PROJECT PROPOSAL

Team name: Team Techno

Project name: Tenacity

Affiliation: Ghulam Ishaq Khan Institute of Engineering Sciences and Technology, Pakistan.

Submission date: 31st March 2024

Version: 1.0

1. Team Introduction:

Team Techno is a student robotics team of fifty-seven undergraduate students, led by an executive council comprising a Team Lead, Manager, and Technical Lead, each possessing four years of experience. Our team spans across four technical domains: Autonomy & Robotics Integration (A & RI), Electronics, Mechanical Engineering, and Astrobiology, complemented by expertise in Marketing, Sponsorship, and Documentation. While our journey in the University Rover Challenge saw us narrowly miss the finals, our performance garnered commendable recognition and valuable experience with a strong overall score.

Among our members we have Harris Abdullah, our Team Lead, boasting a background in Computer Science. His portfolio includes projects focused on autonomous navigation and object detection. With expertise in Computer Vision and Drones, he clinched the prestigious Dawn Jeager Tenacity Award in AUVSI SUAS 2023 for developing a fully autonomous drone capable of precise payload delivery.

AbdurRehman Ikram, our Technical Lead, excels in mechanical design. He has engineered a full-scale, six-degree-of-freedom robotic arm, showcasing his prowess in mechanical innovation.

Muhammad Aashir, our diligent Manager and Electronics Head, is leading a project on Autonomous Driving Car, as his Final Year Project, integrating custom-built circuits and sensory systems for enhanced efficiency and control.

AbdurRehman Naeem and Ali Mir, our Mechanical Heads, have spearheaded a venture in agricultural robotics — a weed-plucking farmbot bearing resemblance to our rover. Their project amalgamates a drone with an integrated robotic arm for seamless plucking and field analysis.

We also have esteemed Team Advisor, Dr. Muhammad Hanif, with over two decades of experience. His PhD from the Australian National University, specializing in Computer Vision and Image Processing, will be essential in guiding our team's endeavours.

Together, our team embodies a diverse array of talents and experiences, poised to deliver a project of exceptional quality and ingenuity for the ERC competition.

2. Requirements and Key Objectives:

Team Techno is fully committed to the ethos and objectives of the ERC 2024, having undertaken a meticulous review of the competition rules and requirements. Our project, Tenacity, will be designed not just to participate in the challenge but to excel, embodying advanced technological capabilities and innovative engineering solutions tailored to the Martian-like terrain and tasks outlined for this year's competition. Here, we delineate our understanding of the requirements and our strategic approach to meet and exceed these standards. Although a general understating of the rules and rover systems was demanded, we have also added some additional knowledge based on our previous experience in building a rover.

2.1 Mission Execution Strategy:

Our adherence to the ERC 2024 rules is manifested in Tenacity's design and operational capabilities, specifically engineered to perform intricate tasks on the Martian-like surface. Key areas of compliance and innovation include:

2.1.1 Science Mission:

The Science Task for the ERC 2024 is multifaceted, designed to simulate a series of critical scientific exploration activities on Mars. Team Techno's Tenacity rover will be equipped to excel in all aspects of this task, from identifying promising sites for life detection to collecting valuable scientific samples and assisting in the construction of Martian infrastructure. Below are the strategies and technologies Tenacity will employ for each subtask:

1) Exploration

Exploration is the initial and critical step in Martian scientific missions, requiring the rover to identify sites with high potential for life detection. Tenacity will be equipped with:

i) High-Resolution Imaging Systems: Utilizing a suite of cameras and spectrometers, Tenacity will analyse surface features and mineral compositions from afar, pinpointing areas of interest for further study.
ii) Environmental Sensors: These sensors assess conditions such as humidity, temperature, and chemical signatures.

2) Sample Collection

Sample collection is divided into two main activities: surface sampling and deep sampling.

i) Surface Sampling (Grabbing Rocks): Tenacity's robotic arm will be fitted with a versatile end-effector capable of picking up rocks and regolith. This allows for the collection of surface samples with varied textures and compositions, essential for a comprehensive Martian study.

ii) Deep Sampling (Digging): Planned to be equipped with a robust drilling system, Tenacity will perform deep sampling by digging into the Martian soil. This mechanism will be designed to reach depths beyond the oxidized surface layers, retrieving subsamples that are more likely to contain organic materials or evidence of water.

