BALUCHISTAN UNIVERSITY OF INFORMATION TECHNOLOGY, ENGINEERING AND MANAGEMENT SCIENCES

Machine Learning Project

# Case Study: Role of Machine Learning in NASA's Self Driving Perseverance Rover

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# Role of Machine Learning in Rover Navigation on Mars

Presented by Qasim Ajlal

***Abstract*—Elon Musk and SpaceX are actively working on plans to send humans to Mars, while NASA's Artemis program aims to return people to the moon. The recent surge in space exploration, both by private companies and governments, reflects a widespread desire to turn science fiction dreams of colonizing celestial bodies into reality.**

**However, the challenges of establishing human presence on Mars are significant. Unlike Earth, Mars lacks a magnetic field and a protective atmosphere. On our planet, the magnetic field shields us from solar radiation, and the ozone layer filters out harmful UV light. Mars, in contrast, is essentially a vast, uninhabitable desert exposed to high levels of radiation. Additionally, the planet experiences frequent dust storms, with occasional global storms blocking sunlight for extended periods. These environmental factors pose considerable obstacles to human activities on Mars.**

## I. Problem Statement

The effective incorporation of machine learning into the navigation systems of Mars rovers represents a pivotal juncture in the realm of space exploration. This intersection of technology and exploration introduces both significant challenges and promising prospects. The focus of this case study is to delve into the multifaceted nature of these challenges, recognizing the simultaneous role they play as opportunities in enhancing the rover's navigational capabilities on the Martian landscape.

At the core of this inquiry lies the intricate balance between leveraging advanced machine learning algorithms and the inherent complexities associated with extraterrestrial exploration. The autonomous decision-making prowess afforded by machine learning presents a compelling advantage, promising increased efficiency and adaptability for rovers traversing the rugged Martian topography. However, a paramount concern arises in effectively mitigating the diverse environmental uncertainties that characterize the Martian terrain.

The unique challenges include, but are not limited to, the absence of a magnetic field, atmospheric differences, and the occurrence of dust storms. These factors collectively contribute to an environment where the rover's navigation is intricately intertwined with its ability to discern and respond to unpredictable circumstances. The limited computational resources available further compound this challenge, necessitating a nuanced approach to optimize the allocation and execution of machine learning algorithms.

In light of these considerations, the overarching problem statement revolves around the need to strike an optimal balance between harnessing the potential of machine learning for autonomous navigation and addressing the constraints posed by the Martian environment. This includes developing strategies that ensure real-time adaptability, minimize computational demands, and enhance the rover's resilience to unforeseen challenges. Ultimately, the resolution of this problem is imperative for maximizing the scientific yield of Mars exploration missions and advancing our understanding of the Red Planet's mysteries.

## II. Introduction

Mars, both literally and metaphorically distant from Earth, presents a challenging environment for human exploration. The absence of a protective atmosphere and magnetic field on Mars exposes astronauts to potential harm from solar radiation, emphasizing the need for advanced solutions to ensure their safety. Fortunately, rovers have proven to be invaluable assets on Mars and the Moon, playing a crucial role in ongoing and future space missions. These robotic vehicles enable the remote execution of experiments and facilitate the transportation of goods between bases, mitigating the risks associated with direct human exposure to the harsh Martian conditions.

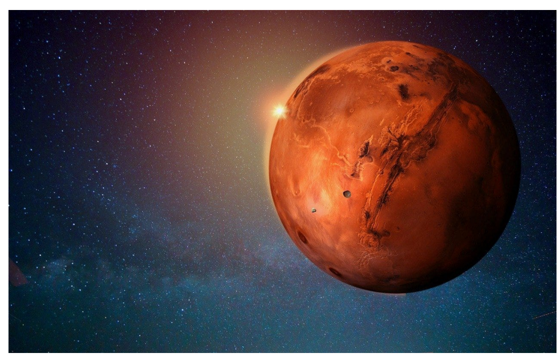

Fig. 1. Credit: NASA

However, a notable limitation hinders the full potential of rovers in space exploration – their sluggish speed. Currently, a dedicated team at NASA meticulously crafts daily instructions for rovers, dictating their movements and specifying which experiments to conduct. This manual process, while effective, consumes valuable engineering time that could be allocated to more innovative tasks. The Perseverance Rover, for instance, typically moves at a modest speed of about 4 centimeters per second, a deliberate limitation imposed by NASA to prevent potential collisions or entanglements.

