with the gripper's fingers perpendicular to the tube's rotational axis. This grasp is referred to as radial grip. In the next stage, the robotic arm moves the tube closer to the rover and locks it in a bracket to perform the re-gripping process. Here the grip is changed from radial to axial, holding the tube vertically with the tube rotational axis parallel to the gripper's fingers. This change of gripping is required in order to enable the gripper to lock the tube in the final storage area on-board the rover. The flow chart in Figure 1 illustrates this process.

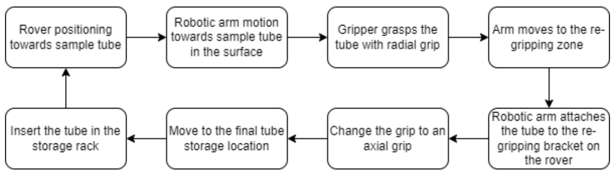


Figure 1: Flowchart of the tube retrieval operations

Taking into consideration this operational process, this paper proposes a technical solution for the robotic arm and gripper end-effector that enables this flow of action and that is compliant with the given requirements. The technical design elaborated on in this paper was developed in partnership with Rover Company Ltd. (RCL) for the mechanical components, as well as with Eltrex Motion B.V. for the avionics.

2. ROBOTIC ARM DESIGN AND TECHNICAL SPECIFICATIONS

The specifications of the robotic arm were selected based on multiple factors. On one hand there are factors related to MaRTA, such as the rover size, mass, and ground clearance. On the other hand there are factors related to the sample tube intended for pick-up, such as its mass, volume, and geometry.

The manipulator in development has six joints and is in a Pan-Tilt-Tilt-Roll-Tilt-Roll configuration. Although the configuration differs from the manipulator on the MSR mission rover (Roll-Pan-Pan-Roll-Pan-Roll), measures have been taken to ensure the viability of the comparability of both scenarios.

The initial design of the manipulator was intended to have $\pm 125°$ of range on joint 2 and 5, and $\pm 135°$ on joint 3.

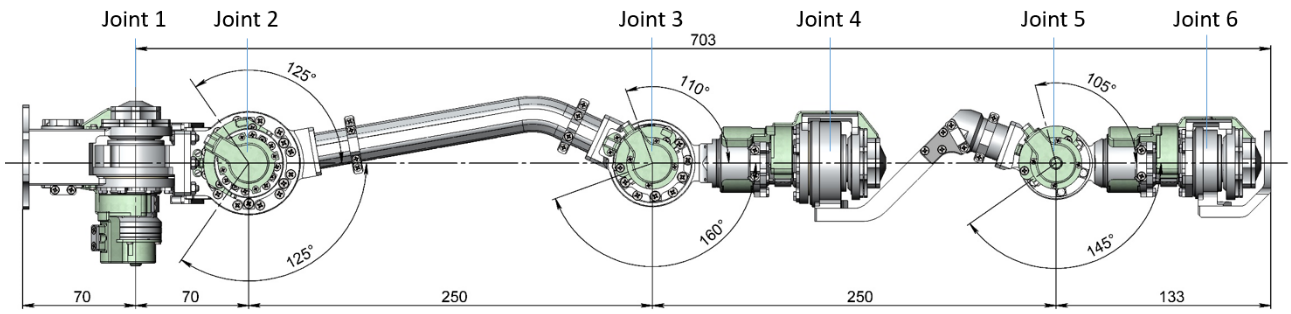


Figure 2: MaRTA robotic arm schematic (all dimensions in mm) showing the tailored design for increasing joints 3 and 5 range in one of the direction.

Through simulations and analysis it was concluded that this angular range would not fulfill the operational reach requirements and complete the sample acquisition process as intended. As a consequence, the design of the manipulator follows a pragmatic approach by offsetting the range of joints 3 and 5 (Figure 2) and, therefore, increasing the range of these joints in one of the directions; this results in an asymmetric joint range. The offset direction was chosen considering that the manipulator will be mounted on the front right of MaRTA, as depicted in Figure 3.