3) Construction:

The construction subtask involves using provided materials to build a structure, such as passing a trench through constructing a wall.

2.1.2 Navigation Mission:

In the Navigation Mission, Team Techno's Tenacity rover and its accompanying drone will leverage cutting-edge algorithms and hardware to ensure superior performance in autonomous navigation, landmark detection, and waypoint verification. The strategic integration of these technologies will highlight our commitment to pushing the boundaries of what's possible in robotic exploration.

1) Traversal:

For the Traversal subtask, Tenacity will employ the following technologies and methodologies:

i) Autonomous Navigation System: Tenacity will utilize the ROS (Robot Operating System) platform, augmented with advanced pathfinding algorithms like RRT* (Rapidly exploring Random Trees Star) for efficient and dynamic route planning. This system will enable Tenacity to navigate complex Martian-like terrains autonomously by generating optimal paths that account for obstacles, terrain ruggedness, and mission objectives.

ii) Landmark Detection Algorithms: For landmark detection, Tenacity will implement Convolutional Neural Networks (CNN), specifically utilizing architectures such as YOLO (You Only Look Once) and Faster R-CNN. These algorithms are renowned for their speed and accuracy in object detection and will be trained on a dataset of Martian-like features to ensure high precision in real-time landmark identification.

iii) Waypoint Verification: The NVIDIA Jetson Nano will serve as the computational heart for waypoint verification. This powerful yet compact GPU-enabled platform will process GNSS data and video feeds to accurately determine Tenacity's location relative to predefined waypoints. The Jetson Nano's capabilities make it ideal for handling the computationally intensive tasks of image processing and data analysis in real-time, ensuring precise navigation and successful waypoint verification.

2) Droning:

In the Droning subtask, Team Techno's strategy will incorporate sophisticated technology and algorithms to ensure that the autonomous drone not only complements the Tenacity rover's ground operations but also stands as a testament to innovation in aerial robotics. Here's how we plan to implement these advancements:

i) Autonomous Navigation: To facilitate precise autonomous navigation, the drone will utilize GNSS technology accompanied with mission planner alongside advanced algorithms for spatial positioning and route optimization. The integration of GNSS data with onboard sensor inputs will enable the drone to maintain accurate flight paths even in the challenging and dynamic Martian-like environment.

ii) Emergency Landing Simulation: To simulate an emergency landing, such as in response to a sandstorm, the drone will use a combination of LIDAR and ultrasonic sensors to rapidly assess the terrain below for a safe landing spot. This decision-making process will be governed by a specifically designed algorithm that prioritizes safety, minimizing potential damage to the drone and ensuring it can resume its mission once conditions improve.

iii) Aerial Imaging and Analysis: For detailed aerial imaging, the drone will employ a high-resolution camera along with a gimbal.

2.1.3 Maintenance Mission:

For the Maintenance Mission of the ERC 2024, Team Techno plans to deploy the Tenacity rover equipped with a sophisticated manipulating device. This device is designed to perform a variety of tasks essential for the maintenance of Martian infrastructure, including manipulating switches, measuring voltage, and inserting plugs into sockets. The strategic implementation of advanced technologies and innovative engineering solutions will enable Tenacity to demonstrate exceptional proficiency in these tasks.

1) Manipulating Device Design: Tenacity's manipulating device will feature a highly dexterous robotic arm equipped with an end-effector capable of precision grasping and manipulation. This design allows for the handling of various tools and components necessary for maintenance tasks, including switches, plugs, and measurement devices.

2) Haptic Feedback for Delicate Operations: To ensure the successful manipulation of switches and insertion of plugs into sockets, the robotic arm will incorporate

haptic feedback technology. This will allow the device to apply the correct amount of force for each task, preventing damage to delicate infrastructure components while ensuring secure and effective manipulation.

3) Voltage Measurement Integration: The manipulating device will also be equipped with a built-in voltmeter, capable of safely measuring voltage levels in Martian infrastructure systems. This integration allows Tenacity to perform diagnostic and maintenance tasks efficiently, without the need for separate measurement tools.