The desire for increased rover autonomy becomes evident in the quest for more efficient exploration. The notion of rovers driving themselves without constant human intervention emerges as a compelling solution. Imagine a scenario where a human or artificial intelligence identifies an area of interest, instructs the rover to navigate there, and the rover autonomously executes the command. This streamlined process resembles using a GPS for navigation, analogous to finding the nearest restaurant without manually plotting the route on a map. While the latter approach may be cost-effective, the potential time savings and operational efficiency gained by allowing rovers to navigate independently are considerable, offering a promising avenue for advancing exploration capabilities on Mars.

## III. Background

The exploration of Mars has long captivated human curiosity, with scientific missions seeking to unravel the mysteries of the Red Planet's geology, climate, and potential habitability. Central to these endeavors is the deployment of rovers equipped with advanced technologies to navigate the challenging Martian terrain and gather crucial data for scientific analysis. As technology evolves, the integration of machine learning has emerged as a transformative force, promising to enhance the autonomy and decision-making capabilities of these rovers.

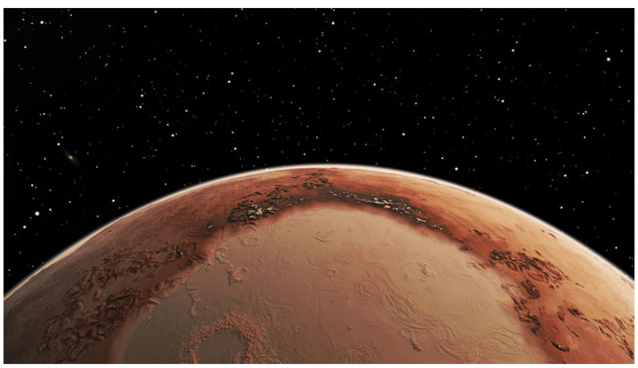

Fig. 2. Credit: NASA

Machine learning, a subset of artificial intelligence, enables systems to learn from data and make informed decisions without explicit programming. In the context of Mars exploration, the incorporation of machine learning into rover navigation systems represents a paradigm shift in how these robotic vehicles traverse the unpredictable Martian landscape. Unlike traditional navigation methods, machine learning empowers rovers to adapt in real-time to the dynamic and often hazardous environmental conditions on Mars.

The significance of this integration lies in its potential to overcome challenges inherent to extraterrestrial exploration. Mars lacks a magnetic field and has a thin atmosphere, exposing its surface to elevated levels of solar radiation. Additionally, the planet experiences frequent dust storms that can obscure visibility and disrupt communication. These environmental factors necessitate advanced navigation systems capable of autonomous decision-making to ensure the safety and efficacy of rover missions.

Despite the promise that machine learning holds, the successful implementation of these algorithms in the Martian context is not without its complexities. The interplay between computational limitations, the need for real-time adaptability, and the diverse environmental uncertainties on Mars introduces a nuanced set of challenges. This case study aims to delve into the intricacies of these challenges and opportunities, seeking to unravel the delicate balance required to optimize rover navigation through the application of machine learning in the unique and demanding Martian environment. By understanding and addressing these challenges, the study aims to contribute valuable insights that can inform the future design and execution of Mars exploration missions.

## IV. Objectives

In contemplating the future of space exploration, the current method employed by rovers, utilizing a combination of human commands and AutoNav for traversing Mars, prompts important considerations. As aspirations for human missions to Mars and the Moon gain momentum, the question of the sustainability of manually controlling rovers becomes paramount. The intricacies of instructing each robot individually, coupled with the relatively slow pace of the rovers—especially during the AutoNav cycle, which moves at a modest 4 centimeters per second—prompt an exploration of more efficient and forward-thinking solutions.

Addressing these challenges necessitates a paradigm shift in the control mechanisms of rovers. One avenue lies in maximizing the utilization of AutoNav, reducing the dependence on direct human input. This approach not only streamlines mission processes but also raises the prospect of enhanced efficiency in transporting goods between colonies, crucial for sustaining future space endeavors. The evolution toward more autonomous systems is underscored by the need for advanced machine learning capabilities capable of making rapid decisions and executing operations with minimal human intervention.