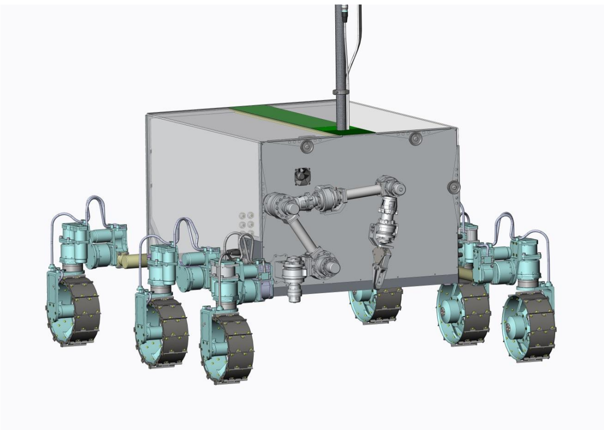


Figure 3: Initial robotic arm design on MaRTA

This configuration aims to provide a wider operational range to the surface and to the sample tube storage area when compared to a configuration where joints 3 and 5 have symmetric ranges.

Each joint features a Maxon motor with Hall sensor and two Harmonic Drive gearboxes. This combination will allow the arm to have a maximum payload capacity of $0.9\,\mathrm{kg}$ at the tip and a maximum moving speed of $5\,°/\mathrm{s}$.

As a position sensor an absolute encoder was chosen, namely the Netzer DS-25, which size is appropriate for each joint ($25\,\mathrm{mm}$ outer diameter) and which has an accuracy of $\pm\,0.01°$.

A Force/Torque sensor will be integrated into the tip of the robotic arm (ATI Mini 40). The use of this sensor allows a safer motion of the arm since any force applied to the gripper will be measured and appropriate actions can be taken if required. Particularly in the tube pick-up stage, where there is a high chance of the gripper colliding with the ground, this data will be crucial.

Table 1 contains all the mentioned specifications of the robotic arm.

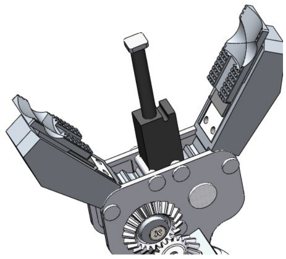
Motors	Maxon EC 20 motors ($3\,\mathrm{W}$ and $5\,\mathrm{W}$) with Hall sensors
Gearboxes	Harmonic Drives CSF series (two on each joint)
Payload	$0.9\,\mathrm{kg}$
Mass	$3\,\mathrm{kg}$
Length	$703\,\mathrm{mm}$
DoF	6
Accuracy	$\pm 5\,\mathrm{mm}$
Absolute position sensor	Netzer DS-25
Force/Torque sensor	ATI Mini 40

Table 1: Robotic arm specifications

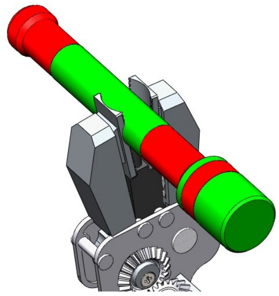
3. GRIPPER DESIGN AND TECHNICAL SPECIFICATIONS

The second important component is the gripper to be attached to the robotic arm, which will feature a parallel closing mechanism consisting of two opposing fingers. It is designed to pick up mock-up sample tubes which are representative of the ones already on Mars in terms of size and mass. The fingers will feature the negative shape of the tube for the radial and axial grip, blocking at least two translational degrees of freedom.

To activate the closing mechanism and to ensure that the sample tube is in the desired position, the gripper will feature a potentiometer (Sensata 9610R3.4KL2.0) triggered by a bar. This bar is intended to be pushed by the tube when the gripper initiates the physical contact and, depending on the value given by the potentiometer, the



(a) Gripper in open position



(b) Gripper with tube

Figure 4: Depiction of bar sensor concept. The bar can be observed in the top of the potentiometer rod. This potentiometer will be triggered as soon as the bar establishes physical contact with the sample tube in the surface.

closing mechanism is triggered. This sensor will resemble the concept depicted in Figure 4.