2.1.4 Probing Mission:

For the Probing Mission in the ERC 2024, Team Techno's Tenacity rover is designed to showcase its capabilities in rapidly collecting samples or probes for scientific analysis and delivering them to a module for return to Earth. This task draws inspiration from landmark missions such as NASA's Mars Sample Return (MSR) and ESA's Sample Fetch Rover (SFR), emphasizing the critical role of autonomous rovers in future Martian exploration and sample return missions.

1) Autonomous Navigation:
   The Tenacity rover employs advanced autonomous navigation systems to effectively traverse the Martian-like terrain of the ERC 2024. Starting from one of five predefined locations, Tenacity uses GNSS data and computer vision to accurately identify its starting point. Utilizing the Robot Operating System (ROS) and Rapidly exploring Random Trees Star (RRT*) algorithms, the rover dynamically plans the most efficient paths to the target probes, ensuring obstacle avoidance and optimal route selection. This sophisticated navigation system is further enhanced by integrating "Mission Planner" software, which aids in real-time route optimization and adjustments based on environmental conditions and task requirements.

2) Detection and Retrieval:

   For the crucial tasks of detecting and retrieving scientific probes:

   i) Color Recognition: Tenacity's high-definition imaging systems are equipped with custom-designed image recognition algorithms that specifically target the yellow-green color of the probes. This precision allows the rover to efficiently locate the probes in diverse environmental backgrounds.

ii) Robotic Manipulation: The rover's dexterous robotic arm, featuring a specially designed gripper, is optimized for the physical characteristics of the aluminium probes. It can precisely grasp and lift the probes, thanks to integrated haptic feedback technology that adjusts the force applied, avoiding damage to the probes during collection.

iii) Technological Innovations: Utilizing deep learning models such as SSD (Single Shot Multibox Detector) for real-time object detection from aerial images, Tenacity enhances its detection capabilities, especially when supported by aerial reconnaissance from an accompanying drone.

3) Onboard Storage:

Upon retrieval, the probes are securely stored in Tenacity’s onboard container system, designed to accommodate the specific dimensions and material properties of the aluminium probes. This storage system ensures the probes are safely held during transit, minimizing the risk of damage or displacement as the rover navigates back to the delivery module. The container’s design is a testament to Team Techno's attention to detail, ensuring that the collected scientific data is preserved intact for analysis back on Earth.

2.2 Compliance with the Provided Requirements:

ID	Short Name	Description	Test Methodology	Compliance Status	Assumptions
REQ-DES-010	Communication	Use defined communication frequencies with power limitations for rover and UAV communication.	R, I	C	Communication frequencies and power limitations will be adhered to as per ERC rules.
REQ-DES-020	Safety - Rover	Equip rover with an easily accessible physical red emergency stop button.	R, I	C	Compliance will be ensured by designing an emergency circuit with

					industrial-grade components.
REQ-DES-030	Additional Safety	Equip rover with a physical emergency button in addition to the RF certified EM button.	R, I	C	This is an additional measure to REQ-DES-020; no extra constraints.
REQ-DES-040	Safety - Drone	Control for drone shall include an easily accessible physical emergency button.	R, I	C	Drone will autoland in emergencies, ensuring compliance through system design.
REQ-DES-050	Activity Indicator	Rover to have an indicator lamp with 1 or more colors to indicate state.	R, I	C	Yellow, orange, or red colors recommended; will use standard industrial device.
REQ-DES-060	Indicator Visibility	Indicator must be visible from 10m away and attract attention by blinking or flashing.	I, T	C	Visibility to be tested under various light conditions to ensure compliance.
REQ-DES-070	Regolith Storage	Store regolith sample in onboard container.	R, I, T	C	Container design will accommodate sample size and prevent contamination.
REQ-DES-080	Rock Sample	Rock sample shall be stored in the onboard container.	R, I	C	Container will be designed to securely store and protect rock samples from contamination.