Looking beyond the current state, envisioning the future of rovers involves conceptualizing machine learning algorithms that extend beyond mere movement control. The theoretical framework suggests these algorithms could craft intricate mission paths spanning thousands of meters, leveraging detailed mapping data. This innovative approach was illuminated in discussions at the virtual AI Systems Summit by Kisaco Research, where Shreyansh Daftry presented insights into machine learning systems for rover navigation. The vision of a ”Google Maps for Mars” scenario implies a departure from manually charting general routes. Instead, a person could simply provide the rover with a destination, allowing it to autonomously navigate toward the specified point, akin to using a GPS system.

Moreover, advancements in machine learning pave the way for the development of purpose-built, cost-effective rovers. Tailored for specific tasks such as transporting goods and conducting operations outside Martian habitats, these rovers could be lighter and more economical. While the visual representation of a rover carrying crates, generated by Canva's AI image generator, serves as a conceptual example, the integration of superior machine learning capabilities with such rovers has the potential to significantly enhance travel speed. This holistic approach not only contributes to the acceleration of experiments and missions by astronauts but also underscores the transformative potential of technology in optimizing the efficiency and effectiveness of future extraterrestrial exploration endeavors.

## V. Scope

### A. Navigational Advancements in Mars Rovers

The scope of this case study extends beyond a mere exploration of the navigational intricacies of Mars rovers; it delves into the profound technological strides made in enhancing their autonomy and efficiency. By focusing on the interplay of machine learning, AutoNav, and eNav systems, this study aims to provide an in-depth understanding of the challenges faced, the technological advancements achieved, and the future prospects that lie on the horizon.

### B. Navigational Challenges

**Unraveling the "Overthinking" Phenomenon:** An essential aspect of the scope involves dissecting the challenges associated with the phenomenon known as "overthinking" in rover navigation. The study aims to unravel the complexities behind rover pauses due to poor path rankings or prolonged ACE evaluations. By scrutinizing these challenges, we can glean insights into the operational constraints faced by rovers and explore potential avenues for improvement.

### C. Technological Evolution

**From Curiosity to Perseverance:** A historical examination forms a crucial component of this case study, tracing the technological evolution from earlier rovers, such as Curiosity, to the advancements embodied in Perseverance. Understanding the transition from periodic halts for terrain evaluation to real-time decision-making with AutoNav illustrates the trajectory of progress in space robotics and machine learning capabilities. This analysis will contribute to identifying the pivotal milestones in rover technology.

### D. Human-Machine Interaction

**Striking a Delicate Balance:** The study delves into the intricacies of the human-machine interaction in rover navigation. While Perseverance showcases unprecedented autonomy, the reliance on human input for specific maneuvers highlights the delicate balance between machine-driven decision-making and human-guided precision. Evaluating the coexistence of these elements is paramount in understanding the practical implications and future directions for autonomous space exploration.

### E. Future Prospects

**Unlocking New Frontiers:** Looking forward, the case study explores the future prospects of autonomous robotic exploration on Mars. By addressing current challenges systematically, the study aims to uncover potential advancements that could propel Martian rovers towards greater independence and capability. The prospects include refining existing systems, addressing computational demands, and envisioning a future where autonomous rovers play a pivotal role in unlocking new realms of scientific discovery on the Red Planet.

Fig. 3. CCREDIT: Canva AI Image Generation

### F. Implications for Space Exploration

**Bridging Technological Gaps:** The broader scope of this study encompasses the implications of navigational advancements in Mars rovers for the broader landscape of space exploration. Analyzing the technological gaps bridged by machine learning, AutoNav, and eNav sheds light on how these innovations may influence future mission planning, the feasibility of human missions to Mars, and the overall trajectory of our exploration endeavors beyond Earth.

In essence, the scope of this case study is not confined solely to the technical intricacies of rover navigation but extends to the broader implications, challenges, and futuristic possibilities that arise from the integration of cutting-edge technologies in the realm of extraterrestrial exploration.

