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Mars Explorer Experiments: Ideas from Data Mining Point of View

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***Abstract**: In the context of the "Mars Explorer Experiments," a set of autonomous agents (vehicles) must navigate an unknown, obstacle-filled terrain to locate and collect rock samples, with limited communication between agents and no prior detailed map of the planet. This paper explores the application of data mining techniques in the development of autonomous vehicle control architectures for Mars exploration, specifically focused on the task of collecting precious rock samples according to three types of agents (Cooperative Agents, Non-Cooperative Agents, Subsumption Architecture) through describing the agent with the data mining point of view (problem statement in agent, solution using data mining algorithms, discussion problem and solution from data mining point of view). A significant portion of the paper discusses how data mining approaches such as clustering, reinforcement learning, anomaly detection, and pattern mining can be employed to improve agent coordination, exploration strategies, and real-time decision-making in dynamic and uncertain environments. Incorporating data mining algorithms into 'Mars exploration experiments' shows a hopeful way to boost the performance and decision-making abilities of autonomous agents on Mars. The paper shows that the data mining algorithms are not just beneficial but essential in developing intelligent, cooperative, and autonomous systems for Mars exploration vehicles.*

***Keywords**: Mars Explorer, Data Mining Algorithm, Agent, Rational Agent.*

Abbreviations:
LSTM: Long Short-Term Memory
MER: Mars Exploration Rover
CDA: Crater Detection Algorithm
CNN: Convolutional Neural Network
CFD: Computational Fluid Dynamics
LEMEFV: Long-Endurance Mars Exploration Flying Vehicle

I. INTRODUCTION

There are many types of robots, each one with a special task, such as space robots, which are used in space exploration. The scientific world is growing in space transportation, on-orbit construction, maintenance, and planetary exploration [1]. It is growing from traditional methods to scientific methods. These robots play a crucial role as facilitators for future space missions, both unmanned and human. However, the design, production, and management of space robots present significant challenges due to the unique environment in which they operate, which differs greatly from conditions on Earth [2]. The field of space robotics requires interdisciplinary collaboration among many sciences and other experts, all working toward a common goal [3].

Time communication delays and restricted sources of power are the main challenges faced by space robots. There are many ways to control space robots, such as remotely from ground stations. Therefore, increase the independence of these robots [1]. The accumulation of space debris is the main challenge and issue in scientific space, this debris can hazard to many things, such as satellites [2].

NASA's Perseverance rover, which successfully landed on Mars in February 2021, is equipped with a new autonomous driving algorithm called Enhanced AutoNav (ENav) [4]. This system is based on the tree path planner, which is the best system compared with older systems. This rover has driven more than 2.2 km, which is the best distance compared with other rovers such as the Curiosity rover [5].

On the other side, the ENav's is not a better form for the human rover drivers. The human driver can decide the best decision when they often struggle (such as in challenging terrains). The human rover manually guides the rover through many ways and issues to reach the goal in a safety [4]. The major obstacles to further advancements in extraterrestrial autonomous driving include limited hardware resources available onboard, no mechanical damage, etc. [6].

The agent used in Mars exploration suffers from a lack of applied of modern and advanced data mining algorithms. So, our key motivation is to study how best to effectively integrate data mining methods with Mars explorer experiments, by carefully viewing a set of behavior rules, and idea data mining. And the discussion integrates data mining and artificial intelligence where it is most useful.

Organized the paper as follows: The related works are presented in Section 2. Agent definition and types are described in section 3. Mars explorer experiments are shown in section 4. Then, the Mars agent from a data mining point of view will be described in section 5. Finally, the conclusion will be presented in section 6.

II. RELATED WORK

There are many studies in this area. This section will show sets of these studies, and Table 1 shows the comparison between the related work papers based on the Techniques of the data mining area.

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Bass and et. al. (2005) [7], The paper focuses on the Mars Exploration Rover (MER) mission's decision to operate on Mars Time and discusses the implications of this decision on tactical operations and mission planning. Analyzes how time synchronization (Mars-time) affects mission planning for Mars rovers.

Eppes and et. al. (2010) [8], This work describes prototype software developed to allow scientists to locate and explore 2D and 3D imagery captured by NASA's Mars Exploration Rovers, facilitating measurements and geological analysis. Introduces 3D visualization and data-mining tools to enhance Mars rover image analysis.

Shuliang and et. al. (2014) [9], This study proposes a method to extract rocks from Martian surface images by modeling the interaction between pixels, utilizing hierarchical grids for clustering and detection. Proposes a new method to extract rocks from Martian surface images.

Hundman and et al. (2018) [10], The study demonstrates the effectiveness of Long Short-Term Memory (LSTM) networks in detecting anomalies in spacecraft telemetry data, using data from the Mars Science Laboratory rover, Curiosity. Demonstrates the use of LSTMs for anomaly detection on Mars rover telemetry data.

Momennasab (2021) [11], This paper provides an overview of Mars' features and phenomena, discusses uncertainties in Mars exploration, and summarizes current and potential future applications of machine learning techniques in Mars missions. Discusses potential future applications of machine learning for Mars exploration missions.

Lee and et. Al. (2021) [12], This research presents an automated Crater Detection Algorithm (CDA) that identifies and locates craters on Mars' surface, achieving performance comparable to expert human researchers. Introduces Convolutional Neural Network (CNN) for automated detection of craters from Mars rover images.

Never and et. Al. (2021) [13], The paper investigates deep learning methods for classifying and detecting Martian rocks using the Perseverance rover's onboard computer vision system, achieving high accuracy in rock detection. Implements deep learning for detecting and classifying rocks on Mars.

Pohly and et. Al. (2021) [14], The paper proposes a scaling method based on neural networks trained on 3D Navier-Stokes solutions to determine wing sizes and kinematic values for bioinspired Mars flight vehicles. Applies data mining techniques to optimize Mars flight vehicles based on Computational Fluid Dynamics (CFD) data.

Petrovsky and et al. (2022) [15], The paper suggests a concept for using a modular robotic swarm consisting of independent two-wheeled robots for Mars exploration, highlighting potential advantages and challenges. Proposes a robotic swarm concept for Mars rover exploration and its potential benefits.

Karpovich and et. Al. (2023) [16], This brief presents specifications for the Long-Endurance Mars Exploration Flying Vehicle (LEMFEV), based on analyses of previous Mars missions and scientific data collected by operating Martian probes. Applies machine learning and optimization techniques for flight vehicles, improving endurance on Mars.

Table-I: Comparison of Related Works on Data Mining in Mars Exploration

Paper Title	Techniques Used
Machine Learning for Mars Exploration [11]	Machine Learning
Detecting Spacecraft Anomalies Using LSTMs [10]	Long Short-Term Memory, Anomaly Detection
Automated Crater Detection with Human-Level Performance [12]	Deep Learning (Convolutional Neural Networks)
Rock Hunting with Martian Machine Vision [13]	Deep Learning (Computer Vision)
A Novel Method to Extract Rocks from Mars Images [9]	Clustering, Feature Extraction
Data-Driven CFD Scaling of Bioinspired Mars Flight Vehicles for Hover [14]	Data Mining, Computational Fluid Dynamics
Development of 3-D Visualization and Data-Mining Software [8]	Data Mining, 3D Visualization
The Two-Wheeled Robotic Swarm Concept for Mars Exploration [15]	Swarm Intelligence, Data Mining
Long-Endurance Mars Exploration Flying Vehicle [16]	Machine Learning, