Europian Rover Challenge 2019

Preliminary Report

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Rover Name: **AVIJATRIK 3.0**

Affiliation: **IUT IEEE RAS & IUT**

Version: **1.0**

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1. Project Assumptions

Since in the proposal we submitted the assumptions initially, here we are stating the assumptions in a detailed manner:

- The rover built will be a fully radio-controlled prototype of Mars Rover with a multi-purpose hand and science task module to carry out in situ lab experiments and collect sample and data.
- The weight of the rover should not be more than 50 kg.
- The range of communication of the rover should be more than 100 m at least.
- The rover body and wheel will be built to be compatible with the rough and challenging terrain mars without making any disturbance to the on board devices.
- The hand will be able to do the maintenance task and collection task at the same time but not the science task as the gripper needs to change with a shovel. It can be operated in both RC mode and automatic mode. For the automatic mode an automation system will be implemented so that the hand can automatically detect object and carry out different tasks.
- The rover will also be able to map the surroundings and automatically travel to destination with the help of predefined signs and routes.
- On board power system will ensure the run time to be more than 90 minutes.
- Finally, the rover will be able to carry out the four tasks:
  1. The Science Task: The science task will contain different level of soil drilling, cachingand in-situ sample example.
  2. The Maintenance Task:Maintenance tasks will be mainly focused on task automation, teleoperator interface, end effector performance and manipulator performance. Tasks automation should be presented in one or more cases.
  3. The Collection Task: The collection tasks will be focused on automation elements detection, approach and collection, operation robustness, containerand chance design, delivering the container to designated place etc.
  4. Automatic Traversal: The rover is to traverse autonomously and follow four way points provided from the work station. The rover must possess on board detection and image processing capability to understand sign and avoid obstacles.

2. Technical Requirements

2.1 Science task

- The rover should be equipped with device to extract the soil both from surface and subsurface layer, which might be 15 to 35 cm below surface.
- The rover should have a surface sampling device that should be prepared to handle different type of loose soil.
- According to science task 4 samples are to be collected of which three from surface and one from deep sub surface layer about 15 to 35cm
- Deep sampling device should be prepared on the rover to handle materials from loose soil tohard gypsum and the deep sample should at least contain material from the deepest reached point. Inideal scenario team should present unmixed, undisturbed cross-section of alllayers from the surface to the deepest reached point. Also,
  - The rover should be equipped with at least one sampling device.
  - Rover must be equipped with at least one sample container;
  - Samples should be delivered in dedicated containers, one container for eachsample;

- Containers can be manipulated and removed from the robot only in the company of judge;
- Container design and sample insertion method/device should be inspired by real mission's requirements;
- Minimum resolution of the images is 800x600 pixels. Object of the image (sample location or sample itself) should occupy major part of the image. Image quality should be reasonable for scientific needs;
- Any additional physical parameters must be documented in the control station and stored till judge inspection after task attempt end. Judge will evaluate quality of received data;
- The trench should have minimum 30cm length, minimum 5cm depth and at least one wall steep enough to present clearly visible soil layers. This findings should be documented on a photo.

The method for sampling reaction forces/torques separation from rover body should be presented and will be scored by judge based on operation observation.

2.3 Maintenance Task

- Approach switches in the board panel and turn it off or on and rotate knob to at least 5-degree precision.
- Grasp the high-power plug from the ground and insert it into the socket
- Controls can be located on vertical panels between 0.2m and 1.5m above the ground;
- tracking of controls positions and etiquettes during robot and arm movement;
- The rover shall be equipped with manipulation device which is able to pick up cache and place it into container on-board;
- Voltage measurement is conducted on standard German type F/French type E similar power socket or terminals with similar dimensions and connection requirements;
- Voltage level is between 1.0VDC and 24.0VDC and should be reported with 0.5V accuracy;
- High-power plug type is IEC 60309 with maximum 10cm handle diameter;

Some of the panel elements may be covered by MLI-like (Multi-Layer Insulation) material attached. Thus, enough force is needed to penetrate the switch board socket in order to measure voltage

2.4 Traversal Task

- Use of GNSS receivers and any other localization reference system is not allowed.
- Localization and mapping using image processing and slam algorithm. Create a probability stick map
- Implementation of especial sensor like LIDAR to implement safe routing technology that is to select an automatic route with less obstruction.
- On-board data processing application should be used for rover localization based on natural terrain features, however navigation landmarks can be placed for absolute reference on team request. Use of landmarks result with penalty points.
- The rover system can utilize coarse height map of the arena provided by organizers, however solutions working without using predefined map will be scored extra.
- System should be able to plan optimal path based on given map and way-points coordinates.

2.5 Communication

- Maximum range between base antenna and rover would be less than 100m.
- Line of site connection may be obstructed due to terrain morphology
- 2.4 GHz Wi-Fi standard is accepted and transmission power up to 100mW EIRP
- accepted standards: 802.11b/g (802.11n forbidden);
- only one 20 MHz channel can be used

- Other systems like analog video cameras or RC controllers using frequencies 2412-2472 MHz and 5260-5700 MHz are forbidden.
- The video stream should have minimal delay and reasonable resolution in order to carry task especially the maintenance task.
- For maintenance task, we need at least three cameras to operate simultaneously for better view and depth perception.

2.6 Power

- On board independent rechargeable power system to support the whole system for at least 60 minutes.
- Low power device to be used to increase efficiency.

2.7 Safety System

- An emergency stop switches clearly visible on the rover for emergency shutdown.
- Indicator light symbolizing the current state of the rover.

3. Technical Design

The technical design for each section of the rover is made and reviewed, based on the technical requirement for each task. The major changes that we made (if any) is highlighted in the modification part. Any practical problem that we found is listed with the risk assessment. The proposed design solves all the requirements. If any requirement is not met or still under design phase will be discussed in risk problem identified section.

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3.1 Body Material

The rover comprises of stainless steel, mild steel, hardened steel, aluminum, ABS,PLA and nylon throughout its entire modular structure. Aluminum, due its lightweight and strength, has been used for most of the structural frame. Using stainless steel as the principal material last year made the rover overweight resulting in other hardware issues. Different extruded aluminium profiles would be used on demand. The profiles will be bolted or welded depending on modularity of certain sections.