Furthermore, the gripper will have a load cell (Forsentek FMZK) in each finger, which will give feedback of the force that the two opposite fingers exert on the tube at all stages of the operation. While the load cells are certified up to $100\,\mathrm{N}$, the maximum force that the fingers will exert on the tube will not be in excess of $40\,\mathrm{N}$. Given the low rated output voltage ($1\,\mathrm{mV/V}$) of the load cells, these need to be amplified. On-board MaRTA, there will be a signal amplifier (Forsentek LC3A) that ensures that the signal is forwarded to an analog input of the controller (Elmo Gold Twitter) in the range of $0\,\mathrm{V}$ to $10\,\mathrm{V}$.

For the motor and gearbox selection, studies were conducted in order to design an actuator that could be compact, light, but yet capable of exerting $40\,\mathrm{N}$ of force in the tip of the fingers. The solution found was a Maxon EC 9.2 motor (with $0.5\,\mathrm{W}$ of power) with a 64:1 first gear stage (Maxon GP10A), a 1.1:1 second gear stage (a RCL in house development RCL-IT spur gear), a 100:1 third stage (Harmonic drive CSF series), and finally a 2.5:1 fourth stage (another RCL-IT). This gear set can be seen in the Figure 5.

Table 2 contains all the mentioned specifications of the gripper.

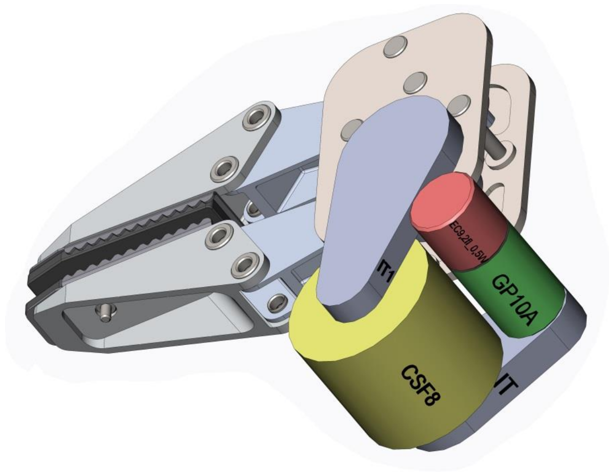


Figure 5: Gripper Drive. This figure depicts the gripper containing the Maxon motor (in red) and the four gearboxes (in gray, green and yellow) mentioned in Table 2

Motor	Maxon EC 9.2 motor ($0.5\,\mathrm{W}$) with Hall sensor
Gearboxes (ratio)	1 - Maxon GP10 A (64) 2 - RCL - IT (1.1) 3 - HD CSF series (100) 4 - RCL -IT (2.5)
Max. force at tip of fingers	$\approx 46\,\mathrm{N}$
Mass	$< 0.4\,\mathrm{kg}$
Max. volume	$72\,\mathrm{mm}$ diameter $85\,\mathrm{mm}$ length
Absolute position sensor	Netzer DS-25
Bar Sensor Potentiomer	Sensata 9610R3.4KL2.0
Load Cells Amplifier	Forsentek FMZK-10KG Forsentek LC3A

Table 2: Gripper end-effector specifications.

4. ROBOTIC ARM AND GRIPPER AVIONICS

On the avionics side, the arm and gripper will be powered by a power condition and distribution board on MaRTA. This board will not only power the motors, but also all sensors. For controlling the motors and interpreting the sensors feedback, ELMO motion controllers were selected to be mounted on two separate PCBs on MaRTA, as each board supports up to three drives. These PCBs have a similar design, but with slight differences to match the different requirements of the gripper and the robotic arm.