## VI. Methodology

### A. Machine Learning

**Empowering Autonomous Rover Movement:** Machine learning emerges as a pivotal solution to enhance the autonomy of Mars rovers, enabling faster and more efficient exploration. In essence, machine learning involves teaching a computer how to perform specific tasks, a concept crucial in the context of rover navigation on the Martian surface.

### B. AutoNav and eNav

**Navigational Technologies on Mars:** AutoNav, akin to the Tesla autopilot for Mars rovers, stands at the forefront of autonomous navigation. It operates by capturing images of the rover's surroundings, analyzing potential hazards, constructing a 2.5D elevation map of the terrain, generating various potential paths, and ultimately selecting the optimal route. Enhanced AutoNav (eNav) complements this process by managing a comprehensive list of paths and employing the Approximate

Clearance Evaluation (ACE) algorithm to assess the safety of each path.

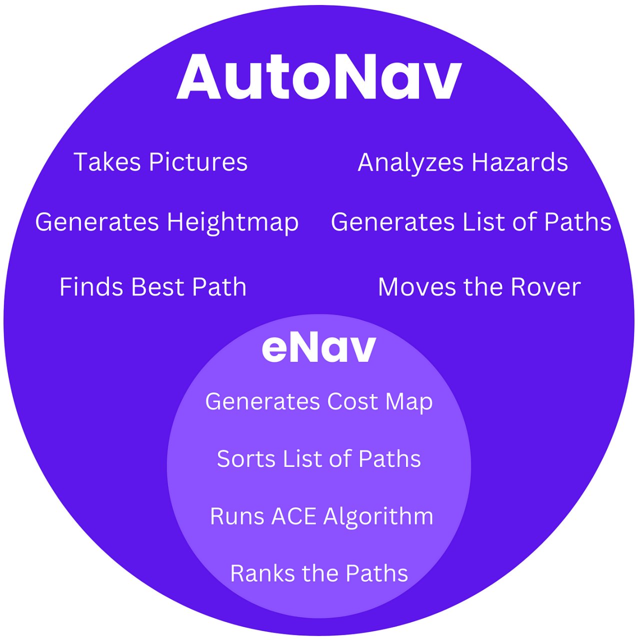


Fig. 4. CCREDIT: Google

**The eNav and ACE Algorithm Workflow:** The planning process begins with the rover capturing stereo camera images of its surroundings, which are then transformed into a 3D point cloud. This data is sent to eNav, which updates a 2.5D height map centered on the rover. A machine-learning algorithm analyzes the terrain, producing a cost map that rates the potential danger of each cell. The algorithm then generates an array of paths, with rankings determined by factors such as steering changes and overall safety.

The ACE algorithm evaluates each path, considering critical factors like wheel height, rover attitude, suspension angles, and clearance from the terrain. If any limits set by NASA engineers are exceeded, the path is deemed unsafe with an infinite cost. Only paths within specified limits proceed to the next stage. The ACE algorithm assigns a cost based on proximity to these limits, ultimately validating the path with the lowest finite cost, providing a safe and feasible route for the rover.

### C. *Executing Rover Movements*

**Safety and Efficiency:** Upon finding a validated path, the rover begins its movement, but with caution. The rover executes only the initial segment of the path, such as the first meter of a straight line or arc, or the first 30 degrees of a turn in place. This cautious approach ensures that the rover avoids potential damage during its extensive journey, as there are no engineers on Mars for immediate repairs. The rover continuously captures images during its movement, initiating a planning cycle to find the next maneuver. This iterative process ensures a meticulous balance between efficiency and safety.

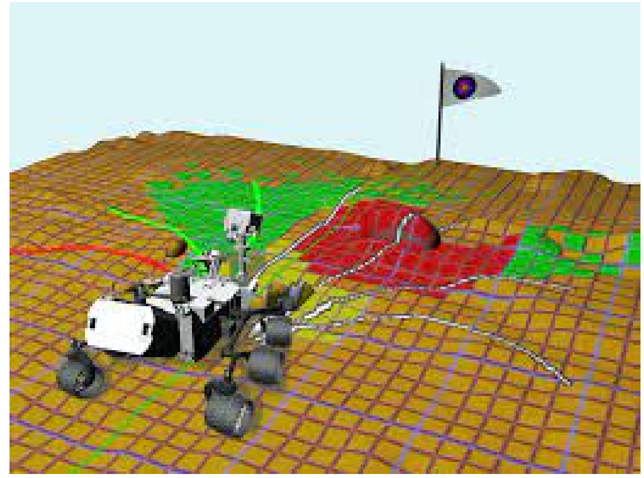

Fig. 5. CREDIT: Jet Propulsion Laboratory, NASA

## VII. Discussion

### A. *Navigational Innovations and Future Trajectories for Mars Rovers*

The discussions stemming from this case study encompass a comprehensive exploration of the navigational innovations witnessed in Mars rovers, unraveling their implications and setting the stage for future trajectories in space exploration.