REQ-DES-090	Deep Sample	Deep sample shall be stored in the onboard container.	R, I	C	Onboard container will have compartments for different sample types, including deep samples.
REQ-DES-100	Batteries	Batteries of the rover shall be replaceable or able to be quickly charged in order to realize the next task shortly after completion of the current one.	R, I	C	Battery system design will allow for quick replacement or fast charging, ensuring minimal downtime.
REQ-DES-110	Interferences	The communication system shall not be prone to interferences coming from the nearby networks (mainly WiFi) or rovers from other teams.	R, A, T	C	Communication system will be tested in environments with potential interference to ensure robustness.
REQ-DES-120	CoG	CoG of the rover shall be sufficiently low in order to avoid increased susceptibility for flipping over on the steep slopes.	A	C	None
REQ-DES-130	Rigidity of Wheels	Wheels shall be rigid enough to perform on different terrain types as well as slopes (even steep).	A, T	C	Wheel materials and structure will be chosen to ensure durability and rigidity under all operational conditions.

REQ-DES-140	Interfaces	Rover shall be able to grab/collect the following objects: - Material samples (surface and deep) - Blocks made of polystyrene foam (Construction Sub-Task) - Switches, electromagnet, plugs (Maintenance Task) - Probes (Probing Task)	R, A, T	C	Manipulator design will include versatile end-effectors capable of handling various objects as specified.
REQ-DES-150	Redundancy	Redundancy shall be implemented to the most important systems of the rover	R, A, T	C	Critical systems will have redundancy to ensure operational reliability, detailed planning and testing will identify and mitigate single points of failure.
REQ-ENV-010	Operational Temperatures	The rover shall operate nominally in a temperature range between 0Â°C and +30Â°C.	A, T	C	Design and materials selection will consider temperature resilience.
REQ-ENV-020	Rain	The rover shall be able to withstand moderate amounts of rain.	A, T	C	Rover's exterior will be waterproofed to ensure functionality in rain.

REQ-ENV-030	Mud	The rover shall not be susceptible to dust or mud that can be encountered on the Mars Yard.	A, T	C	Protective coatings and seals will prevent dust and mud interference.
REQ-ENV-040	Low Light Operations	The rover shall be able to execute all the tasks in low light conditions, e.g., during the night with additional artificial lights provided by the organizer.	A, T	C	Lighting systems will be tested to ensure adequacy in low light conditions.
REQ-FUN-010	Max Speed	The rover shall be able to move forwards and backwards with a speed equal or lower than 1 m/s on flat surface and on slopes.	T	C	None
REQ-FUN-020	Terrain	The rover shall be built to handle challenging terrain, appropriate dust and general weather conditions (incl. moderate rain).	T, A	C	Terrain adaptability will be a focus in the design and testing phases.
REQ-FUN-030	Turning	The rover shall be able to achieve a finite turning radius in both directions when moving backwards and forwards on a flat surface.	T	C	None

REQ-FUN-040	Communication Range	The rover shall maintain communication with antenna mast up to 100 metres of distance.	A, T	C	Communication system's range and reliability will be verified through testing.
REQ-FUN-050	Communication over Terrain	The rover shall maintain connection with antenna mast without line of sight when obscured by natural terrain.	A, T	PC	While direct line of sight is not always possible, efforts will be made to ensure robust communication .
REQ-FUN-060	Autonomy	Rover shall be able to perform certain parts of all tasks in the autonomous mode (i.e., samples collection in the Science Task (Surface/Deep Sampling), full Navigation Task (Traverse + Droning), full Maintenance Task).	A, T	C	Autonomous functions will be developed and tested extensively for reliability.
REQ-FUN-070	Autonomy Indicator	The rover shall emit visible signals when performing autonomy operations that are different from the signals emitted when being controlled by the team.	T,	C	A dual-color LED system will be used to indicate manual vs. autonomous modes.
REQ-FUN-080	Regolith Sample Collection	The rover shall collect two surface samples	T	C	None

		(regolith and rock of at least 15 cm along its longest axis as a goal) when configured for the Science Task, Surface Sampling Sub-Task.			
REQ-FUN-090	Regolith Sample Mass	Mass of the collected regolith/rock sample shall be 100g or higher.	I	C	None
REQ-FUN-100	Regolith Sample Measurement	Onboard container shall allow for weight measurement of the collected regolith sample with accuracy of at least 1g.	I	C	None
REQ-FUN-110	Rock Sample Collection	The rover shall collect one rock sample of at least 15 cm along its longest axis when configured for the Science Task.	T	C	None
REQ-FUN-120	Rock Sample Measurement	Onboard container shall allow for weight measurement of the collected rock sample with accuracy of 1g.	I	C	None
REQ-FUN-130	Deep Sample Collection	The rover shall collect at least 100 grams of soil by drilling into the Mars Yard's surface to >30 cm depth when	T	C	None