The basic segments of the rover body, namely, the main structural body, rocker arms, bogie arms and the differential parts are being constructed by using stainless steel and aluminium.

The definitive elasticity of 860 MPa, high temperature withstanding of 600 degree Celsius,minimum yield strength of 355N/mm^2, corrosion resistivity and malleability of stainless steel made it suitable for its decided use. Al6063-T5 grade aluminum alloy profile with a tensile strength of 250 N/mm^2, modulus of elasticity of 70 kN/mm^2, lightweight and corrosion resistivity are the key factors for which the four-wheel transversely split differential drive system was built using aluminum. The robustness of the stainless steel and the light weight of aluminum, with the given orientation of the way they are connected, means the structure can withstand an overall weight of 72kg. However, the estimated weight will be around 42kg this time around owing to the efficient tweaks in design of the robotic arm and the base plate and the use of aluminum in the rover skeleton.

The custom-made wheel spokes and plates use milled aluminium. The robotic arm comprised of aluminum and stainless-steel composite structure gives rigidity at front since the lifting of objects and maintenance tasks demand great measures of strength.

Most of the actuators are closed loop but for those which are not, 3D printed mounts out of PLA and ABS are used for mounting the digital encoders with the motor shafts ensuring very high resolution with no backlash error. This also provides room for other systems like the driver unit and the closed loop controller.

The housing of the bearing in the pivot of the rocker bogie and that containing the wheels are made up of mild steel.

Brass bushings are used in areas where ball bearings cannot be used in order to reduce friction.

3.2 Rocker Bogie Mechanism

The rocker-bogie mechanism is implemented in such a way, which facilitates optimum traction and perfect weight balance on uneven surfaces. The rocker-bogie suspension system balances the rover on the event of sudden change of position while moving on a rocky terrain. If one side of the rover were to travel over a rock, the rover would lose its balance. By the means of the differential bar, the imbalance is totally overcome. Therefore, on any given condition of obstacle of surface, the rover chassis remains level to the ground surface. The differential drive wheels are spaced in a 1:1 ratio. No spring or hydraulic suspension was used here, because this type of suspension is less stable. But in rocker-bogie suspension system maximum stability is ensured. The rocker-bogie mechanism is designed so that the rover can cruise over a slope in excess of 60 degree or even more. The upper differential bar was set at the back part of the rover body, so weight balance in the body was ensured easily.

Two milled aluminum bars were attached to the freely rotating housing of the pivot, with a bearing in it, attached by means of recirculating-ball nut and screw mechanism. The end of the aluminium bar have a U-shaped plate. The U-shaped plate contains two bearings at each end that contain the wheels in it. This U-shaped plate is removable as well, creating a further modular system in the lower portion of the rover as well. The U-shaped plates are made up of mild steel.

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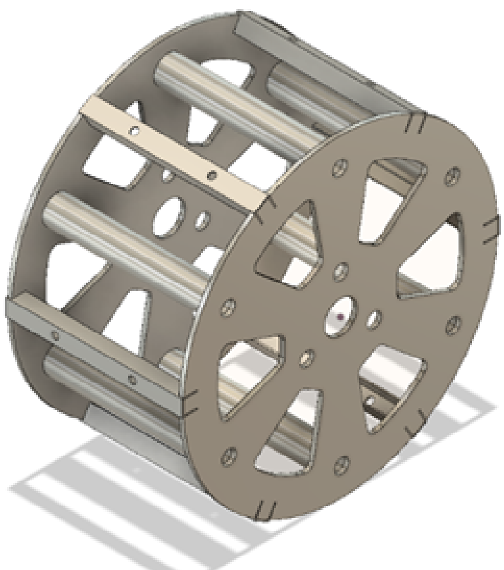
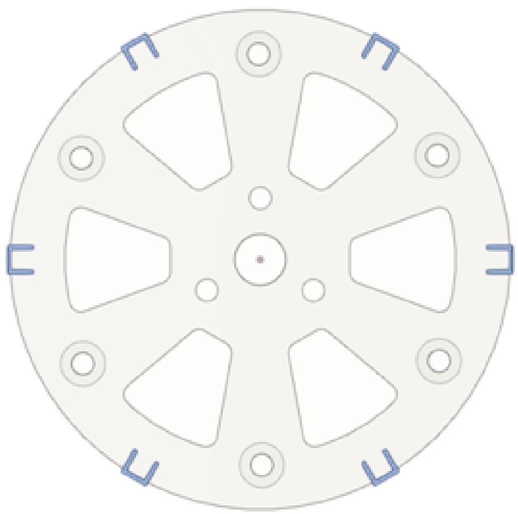
3.3 Wheels

Four custom made wheels are being used. Aluminum wire spokes (wheel flexures) are mounted tangentially to the hub. Tangential spoking allows for the transfer of torque between the rim and the hub. Tangential spokes are necessary for the drive wheel, which has torque at the hub from the drive motors. ‘I’ shaped stiffening rings are internally positioned to reduce maximum unsupported length to prevent collapse under external pressure load.

The outer edge of the wheel holding the tire is made up of aluminium sheet with a width of20cm. Skin grouser treads are wrapped around the outer rim with hand-made tractionimprovement patterns implemented on the surface. A CAD design is provided below:





The wheels are having a corner wheel steering mechanism with the addition of one more drivemotor to each one of them. Corner wheel steering method gives the rover the independence of moving in parallel in any given direction without the rotation of the entire body and also rotating with zero clearance.

Universal joint connection at each wheel is made with the drive motors. Ball bearings used at each joint to ensure smooth transition of the wheel and Computer Numerical Control (CNC) device has been used to create the housing of the bearings.

Modification

The width of the wheels is increased to increase the traction force and better stability. The body measurements are slightly change for a compact frame and better differential drive.Aluminum has been used in most of the cases for reduction of weight.Finite element analysis has been implemented for a more optimized structure making it more durable and light.

3.4 Robotic Arm

The robotic arm is equipped with six degrees of freedom. The rotating base plate, which is driven by a closed loop geared stepper motor and further 8:1 gear reduction with a spur gear arrangement, which maneuvers the entire robotic arm in any wanted direction offers the first rotational freedom. The secondary arm attached directly to the base plate driven by a high torque stepper with planetary gearbox makes the entire set up move up and down and gives the second degree of freedom. The up and down movement of the primary arm which is also driven by a high torque stepper with planetary gear reduction is what gives the third degree of freedom. The ability of the primary arm to make wave-like movement, as it moves left and right, is what gives the fourth degree of freedom. The movement of the grabber in the x & y-plane with the help of two closed loop geared motors attached at its end enables the fifth degree of freedom. The ability of rotating the entire grabber 360 degrees by means of screw driven rotating platform is what offers the final degree of rotational freedom.

The primary and secondary arms are milled aluminum bars which are driven by those geared stepper motors attached to them and they can be easily separated from the base plate as well; further solidifying the modular approach claim.

3.5 Robotic Claw

Two claw grabbers which is able to grab with organic motion mounted on the wrist joint that is able to rotate 360 can turn knobs for maintenance task. The arm has maximum vertical reach of 65 cm & maximum horizontal reach of 70 cm. Two closed loop high torque stepper motor are used allowing the arm to access wide regions. The arm has two replaceable wrists: a shovel and a gripper. The provided steppers can withstand 6kg.m static load and 4kg.m dynamic load each, which made the soil digging and weight lifting tasks easy. It can easily lift weights up to 3-5 kg. Archimedes' screw is used for digging soil and lifting it from 10cm below from surface. Stainless steel has been used to make sure there is a smooth operating range with no bending occurrences.

Modification

The hand design of the rover is upgraded from using linear actuators to closed loop geared stepper motors for very precise motion and feedback system for automation .This also enables the use of inverse kinematics control for the robotic arm.

Problems Identified

A prototype arm was created but we could not get the desired precision due to structural tolerances.We are working to make a much more rigid arm with as much low tolerances possible.

3.6 Science Task Module

Our need will be to decide the ability of a specific geographical region to help the presence of microbial living things. Since countless number of studies have demonstrated that a flourishing populace of microbial living things is regularly an antecedent to more propel life. Various soil tests will be gathered with the guide of our rover's multi-purpose hand. The tests will then be analyzed, particularly concentrating on the accompanying properties of the specimen, namely;

Temperature

Temperature readings will be taken directly from at both the surface level and beneath the surface, through a temperature probe (implementing a DS18b20 Sensor) which will be attached to the rover hand.

Moisture

Moisture data will also be collected in a similar manner through a soil moisture sensor (Grove moisture sensor).

pH

After completion of the temperature and the moisture data collection from a specific spot, a soil sample from that spot will be taken and deposited into our on-board chemistry lab.

The weight and pH of the sample will be measured as the system below, illustrates:

The shovel attachment of our rover hand will be used to excavate the sample which will then be held in a funnel which utilizes a servo lock with silicon gasket providing an airtight environment so that no external factors can contaminate it; here the weight of the sample will be measured using a flex sensor in a Wheatstone bridge formation. The funnel will then be unlocked, while a vibrator motor is used to remove the sample completely so that it is free for the next sample. When the sample is deposited in to one of the six containers, a pH probe will be linearly actuated to get the pH reading, after which the container base will be rotated to put the next container in place.

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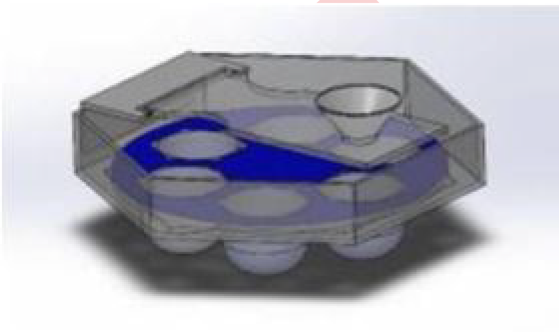
As the base is rotated the container shifts and hides inside the protective layer and enclose each slot, ensuring the containers remain intact.



All the on-board sensors will be interfaced with a dedicated teensy dev board acting as a slave which will perform all the computational task and send the data to the master board. In order to eliminate unwanted atmospheric effects, which may lead to erroneous readings, the temperature and moisture measurements will be taken in-situ. Once the pH measurement is acquired.The whole science task module can be detached from the rover body releasing a locking tab.

Modification

The scientific tray will be having pressure sensors embedded under all the containers. The pressure sensor will be calibrated to give the weight of the sample.

The number of slots is increased to six, for backup purposes

Airtight sealing of containers.

Modular system for quick and easy transferring of the contents to the base station lab.

Problems Identified

Making the container airtight became an issue since the dirts contaminate the silicon gasket and leaks air .We are experimenting with silica gel gasket to eliminate this problem.

3.6.1 Peripheral Designs of the Science Task Module

Camera position

Camera stand may seem a trivial thing to discuss but for proper operation and camera feedback the stand must be placed in suitable location with detachable mounting system to place the cameras.

A stand with adjustable height is placed at the back end of the rover where the wide-angle camera will be placed

Two normal mounts will be used one at the second arm of the hand at another at the front body of the rover.

Antenna Mount

The Omni directional antenna for 2.4 GHz is quite large and heavy so it needs a proper mount to keep it in correct orientation even after rough vibration.

Collection Task Container

A detachable open container is designed according to the cache size given so that the hand can pick it up and drop it in correct orientation into one of the four slots in that container. Each slot will be a funnel shaped with upper diameter about 35 mm and lower close end will be about 25 mm and a total height of 250mm so that it holds the cache in correct orientation till the finishing line .

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3.7 Electrical Architecture

The electrical team mainly has two fundamental function:

1. Ensure a viable controlling system

2. Ensure adequate power for the system.

However, they also need to collaborate extensively with the software and communication team.

For the first time, we plan to implement artificial intelligence and make the rover more autonomous. The additional hardware required will be discussed in their respective sections.

3.7.1 Control system

Control

A dedicated PCB was designed for the control system to make it more modular and robust. At the heart of the control system is a Teensy USB Development Board which features a 32 bit 180 MHz ARM Cortex-M4 processor with floating point unit. Three other Teensy dev boards are being used as slave which is used for the driving system, the robotic arm motor controller and the science task. The PCBs featured all types of connectors & terminals for communication, sensors and PWM signals with plug-n-play approach in mind.

Three different motor drivers were used. IBT2 (BTS7960) H-bridge with current ratings of 43A (peak) and operating voltage of 6V-27V and up to 25KHz PWM input support were used for the closed loop geared motors running 24 volts.Dual Monster Moto Shield VNH2SP30 DC Motor Driver 2x14A (Peak 30A) with voltage rating of 16V are used for motors running on 12volts.

Feedback

High resolution magneticencoders were used in the geared stepper motor at the base plate for obtaining real time actual position of the arm. Integrated encoders in the geared motors of the arm further enhances the precision of positioning data. Hall Effect sensors are used in order to make precise opening and closing of the claw in the geared motors dedicated for the purpose. The claws are also equipped with pressure sensor for a real time feedback of the pressure of the grip.

Geared motors at the wheels for the purpose of corner steering also have optical encoders of high resolution which helps in executing the parallel movement of the rover in any direction without rotating the body.

Modification

Feedback system has been introduced this time around for increasing accuracy of the motors and the actuators and manipulate them accurately to preferred position according to task demands.

Problems Identified

The IBT2 controllers used have tendency to get short circuited and burn up at times of slight inconveniences, so backup motor controllers are kept at times of this unwanted scenarios and VNH2SP30 driver is used where possible.

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3.7.2 Power system

Electrical systems are separated into sections. One 11.1V-2.2Ah LiPo battery was used to power the microcontrollers and signal electronics. Rover arm and science task module was powered by another 11.1V-5.5Ah LiPo the 12V systems and two 11.1V-5.5Ah LiPo are connected in series to produce 24V where necessary.

Separate bus with voltage levels of 3.3V, 5V, 6V and 9V were provided using multiple XL4005 DC-DC Buck converter to supply power to the required electronics & sensor modules. It has a maximum current rating of 10A and input voltage range of 3.2V to 40V and output voltage range of 1.25V-35V. The 12v for DC motors was supplied directly from the battery. Beside since the teensy runs on 3.3volts and many of the sensors require 5volts logic level, so we used logic level shifter to solve this problem.

With the given power sources, the rover has a runtime of up to 90 minutes with nominal usage.

Modification

The whole power distribution was constructed in a symmetric way to maintain balance of load. The wiring of the entire system is done through spiral plastic pipes to maintain an organized system throughout.

Risk assessment

In cases of extreme rocky terrain traversal for a prolonged period, chances are the motors will draw a large amount of current from the batteries and this might cause an unwanted hindrance in the rover operation.

This dilemma is tackled by means of efficient wheel designing so that any type of obstacles can be overcome with the minimal torque, hence minimal discharge of batteries.

Onboard current sensing module will monitor the current consumption and alert if overcurrent is drawn and immediately restrict current to that part.

3.8 Communication

For real-time video feed and reliable data transfer a point to multiple point wireless communication at 2.4 GHz band will be used, just as promised since 5GHz routers have limited range and too expensive. However, there will be a change in the technic and devices used. Two "of-the-shelf" routers will be used called RB-Metal-2SHPn router, one at the base station and the other on the rover. At the rover, one RB-Metal-2SHPn router connected with a 10-dbi Omni-directional antenna, connected with the onboard processor with an Ethernet connection. At the base station, we will use another RB-Metal-2SHPn router hooked to a directional sector antenna for better directivity. This router will be set in AP mode so we can access the network with our devices at the base station but the two routers will be connected in bridge mode. Thus, we call it PTMP (point to multiple point) connection.

This network system will ensure real time video feedback from the rover and reliable data transfer to and from the rover at about 54 Mbps.

Besides this we have two other radio links for FRSKY R9M RF controller running on 868MHz (EU LBT) which will be used for manual controlling of the rover. Since the transmitter operates on dedicated RF link,so latency is very low which is needed for controlling .The transmitter has 16 channels which is enough for all the manual controls from driving to robotic arm.

And another analog video transmission system running on 5.8 GHz. This will be used for transmitting lag free video needed for manual control of the rover .Reason behind Selecting this system over others is mainly due to long range and low latency video transmission capability.

The following table shows in details the entire setup described in a simplified form.

Serial	Setup	Frequency	Purpose
1	RB Metal for P2P Connection	2.4 GHz	1. Data Transmission 2. Image Processing
2	866 MHz Controller Module	ISM Band 866 MHz	Robotic controller for driving and arm control
3	FPV (First Person Viewing)	5 GHz	Real-time Video Feedback

While designing the system we took a number of major problems we faced in the past, mentioned in the problem-identified part below.

Problems Identified

Short range

To tackle this we used high gain antenna and powerful router with high transmitting power of up to 32dbm. Theoretically, the range is about 1km, but practical results are indicating a range of 160 meters (approx.) for LOS, which is still more than our requirement. (The test was done without the full setup).Using 868MHz we get a very high range of about 40km LOS and about 2.5 km non-LOS which is enough to our need. Though 5.8GHz has reduced range but with directional patch antenna we ensured a range of about 200 meters.

Lagging Video Feedback

With the Omni directional antenna on the over connectivity will not be a problem anymore, and with the high gain we hope to gain better speed. The bridge connection will avoid both interference and higher data transfer rate. The analog video transmission has an overall lag of 1-2 milliseconds which is enough for lag free video for controlling of the rover.

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Bandwidth Selection

The built-in routerOS that comes with the RB-Metal-2SHPn routerenable us to search suitable channel, size of bandwidth to be used, limiting the transmitting power as per regulation, and the type of connection mode we want to use. Thus, we will be able to adapt and strictly follow the regulations set by authority. Both the FRSKY R9M RF controller and the analog video transmitter poses ability to change transmission power meeting the regulations.

Frequency Regulation

Since 868 MHz, 2.4 GHz and 5.8GHz are free frequency bands all over the world we finally settled for these bands. The modules have FCC, IC and CE approvals.

Interference

Interference is still a big issue for 2.4 GHz,however bridging and high gain antennas may help minimize the problem but we are still working to solve the problem. However, if we maintain our designated channel, interference won't pose much of a threat in our operation. Besides 868MHz and 5.8GHz are relatively less populated bands so interference won't be issue.

Expense

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The frequency band of 5 GHz lost its battle at this point. Although at 5GHz there is less interference, shorter antennas and higher bandwidth but the price of the modules is very high. So, we went for 2.4 GHz which will serve our purpose quite well at lower price.For FRSKY R9M RF controller,it was a bit on the expensive side considering the performance it's a good choice. Due to popular FPV demands the analog video transmission is quite cheap.

On Board Power Consumption

Both the controller and the video transmitter are low powered devices and consumes very low power of about 2.5watt combined and can be powered from the same power source as that for the RB-Metal-2SHPn router .24V and 2A current is required for the routers. So, two 3s Lithium polymer battery of twelve volt in series will be used which is tested to supply 24 volt power supply to the on-board router for about 75 minutes. A voltage sensor will be implemented with a LED light to signal the voltage level.

Modification

Since the ISM bands of 900 MHz are restricted in Europe we will not use XBee 900. Instead we will be using our 2.4 GHz channel for rover control.

The communication device will be connected directly into the on-board CPU we are using.

Testing method

The full setup is not yet tested, but only after qualification result, we plan to do a full test on the range for both Line of sight and Non-line of sight because the apparatus is expensive.

Since we are using directional antenna at the base station, we need to test the maximum angle before which the rover connection fails.

Risk Assessment

- Since we have only one method of communication any failure in this part may lead to total failure of the entire project. So, we need another back up plan. An XBee 2.4GHz will be installed which will only be operated if necessary, and of course with the permission of the authority.

- It is possible that the rover may lose control and go out of range, in that case we need to manually bring it back to range.
- However, once brought in range the rover will connect automatically. Manual restart of the rover will also automatically restart the communication system.

3.9 Software and AI

3.9.1 iData Processing and Visualization

TCP Socket will be used for all sort of data transmission. Base station will act as server, and rover will be act as client.

As there are different types of data so they will be presented in different way.

Images will be in panoramic or 360° view

- 3D mimicry of rover with orientation, hand rotation, gripper conditions
- AR/QR code information viewer
- Science's task's info will be plotted alongside

3.9.2 Control at Base Station

The control of the rover from the base station can be divided into two basic criteria:

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1. Manual control

2. Automation

Manual Control

The rover will mainly be able to control the following:

1. Locomotion
2. Hand maneuver
3. Camera
4. Science task

The rover control system comprises of a custom-made control board. The control board in turn consist of three Microcontroller Unit (MCU) called STM 32, where one MCU is dedicated to the motor control for locomotion, one MCU dedicated for hand maneuver and the last one is used for science task module and sensor. The control board will be directly connected to the onboard Laptop. STM32F103 devices use the Cortex-M3 core, with a maximum CPU speed of 72 MHz, thus it is quite fast and reduces delay time. In the base station a server is created to send respective commands and a of the shelf joystick will be used to develop an ergonomic control system.

Automation

Several task wise automation is implemented as follows:

- Traversal automation: It is discussed in details in the later part of the document.
- Object detection and pick up: This automation is especially relevant for the collection task. Using image processing, we can analyze the camera feedback at the base station to detect an object. If target position of the object is selected in the monitor; the hand will move to the object position and grab it.
- Object dropping: This automation is relevant to both science task and collection task. After the command is initiated, the hand will carry the grabbed object and drop it to the available container or predefined target location.

- Control board automation: This automation is specifically used to detect different kind of switches, predefined beforehand. We can select a certain object or a pixel in the image to automatically move the hand to that position and grab it. That is mouse cursor will select a pixel as target in view window, Hand will automatically move to that target location.

For automation we will clearly use five basic commands, as per requirements. Command will be given some arguments accordingly. The commands are:

1.**Start** - This command will be followed by a string of another command to specify the type of automation required.

2.**Pause**- the system can be paused at any state. During the pause time the red indicator and yellow indicator light will be lit simultaneously.

3.**Resume**- this command will start the system from the point it was left. The resume command can also be sent with another string command in case we want to change the mode of automation.

4.**Manual Takeover**- If we want to take the control to our own hand we can use this command after any of the two commands: the stop command or the pause command.

5.**Stop Command**- This command will stop the automation and move back to a reference state.

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3.9.3 Automatic Traversing

In case of traversing and navigation, will use different sensors and SLAM algorithms.

Here list of sensors and application area is given

Compass
1. Direction Control
2. Initial Heuristics

LIDAR
To create 3D mapping of the area that will be used for SLAM (Simultaneous Localization and Mapping)

Odometer
To calculate traversed distance, will be helpful for heuristics analysis

Sonar
For short distance object detection and localization, sonar sensors will be used. Sonars will be placed at the bottom side of the rover.

Camera

1. AR (Augmented Reality) for perspective correction
2. QR Code scanning
3. Waypoint detection using image processing
4. Special sign or landmark detection