### B. *Overcoming Overthinking*

**Refining Autonomous Decision-Making:** The observed phenomenon of ”overthinking” in rover navigation prompts discussions on strategies to refine autonomous decision-making processes. Investigating ways to mitigate the impact of sub-optimal path rankings and extensive ACE evaluations is critical for enhancing rover efficiency. The discourse will delve into potential algorithmic improvements and system optimizations aimed at minimizing rover pauses during missions.

### C. *Historical Context*

**Lessons from Curiosity to Perseverance:** The historical evolution of rover technology, from the challenges faced by earlier models like Curiosity to the advancements realized in Perseverance, sparks discussions on the lessons learned and the strides made in space robotics. Analyzing this progression will illuminate the key milestones and innovations that have shaped the current landscape of rover navigation, providing valuable insights for future developments.

### D. *Human-Machine Collaboration*

**Striking Optimal Balance:** The interplay between human guidance and machine autonomy in rover navigation prompts discussions on striking an optimal balance. Assessing the advantages and limitations of the current approach, where Perseverance relies on human input for specific maneuvers, opens dialogues on the practical implications of human-machine collaboration. This discussion explores potential avenues for increasing rover autonomy while ensuring precise control when necessary.

### E. Future Trajectories

**Advancements and Uncharted Frontiers:** Delving into the future prospects of autonomous robotic exploration on Mars fosters discussions on the advancements needed to propel Martian rovers into uncharted frontiers. Addressing current challenges, such as computational demands and the intricacies of long-term missions, fuels conversations on the potential breakthroughs that could redefine the capabilities and scope of future exploration endeavors.

### F. Broader Implications for Space Exploration

**A Paradigm Shift:** The broader implications of navigational innovations in Mars rovers extend discussions to the paradigm shift occurring in the landscape of space exploration. Exploring how these technological advancements may influence mission planning, the feasibility of human missions to Mars, and the overall trajectory of space exploration sparks conversations on the transformative impact of cutting-edge technologies beyond Earth.

In conclusion, the discussions prompted by this case study delve into the intricacies of rover navigation, touching upon refinement strategies, historical insights, the delicate balance between human and machine, future trajectories, and the overarching implications for the broader realm of space exploration. These discussions serve as a catalyst for envisioning a future where autonomous rovers play a pivotal role in unlocking the mysteries of Mars and beyond.

## VIII. Conclusion

### A. Challenges and Advancements

**Overcoming Rover "Overthinking":** Despite the remarkable sophistication of the eNav system, certain challenges arise in specific scenarios referred to as "overthinking," introducing a nuanced layer to the autonomous navigation of Mars rovers. In these instances, the rover may pause in its trajectory due to suboptimal path rankings or prolonged Approximate Clearance Evaluation (ACE) assessments. Overthinking proves to be detrimental to mission objectives, imposing constraints on time, augmenting wear and tear on the rover's wheels, and amplifying overall mission risks.

Moreover, the eNav system demands a substantial amount of computing power to execute its intricate decision-making processes. The requirement for such computational resources is a critical consideration in the context of the rover's operational efficiency and the sustainability of long-term missions. The balance between computational demands and mission effectiveness is a continuous focal point in the ongoing quest for optimizing rover autonomy.

### B. Historical Context

**The Evolution from Curiosity to Perseverance:** An insightful perspective can be gained by reflecting on the historical trajectory of rover technology. Previous rovers, exemplified by Curiosity, encountered periodic halts during their missions to evaluate the terrain. These pauses were a consequence of the slower decision-making capabilities inherent in earlier systems. Curiosity's limitations underscore the need for continual advancements in rover technology to meet the demands of dynamic exploration on extraterrestrial surfaces.

The introduction of Perseverance represents a significant leap forward in space robotics and machine learning capabilities. The rover's ability to engage in real-time decision-making concurrently with AutoNav usage stands as a testament to the progress made in enhancing rover autonomy. However, despite these advancements, the reliance on human input for certain maneuvers highlights the intricate balance between machine-driven autonomy and human-guided precision.

### C. Prospects for the Future

**Autonomous Robotic Exploration on Mars:** In conclusion, the integration of machine learning, AutoNav, and eNav heralds a groundbreaking era in the autonomy and efficiency of Mars rovers. The nuanced challenges posed by "overthinking" and the computational demands of eNav serve as focal points for ongoing refinement and improvement. As technology continues to advance, the trajectory of rover evolution aims to address these challenges systematically, laying the foundation for increasingly independent and capable robotic exploration on the Red Planet. The journey toward fully autonomous Martian rovers is an exciting frontier that holds the promise of unlocking new realms of scientific discovery and exploration possibilities in our quest to understand the mysteries of Mars.

## IX. Future Work

### A. Advancing Navigational Capabilities for Mars Rovers

The exploration of navigational capabilities in Mars rovers unveils a realm of possibilities for future work, emphasizing the need for continuous innovation and refinement. As we peer into the horizon of extraterrestrial exploration, several avenues emerge for advancing the autonomy, efficiency, and overall effectiveness of rover navigation on the Martian surface.

### B. Algorithmic Enhancements

**Overcoming "Overthinking" Challenges:** A pivotal focus for future work involves algorithmic enhancements aimed at mitigating the challenges associated with rover "overthinking." Research initiatives can delve into refining the decision-making algorithms, reducing the impact of suboptimal path rankings, and expediting the Approximate Clearance Evaluation (ACE) process. This involves exploring machine learning techniques that enhance the rover's ability to prioritize and assess potential paths swiftly, minimizing pauses and maximizing mission efficiency.

### C. Machine Learning Advancements

**Precision in Autonomous Decision-Making:** The future trajectory of rover navigation hinges on advancements in machine learning. Researchers can explore ways to empower rovers with more sophisticated learning algorithms, allowing them to adapt dynamically to changing terrains and evolving mission parameters. By incorporating advanced machine learning models, the aim is to achieve precision in autonomous decision-making, enabling rovers to navigate more efficiently and make real-time adjustments without compromising safety.

### D. *Human-Rover Interaction*

**Redefining Collaborative Exploration:** The intersection of human guidance and autonomous capabilities presents an intriguing area for future work. Research endeavors can explore ways to enhance the collaborative interaction between humans and rovers. This involves investigating user-friendly interfaces that enable more seamless and intuitive communication with the rover, allowing humans to provide high-level instructions while the rover autonomously refines its path based on overarching mission goals. Striking an optimal balance between human oversight and rover autonomy will be a key consideration in shaping the future of collaborative exploration.

### E. *Computational Efficiency*

**Meeting the Demands of Extended Missions:** As space agencies contemplate extended and more complex missions, future work must address the computational demands associated with advanced navigational systems. Researchers can explore strategies to optimize algorithms for efficiency, investigate novel computing architectures, and implement real-time processing enhancements. This will ensure that rovers can make informed decisions swiftly, contributing to the success of prolonged missions without compromising computing resources.

### F. *Interdisciplinary Collaboration*

**Bridging Gaps for Holistic Solutions:** The future of rover navigation calls for increased interdisciplinary collaboration. Researchers from fields such as robotics, artificial intelligence, materials science, and aerospace engineering can pool their expertise to devise holistic solutions. Collaborative efforts can lead to innovations that address not only navigational challenges but also broader mission objectives, such as payload delivery, sample collection, and environmental monitoring.

### G. *Lightweight Rover Designs*

**Enhancing Speed and Efficiency:** Future work may explore the development of lightweight rover designs optimized for specific tasks, such as transporting goods and materials. By leveraging advancements in materials science and engineering, researchers can design rovers that are not only more cost-effective but also faster and more agile. Lightweight rovers equipped with sophisticated machine learning systems could significantly enhance the speed of travel, enabling astronauts to conduct experiments and missions more efficiently.

### H. *Simulation and Testing*

**Iterative Improvements in a Controlled Environment:** A crucial aspect of future work involves refining navigational systems through extensive simulation and testing. Researchers can create sophisticated virtual environments to simulate various Martian terrains, allowing rovers to navigate autonomously in controlled settings. This iterative process of simulation and testing enables researchers to fine-tune algorithms, identify potential issues, and implement improvements in a controlled and risk-free environment before deploying rovers on actual missions.

In conclusion, the future work in advancing navigational capabilities for Mars rovers encompasses a multidimensional approach, involving algorithmic refinements, machine learning advancements, human-rover interaction optimization, computational efficiency strategies, interdisciplinary collaboration, lightweight rover designs, and rigorous simulation and testing. This holistic perspective underscores the dynamic nature of space exploration research, where continuous innovation and collaboration pave the way for unlocking new frontiers in our quest to understand the mysteries of Mars and beyond.

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**Balochistan University of Information Technology, Engineering and Management Sciences (BUITEMS)**
**Faculty of Information and Communication Technology (FICT)**
**Rubrics for Problem Based Learning (PBL)**

Subject: ____________ Department: ____________
Semester: ____________ Session: ____________
Student name: ____________ CMS ID : ____________

| Performance Indicator | Unsatisfactory | Average | Good | Excellent | Score |
|---|---|---|---|---|---|
| **Understands the Problem (15 Marks)** | Doesn't understand enough to get started or make progress. | Understands enough to solve part of the problem. | Understands the problem. | Understands the problem and Identifies the approach before starting the problem. | |
| | **0-3** | **4-7** | **8-11** | **12-15** | |
| **Uses Information for Problem Solving (10 Marks)** | Used wrong information in trying to solve the problem. | Used not all of the relevant information in trying to solve the problem. | Used all relevant information in trying to solve the problem. | Used implied information not readily apparent in trying to solve the problem. | |
| | **0-1** | **2-4** | **5-7** | **8-10** | |
| **Methodology/Approach (25 Marks)** | Unable to solve the problem or the attempted solution shows inadequate knowledge of engineering, science and mathematics. | Demonstrates the ability to apply some principles of engineering, science and mathematics to solve the problem but not correctly. | Demonstrates the ability to correctly apply principles of engineering, science and mathematics to solve the problem with some guidance. | Demonstrates the ability to correctly apply all the appropriate principles of engineering, science and mathematics to solve the problem. | |
| | 0-5 | 6-11 | 12-18 | 19-25 | |
| **Results, Analysis and Conclusion (25 Marks)** | Fails to interpret the results, analysis and conclusion. | Demonstrates the results, however, the analysis and conclusion are not provided. | Demonstrates the clear results, analysis and conclusion. | Demonstrates the detailed results, analysis, conclusion and future recommendations. | |
| | 0-5 | 6-11 | 12-18 | 19-25 | |
| **Report Writing (10 Marks)** | The document has poor organization and formatting with many grammatical and spelling errors. The appropriate format is not followed. | The document has some organization and formatting with few errors. The appropriate format is followed in few sections of the document. | The document is organized, properly formatted, and error free. The appropriate format is followed. | The document is well organized, properly formatted, and error free. The appropriate format is precisely followed. | |
| | **0-1** | **2-4** | **5-7** | **8-10** | |
| **Presentation and Viva Voce (15 Marks)** | Presentation slides have poor organization and formatting. Student is not prepared and making no attempts to engage audience. Student cannot answer to questions. | Presentation slides have some organization with appropriate graphics and formatting. Student is somewhat prepared and making limited attempts to engage audience. Student feels difficulty to answer questions. | Presentation slides are organized and properly formatted. Student is prepared and delivers presentation while engaging the audience. Student responds to all questions properly. | Presentation slides are well organized and properly formatted. Student is well prepared and delivers clear and continuous presentation while effectively engaging the audience. Student responds to all questions properly and accurately. | |
| | **0-3** | **4-7** | **8-11** | **12-15** | |
| **Total Marks obtained out of 100** | | | | | X |

Marks obtained out of Y = (X/100)×Y ; Y is the total marks of PBL

Instructor Signature: ____________

Fig. 6.