		configured for the Science Task.			
REQ-FUN-140	Deep Sample Measurement	Onboard container shall allow for weight measurement of the collected deep sample with accuracy of 1g.	I	C	None
REQ-FUN-150	Sample Delivery	Rover shall allow for delivery of all the collected samples to the defined finish line in the Science Task.	R, T	C	Design includes a dedicated compartment for secure transport and delivery of samples.
REQ-FUN-160	Weight Measurements	Weight measurements for the different types of samples, i.e., surface (regolith, rock) or deep shall be separately performed onboard the rover without any manual intervention of a member of a team.	I	C	None
REQ-FUN-170	Rover Imagery	The rover shall allow to record and transmit imagery that allows identifying objects on the Mars Yard.	T	C	None

REQ-FUN-180	Drone Imagery	The UAV shall allow to collect imagery of Mars Yard (or Drone Cage) and transmit it to control station when performing ERC Droning Sub-Task.	T	C	None
EQ-FUN-190	Switch Manipulation	The rover shall be able to manipulate switches of lever and rotational type when configured for the Maintenance Task.	T	C	None
REQ-FUN-200	Voltage Measurement	The rover shall measure voltage at a power socket in range between 1.0VDC and 24.0VDC with 0.5V accuracy when configured for the Maintenance task.	T	C	None
REQ-FUN-210	Electromagnetic Lock	The rover shall operate an electromagnetic lock when configured for the Maintenance Task.	T	C	None
REQ-FUN-220	Plug Insertion	The rover shall insert an RJ-45 type plug into the socket when configured for the Maintenance Task.	T	C	None

REQ-FUN-230	Localization	Rover and drone shall be able to determine their position and orientation.	T	C	None
REQ-FUN-240	Object Detection and Localization	Rover and drone shall be able to detect the defined markers and determine their position wrt the rover.	T	C	None
REQ-FUN-250	Collision Avoidance	Rover shall be able to avoid collision with another rover or any other obstacle.	T	C	None
REQ-GEN-010	Rover	Rover shall be a standalone, mobile platform during the whole duration of performing any ERC task.	R, I	C	Design ensures all components are self-contained, emphasizing mobility and autonomy without external support.
REQ-GEN-020	Rover's Design	The team shall design and build their own rover, using self-made and/or COTS (Commercial-Off-The-Shelf) components	R	C	None
REQ-GEN-030	Drone / UAV	The team shall design or choose a COTS UAV (unmanned aerial vehicle) to support completion of the Droning Sub-	R	C	None

		Task during the ERC finals.			
REQ-GEN-040	Rover's Weight	The rover's maximum weight, including payload, shall be equal or lower than 75kg at any time while performing ERC tasks.	I	C	None
REQ-GEN-050	Drone's Weight	The drone's maximum weight, including payload, shall be equal or lower than 5kg at any time while performing ERC tasks.	I	C	None
REQ-GEN-060	Rover Control Equipment	Teams shall use additional equipment to remotely steer and control the rover, communicate with it, and do necessary maintenance with no limitation on the weight of this additional equipment.	R	C	None
REQ-GEN-070	Drone Control Equipment	Teams shall use additional equipment to remotely steer and control the drone, communicate with it, and do necessary maintenance with no limitation	R	C	None

		on the weight of this additional equipment.			
REQ-GEN -080	Science Task	The team shall demonstrate understanding of performing scientific exploration in planetary geology conditions.	R	C	None
REQ-GEN -090	Maintenance Task	The rover shall be equipped with a manipulator that allows operating a maintenance panel designed for a human operator when performing the Maintenance Task.	T	C	None
REQ-GEN -100	Probing Task	The rover shall be equipped with a manipulator that allows collection of the defined probes when performing the Probing Task.	T	C	None
REQ-OPS-010	Basic Communication	The team shall maintain communication with the rover via radio link in real-time during the whole duration of each ERC task.	R, T	C	Implementation of reliable radio communication systems, regularly tested for stability and real-time performance.
REQ-OPS-020	Communications Setup	The team shall be able to initiate the trial of each ERC task with	R, T	C	Strategic placement of communication equipment to

		antenna being located: a) up to 50 metres from the rover; AND b) up to 20 metres away from the control station location.			meet task requirements, supported by signal strength and interference tests.
REQ-OPS-030	Bandwidth	Use of excessive bandwidth shall be avoided. Bandwidth usage shall be reduced to the needed minimum.	A	C	None
REQ-OPS-040	Autonomy	Team Members shall not touch controls in control station during performing ERC tasks if the team wishes to score points for autonomy.	R	C	None
REQ-OPS-050	Safety	The rover shall stop any movement within 1 second after hitting emergency stop button AND remain stationary until the reset procedure is executed.	T	C	None
REQ-OPS-060	Drone Safety	The drone shall perform emergency auto-land after turning emergency mode or when connection is lost.	T	C	None

REQ-OPS-070	Indicator Timing	The indicator lamp shall emit visible signals at least 5 seconds prior to any planned rover activity and continue to emit visible signals until all rover activities are finished.	I	C	None
REQ-OPS-080	Rover Activity Timing	The rover shall not perform any activity within the first 5 seconds of the indicator lamp emitting visible signals.	T	C	None
REQ-OPS-090	Autonomous Delay	The rover shall begin any autonomous operation at least 5 seconds after issuing the command responsible for starting autonomous operations.	T	C	None
REQ-OPS-100	Drone LoS	The UAV shall be always in the Line of Sight (LoS) of the pilot due to safety reasons.	R	C	None
REQ-OPS-110	Rover Navigation	The team should not use visual feedback when performing Navigation Task: Traverse Subtask outside of autonomy mode.	R	C	None

REQ-OPS-120	Drone Navigation	The team should not use visual feedback when performing Navigation Task: Droning Subtask in autonomous mode.	R	C	None
REQ-OPS-130	Task Duration	The rover shall be able to perform ERC tasks of up to 60 minutes of duration.	R, A	C	Energy management and operational efficiency are optimized to support task completion within the 60-minute timeframe, accounting for energy needs of each task.
REQ-OPS-140	Drone - Certified Pilot	Person in control of UAV should be trained and certified pilot (if required), depending on the final design of the UAV. All the applicable requirements associated with drone control are as per the local European and Polish regulations.	R	C	None

REQ-OPS-150	Teleoperation	The ground station shall provide control over every functionality of the rover and the drone.	R, T	C	Advanced teleoperation systems will be implemented to ensure comprehensive control over the rover and UAV, with rigorous testing to validate control effectiveness under various conditions.

2.3 Achievable Ideas and Timeline

Our project timeline is structured to ensure that each phase of Tenacity's development is aligned with the competition's milestones. Key phases include:

1. Design and Simulation (Nov - Feb): Detailed design work, leveraging simulations to test and refine rover systems.
2. Prototype Development (Mar - May): Construction of a functional prototype to evaluate the practical implementation of our designs.
3. Testing and Optimization (Jun - Jul): Rigorous testing of the rover on simulated Martian terrain, with iterative improvements to enhance performance.
4. Mock Missions (Aug): Full-scale rehearsals to ensure seamless operation during the competition.

3. Preliminary Risk Assessment:

3.1 Risk Assessment table:

Risk ID	Risk Name	Description	Risk Category	Risk Owner	Likelihood	Severity	Risk Response Strategy	Mitigation Actions
R1	Scope Creep	Project requirements increase beyond initial estimates	Project Management	Project Manager	3	4	Mitigate	Regular review meetings; strict change control processes
R2	Technical Debt	Accumulation of technical compromises	Technical	Development Team	4	3	Mitigate	Prioritize code quality; allocate time for refactoring
R3	Supply Chain Delays	Delay in receiving critical components	Operational	Procurement Officer	2	3	Transfer	Use multiple suppliers; maintain inventory of critical components
R4	Skill Gaps	Team lacks necessary skills for project execution	Human Resources	HR Manager	3	4	Mitigate	Training programs; hiring or consulting specialists
O1	Technology Advancement	Adoption of new technology enhances project outcome	Opportunity	Project Manager	4	5	Exploit	Stay updated on new tech; allocate resources for tech integration

Likelihood and Severity Scale:

Likelihood:

1. Rare
2. Unlikely
3. Possible
4. Likely
5. Almost Certain

Severity:

1. Negligible
2. Minor
3. Moderate
4. Major
5. Catastrophic

3.2 Additional Analysis

1. High-risk areas, such as Skill Gaps and Scope Creep, require immediate attention. Regular training and a robust change management process can significantly mitigate these risks.
2. The opportunity presented by Technology Advancement can be a game-changer for the project, offering a chance to exceed stakeholder expectations and deliver superior value.
3. Emphasizing Mitigation Actions for identified risks and actively pursuing Exploit strategies for opportunities can ensure project resilience and success.

4. Project Potential Evolution:

Our project, initially conceived for the European Rover Challenge (ERC), is not just about exploring extraterrestrial landscapes. It's a springboard for broader applications, bridging space technology with earthly needs. At its core, our venture utilizes modular robotics, autonomy, and solar power, showcasing a blend of innovation and sustainability.

4.1 Commercialization Pathways:

1. Autonomous Warehousing Solutions: Capitalizing on our project's autonomous navigation capabilities, we plan to adapt and scale the technology for warehousing and inventory management systems. This initiative is bolstered by our successful prototype developed for a technical sponsor, indicating market readiness and operational efficacy.
2. Solar-Powered Delivery Systems: Our vision includes the development of eco-friendly delivery solutions powered by solar energy. This initiative, currently being explored as a Final Year Project (FYP) by one of our team members, aims to revolutionize last-mile delivery services by reducing carbon footprints and operational costs.

4.2 Research and Development Trajectory:

1. Advancements in Autonomous Navigation Algorithms: Building on our project's autonomous capabilities, our R&D efforts will focus on refining algorithms for enhanced decision-making and adaptability in complex environments. This research will contribute to both our warehousing and solar-powered delivery systems.
2. Innovative Energy Solutions: In line with our commitment to sustainability, we will explore improvements in solar energy utilization and storage, aiming to increase efficiency and reliability for both terrestrial and extraterrestrial applications.

4.3 Implementation Plan

Year 1-2: Develop and test autonomous warehousing solutions; prototype solar-powered delivery systems; enhance educational kit offerings.

Year 3: Deploy pilot projects for warehousing solutions; begin small-scale implementation of solar-powered deliveries; publish preliminary research findings.

Year 4-5: Scale commercial offerings based on market feedback; expand educational partnerships; continue publishing breakthroughs in energy solutions and autonomous navigation.

5. Innovative Approach:

Our team is poised to bring a fresh perspective to the European Rover Challenge, diverging from the path trodden by predecessors to introduce a rover design that marries traditional robustness with pioneering innovation. Central to our design philosophy is the integration of novel materials and cutting-edge technological solutions aimed at enhancing performance, autonomy, and adaptability.

1. Material Innovation: Graphene-Infused Composites: At the heart of our rover's structural innovation is the use of graphene-infused composite materials for the chassis. Graphene, known for its exceptional strength-to-weight ratio, significantly reduces the overall mass of our rover without compromising durability. This material choice not only makes our rover more efficient in energy consumption but also improves its manoeuvrability and speed, crucial for navigating the challenging terrains of extraterrestrial environments.

2. Wheel Design: Moving away from the conventional wheel designs seen in previous competitions, our team has developed a unique wheel structure inspired by natural geometries. This new wheel design enhances surface grip and adaptability, enabling our rover to traverse over more diverse and challenging terrains with ease. The integration of flexible, yet durable materials in the wheel construction allows for better shock absorption, providing stability during navigation and task execution.

3. Custom-Built CNN and Autonomous Algorithms: In the realm of autonomy and navigation, we are not content with off-the-shelf solutions. Our team is developing custom-built Convolutional Neural Networks (CNN) and autonomous algorithms tailored specifically to our rover's architecture and mission objectives. These bespoke algorithms are designed to improve the rover's decision-making processes, enabling more accurate and efficient recognition of obstacles, terrain features, and task-relevant objects. Through rigorous training with diverse datasets, our rover's autonomous capabilities will be finely tuned to exhibit unprecedented levels of situational awareness and operational autonomy.