Rover Automation Mechanism

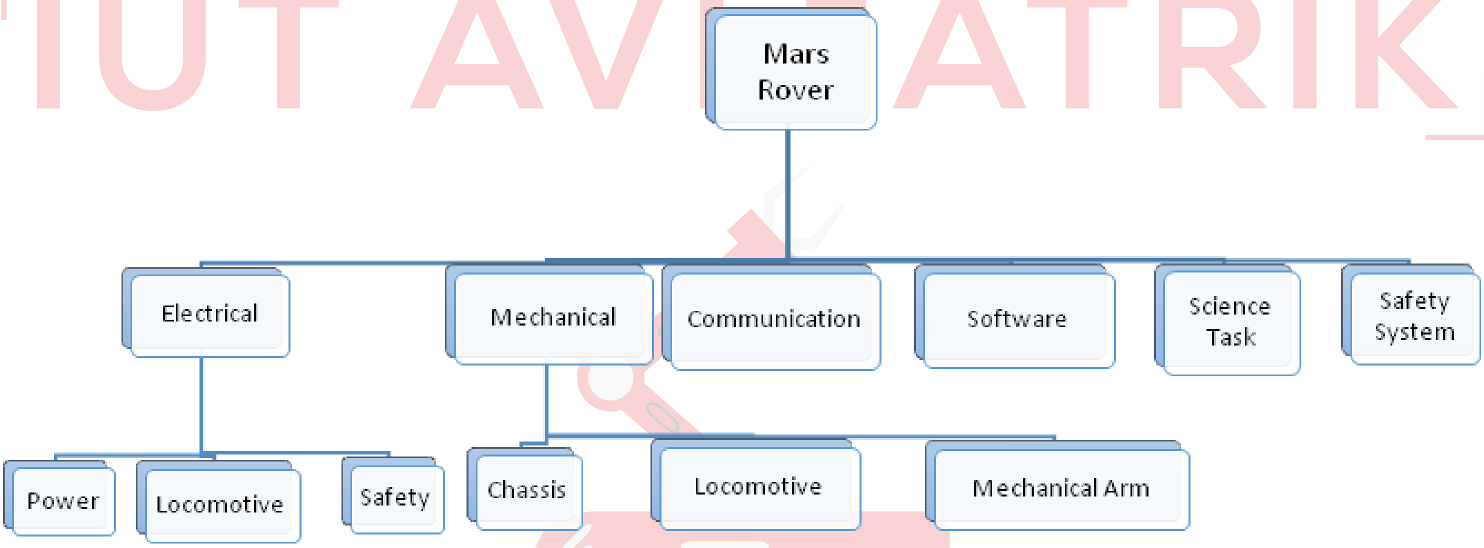
A high configuration laptop is going to be placed on-board in the rover that is used for automation task and establishing a command communication medium along with the base station.

Inverse kinematics algorithm has been used for the controlling the six degrees of freedom. Pre-trained models of various objects (switches, plug, container, hooks etc.) that are needed to be detected during the maintenance task are monitored using an on-board camera so that the grabber can reach that particular object with minute accuracy in accordance with the command.

Neural network (masked RCNN) for semantic segmentation has been used for the purpose of image processing. After obtaining the semantic segment of the objects, the center of the particular object is detected so that it can be grabbed more accurately.

Force-torque sensors for the purpose of load force sensing is an expensive option with the complication of thermal drifts, amplification, interfaces etc. so it is done by software. A dynamic model is developed which computes the load on the motors based on motions. The model is developed by the implementation of Recursive Newton Euler Algorithm or Lagrange-Euler Method, the data is taken as the physical movement takes place and compared against the parameters. However, the accuracy of the software-implemented method is only 60% and steps are taken to augment the accuracy.

4. Systems Breakdown Structure



The project’s work is broken down into 5 main subsystems. Here, a brief of development of each subsystem and the existing relation between them is presented:

4.1 Electrical Subsystem

This is responsible for all the power supply necessary for the rover to do traversal work as well computational work in case of automation. Without the power system the rover is just a pile of metal garbage and all the other systems are useless without this. So the development of power system is crucial for the rover to function. The power system is complete with on board power supply using Lithium Polymer batteries with 10000mAh rating. The power supply goes through the emergency safety system before being distributed throughout the rover. The distribution of power is done by expert hand wiring and through PCB. For adjusting voltage for a specific work we use buck modules (LM2596 DC-DC Module) and boost modules (XL6009 DC Boost ADJ Module). Another major part of electrical subsystem is locomotion system. As the rovers needs to traverse on rough terrain and have precise movement to do specific tasks, locomotive system is important. For traversal, wiper motors are used in the rover design as they provide high torque which is desirable. For controlling the speed we are using Cytron MD10C motor controllers. The rover has a mechanical arm and several servo motors, actuators are necessary for the specific movements. These movements are controlled by IBT-2 H-Bridge motor controller.

4.2 Mechanical Subsystem

A team corresponding to the mechanical works of the rover is responsible for the design of the rover body, suspension system and locomotion. The body will be made out of SS Metal Sheets. The construction and modification will be done by lathe cutting according to design. For suspension, rocker bogie mechanism is implemented. This allows the rover to recover from sudden change of position while moving through a rough terrain. No spring or hydraulic suspension is used. The wheels are designed and custom made by us. As for the robotic arm, it is designed with six degrees of freedom. For every movement suitable motors and actuators are used with motor drives implemented by electrical subsystem. Without a proper design and implementation, the rover won't be able to traverse and do the specific tasks.

4.3 Communication System

For real-time video feed and reliable data transfer, wireless communication at 2.4 GHz band will be used. The system is developed using a base station - Rocket M2, 10 dBi Omni directional antenna - AMO 2G10. For the video feed we are usingFoxeer Mini Pro 1/2.9" CMOS 1.8/2.5mm 1200TVL FPV cameras.

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4.4 Software

This sub-team is responsible for handling data processing and visualization, control at base station, automation (automatic traversing). TCP Socket will be used for all sort of data transmission. For manual control the communication systems will be used. The automation part will be implemented for traversal, object detection, object dropping and control board automations. For developing this system a high configuration laptop is going to be placed on-board in the rover that is used for automation task and establishing a command communication medium along with the base station.Inverse kinematics algorithm has been used for the controlling the six degrees of freedom. Neural network (masked RCNN) for semantic segmentation has been used for the purpose of image processing.

4.5 Science Task

Our need will be to decide the ability of a specific geographical region to help the presence of microbial living things. This subsystem is not directly linked with the other systems, but this system is important for the task as a whole. The object collected by the rover is tested in this system. The system is developed to give temperature reading using LM35Sensor. Using a Grove moisture sensor the system can see if there is any presence of moisture is in the soil or not and the pH of the soil is also measured. This is a really important part of the project as this system acts as an objective of the rovers tasks. This system is dependent on the rover to bring the object to test. Other than that, this is a pretty standalone system.

5. Safety System

5.1 Emergency stop and hardware protection

We have equipped the rover with an easily accessible emergency stop button. To establish this emergency system we chose **Baomain Emergency Stop Switch Push Button Switch AC 600V 10A Red Mushroom 22mm NO NC**, commercially built off shelf module. The switch has one normally closed terminal which will be connected to the main power terminal of the rover system. In case of emergency, one hard hit will detach the rover from the power system completely.