The PCB that is dedicated to the robotic arm is termed Manipulator Motion and Control Subsystem (MMCS) and includes all necessary inputs for each drive, such as a dedicated hall sensor input, an absolute position sensor input, the power supply for the motors, and an Ethernet communication. Additionally, this board can double as a

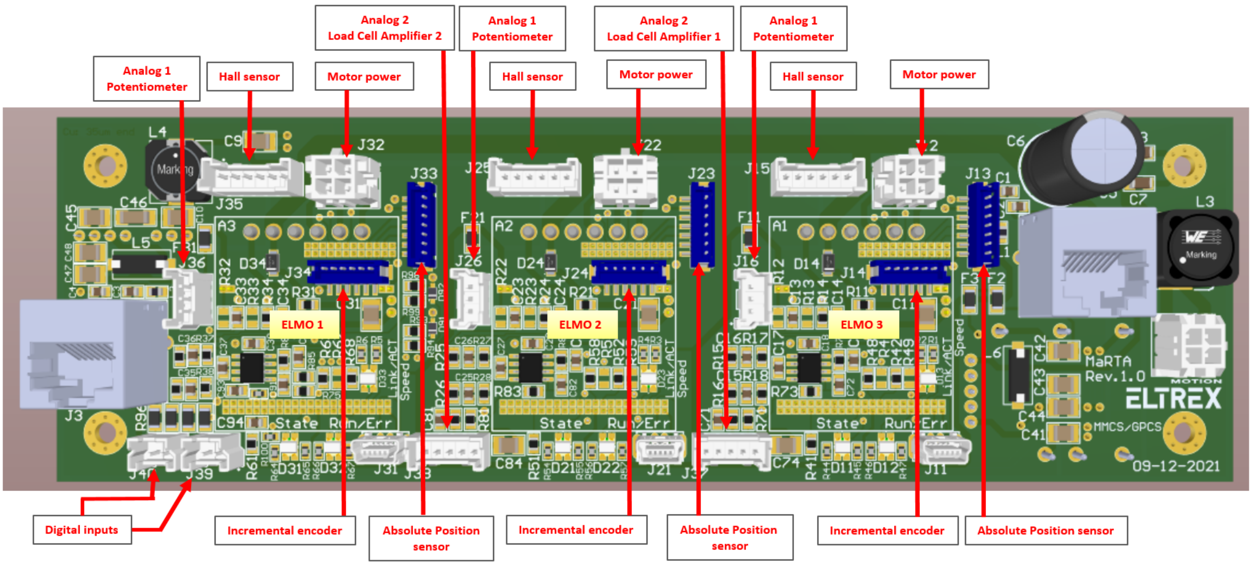


Figure 6: GPCS board with labeled sensor inputs

Motion Control Subsystem (MCS) for MaRTA's locomotion, and, therefore, steering the wheels and controlling the velocity of the platform.

The gripper PCB is denominated as Gripper and Pan and Tilt Unit (PTU) Control subsystem (GPCS). This board includes a few extra analog inputs allowing the processing of the amplified load cell signals individually as well as summed, the bar sensor potentiometer, and a possible potentiometer for the PTU. Additionally, it will have two digital inputs in case a switches are required to replace the bar sensor potentiometer.

Figure 6 depicts the layout of the GPCS board developed by Eltrex Motion B.V..

5. CONCLUSION

The purpose of this project is to have a functioning manipulator and gripper system that can provide the necessary capabilities in order to perform the pick up and storage of the Martian soil sample tubes. Theoretically and in simulation the requirements for the robotic arm and gripper were fulfilled for a successful flow of operations with the specifications mentioned on Table 1 and Table 2. For further confirmations an acceptance review will take place at the time of delivery of all the components.

ACKNOWLEDGMENTS

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REFERENCES

[1] ESA. Mars Sample Return. https://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Exploration/Mars_sample_return, 2019. Accessed: 2022-05-02.

[2] ESA. Sample Fetch Rover for Mars Sample Return Mission. https://www.esa.int/ESA_Multimedia/Videos/2020/02/Sample_Fetch_Rover_for_Mars_Sample_Return_campaign, 2019. Accessed: 2022-05-02.