We have a protection system for our rover with its dedicated PCB. The protection system was designed to be as reliable as possible. Basic features like short-circuit protection, reverse-polarity protection and overcurrent protection were implemented using DC fuses of varying current rating as per requirement. And advanced features like remote current monitoring and remote power turn off were also implemented using 12VDC Relays with load current rating of up to 30A and current sensors (ACS715). Industrial grade toggle switches (DPDT 40A) for manual power ON/Off and another Kill switch for emergency power off were also present to make the entire electrical system fail-safe.

5.2 Activity Indicator

As per the requirement, our rover is equipped with indicator lamp informing about readiness to receive commands. An array of monochromatic LED lights of 10mm is used to strengthen light intensity. Our design uses three blocks of LEDs of different colors to minimize ambiguity since sun rays and other factors may prevent us from recognizing the color that is lit and also the blocks will be illuminant enough to be clearly visible from 10m distance. Furthermore, the indicators are designed to be flashing during an activity to attract attention of people in vicinity. Each block will symbolize three different meaning: stop, processing, ready. Each block will be marked with a colored board as a sign. So, if a block LEDs are lit, we will know exactly what it is. Industrial Grade RGB LEDs requires high power and more expensive, so it was crossed of the list.

The indicator will be directly connected to the STM processor and programmed to indicate three states: **Green** = **Ready** for operation, **Yellow** = **Working**, and **Red** = **Stop**. For automation part, the yellow light will signal continually. Furthermore, the indicator will be active 5 seconds before an activity. At this period the rover will remain still and safe.

6. Preliminary Financial Budget

Electrical System				
Component	**Product Model**	**Quantity**	**Unit Price (USD)**	**Total Price (USD)**
Motor Controllers	Cytron MD10C	15	17.6	265
	IBT-2 H-Bridge	5	14.2	71
Batteries	Lithium Polymer (10000 mAh)	3	38.8	194
Microcontroller	STM32	2	4	8
PCB Boards	2 Layer printing	N/A	N/A	3
Buck Module	LM2596 DC-DC Module	3	6	18
Boost Module	XL6009 DC Boost ADJ Module	2	7	14
Wiring	Electrical wire of various sizes	N/A	N/A	24
	Spiral Pipe	N/A	N/A	6
	Opto-couplers	20	0.25	5
Connectors	Aviation Panel Connector	20	1.75	35
	BNC Connector	20	0.25	5
	Toggle Switches	20	1.2	24
Feedback Tools	Optical Encoders	15	11.73	176
	Rotary Encoders	5	1.2	6
LED		15	0.13	2
			Total	**854**

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Mechanical System			
Component	**Quantity**	**Unit Price (USD)**	**Total Price (USD)**
SS Metal sheet & Aluminum sheet (Body frame, Wheel, Hand frame, Differential bar	-	235	235
Bearing	25	0.6	12
Actuator	3	70	210
Wiper Motor	9	60	540
Worm Gear DC Motor with Encoder	4	41.25	165
Tire Rubber Grip Skin Grouse	1	24	24
Plastic Wood	1	6	6
Connectors	1	24	24
Stepper Motor with planetary gear system	8	53	424
Construction and Modifications using Lethe cutting	1	120	120
		Total	**1760**

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Communication System				
Component	**Product Model**	**Quantity**	**Unit Price (USD)**	**Total Price (USD)**
Base Station	RB Metal	2	87.5	175
10 dBi Omni directional antenna	AMO 2G10	2	130	260
Sector Antenna	AM2G15-120	1	240	240
Radio Transmitter	FrSky 868M 16CH Taranis X9D Plus	1	262	262
Telemetry Module	3DR 500 MW Radio Telemetry 433Mhz 915Mhz Air	1	24.4	24.4
Black Mamba	Flysight Black Mamba 5.8 GHz 2W FPV Vtx Transmitter 2000mW FPV Long Range Video Transmitter	1	45.5	45.5
ts832	Eachine TS832 Boscam FPV 5.8G 32CH 600 mW 7.4-16V Wireless AV Transmitter	1	12	12
Video Transmitter	1500 mW 1.2G Wireless 8CH Transmitter 12CH Receiver	1	60	60
Pxhawk	Pixhawk PX4 PIX 2.4.8 32 Bit Flight Controller Autopilot with 4G SD Safety Switch Buzzer	1	52.5	52.5
Diversity Receiver with Monitor	Eachine LCD5802S 5802 40CH Raceband 5.8G 7 Inch Diversity Receiver Monitor	1	160	160
rg58 Coax Cable	SMA Female Jack to SMA Male Plug RG58 Coaxial Pigtail WIFI Low Loss cable	10 m	N/A	4
FPV Camera	Foxeer Mini Pro 1/2.9" CMOS 1.8/2.5mm 1200TVL	4	10	40
13 dBi diamond antenna	Aomway FPV 5.8G 13 dB High Gain Antenna Signal Booster Diamond Directional Antenna	2	6	12

Circular Polarized Antenna	Fatshark ImmersionRC SpiroNet 5.8 GHz Circular Polarized RHCP FPV Antenna	2	1.75	3.5
			Total	**1350**

Software				
Component	**Product Model**	**Quantity**	**Unit Price (USD)**	**Total Price (USD)**
Lidar	LIDAR-Lite 3 Laser Rangefinder	2	123	246
IMU 10DOF	MPU9255 BMP280	4	22	88
Sonar	HY-SRF05)	5	15	75
Odometer		1	32	32
Webcam		4	50	200
Wide Angle Digital Camera	OldShark Dash Cam, 3"	2	59.9	60
			Total	**700**

7. Lessons Learnt

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Department	**Point of Issue**	**Risk Assessment**
Electrical	Modularity	Even though there wasn't much of a problem with the electrical system last year, we intend to turn our electrical system into a plug and play system. This will reduce the time taken to set up the rover for operation. Using more connectors will help in resolving this.
	Cable management	In order to make the circuit system more presentable, we will try to use as few cables as possible and introduce the system of color coded wiring, so that team members can identify at a glance the purpose of each wire.
	Monitoring	An additional current monitoring system will be added for telemetry module.
	Feedback mechanism	In order to accurately perform tasks, we'll use motors with encoders and feedback system, allowing stepping of motors to higher and accurate performance.
	Processing power	Last year at the heart of our electrical system was Arduino MEGA .It has processing speed of only 16MHz, so to increase processing speed we plan to use Teensy 3.6 instead of Arduino MEGA. There will be also Teensy-Teensy master –slave connections. Teensy 3.6 has a processing speed of 180MHz, meaning more than 11 times faster processing is achieved.
Mechanical	Precision	Using Finite Element Analysis on various sections of the structure, we've modified our previous designs. We will also modify our gripper design and material used for making the claw.

	Weight and size	Previously we've used stainless steel for the structure of rover body. This slowed down the rover and put more stress on our motors. So as a substitute, we are using Aluminum for our frame and body. Aluminum has higher strength to weight ratio compared to steel. Rover body is going to be from CNC cut aluminum panels. Size of body is going to be more compact, enhancing mobility.
	Control feedback	With the addition of closed loop feedback system for the arm, arm movement will be more smooth and precise. This will also help perform automated arm tasks.
	Dedicated analysis and control panel	For manual and some semi-autonomous tasks a separate panel is going to be introduced which will avoid the problem of manual control based on eyesight on distant objects. Here the arm's state and angle of each degree of freedom will be displayed graphically. Also side screens will be available for viewing surrounding during traversal. Some of the sensor values will also be shown at the corner of the screen.
	Method of Control	Our means of commanding our rover for movement and control was through an RC controller last year. This year we plan to do these task using specially dedicated joystick with feedback feature, so that we know exactly how we are operating the rover.
Software	Automation	Even though we had achieved satisfactory results last year, one of the factors putting a constraint on our result was the absence of implementation of automation in our systems, especially in our traversal and science task
	Screen Panel	A new addition to our arsenal would be to include an analysis panel for rover system and maintenance. This would definitely ease up operations and allow us to monitor the rover in real-time.
	Camera	Since we want to apply automation, more data input is required which begs for the addition of new cameras. The cameras will of course be analog cameras for low latency.
	HD digital camera	We suffered last year for the collection task which requires the rover to be semi or fully autonomous for the detecting and picking up part. We plan to make the process smooth and fast by the addition of an HD camera for image processing.
	Stereo imaging	Mapping our surroundings using a normal camera and via the use of image processing had been the normal way of determining object distance from the rover. Now as an improvement we will include stereo image system, which will classify distance in terms of color and thus making depth perception easier for the process of automation.
	LIDAR	In our previous year we performed the traversal task manually which was difficult to accomplish and took more time than anticipated. By the addition of LIDAR, a 3D map can be processed and help to attain autonomous traversal and obstacle detection.

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Technical	Science-task module	Last year one of our highest scores was achieved in Science Task. The missing features were the on-board pH measurement system, air tight containers for samples. We plan on to include these in order to achieve full marks this time.

8. Risk assessment

Department	Point of Issue	Risk Assessment
Electrical	Backup motors and motor drivers	Since the wiper motor will be going through a lot of work during movement, it'll be drawing a lot of current, so it's natural that some of the motors might malfunction or in worst case scenario, the IBT2 motor drivers might burn up due to burst current overflow.
	Circuit protection	If we were to consider the harsh condition in Mars during sandstorms, it would be a disappointment not to come up with an enclosure that prevent external substances from coming into contact with the circuitry.
Mechanical	Motor stepping accuracy	For our purpose of automated hand movements current feedback system involving encoders with motors isn't enough to serve it. So we are going to include more accurate and more expensive motors for even more precise rotation.
	Power Consumption	Due to the harsh terrain that the rover needs to traverse through, current draw will be predictably high. So calculations were made for the power requirement of the entire rover, including the factor of over-discharge issue. Also as an efficient measure wheel design was made in such a way so that it is adaptable to the rugged terrain of the site, putting less pressure on motor and drawing less power.
Communication	Range	If during traversal, the rover goes further than expected, it may cross the range where we can no longer keep communication with it, hindering control. Interference might be another reason for the sudden shortening of range.
	Options for control	Keeping the means of controlling rover limited to 1 method can be risky and in case of a system failure, the rover will be left stranded on a complete standstill.
Technical	Science Task	The containers if left open for too long might get contaminated with other samples. Also there's always a chance of samples mixing up in the excavator bucket itself.
	Collection Task	Due to the dependency on automation this time, the program might not detect the caches quite accurately if enough data isn't fed to the dataset.

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Radio Frequency Form

1. Team Name:

IUT Avijatrik

2. Country:

Bangladesh

3. How many different communication systems are planned to be used?

Three-communication system are to be used.

4. Name of the person responsible for communication system:

Reduan Ahmed Tanim

5. Contact to the person responsible for communication system (e-mail address):

reduanahmedtanim@gmail.com

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6. Photo of the rover:

'To be provided in the final document'

7. Photo of the ground station:

'To be provided in the final document'

8. System information:

Criteria	**System 1**	**System 2**	**System 3**
RF System Name	RB Metal 2SHPN (Rover) and Xiaomi external outdoor Wi-Fi detector	FRSKY R9M RF controller	First Person View (FPV system)
Frequency	2.4 GHz (Wi-Fi)	868 MHz In Europe, LoRaWAN operates in the 863-870 MHz frequency band. This is the Regional ISM band assigned for Europe only.	5.8 GHz (Radio amateur band)
Bandwidth	20 MHz	300 Baud (telemetry Bandwidth)	8 MHz

RF Power (output power + EIRP)	Maximum 32 dBm (variable) But we will keep Tx power set to 20dbm (100 mW) EIRP: 100 mW	Telemetry mode (25mW), non-telemetry mode (200mW) (EU Version) EIRP : 23dbm	600 mW = 27dbm EIRP: 600 mW
Antennas on Rover and Ground Station (Models, Radiation patterns)	8 dBi Omni-directional (on Rover) 2* 9dBi Detachable Omni-Directional Antenna (RP-SMA)		
Modulation	TDD	TDD	TDD
Spectrum Analysis	Will be provided later.	Will be provided later.	Will be provided later.

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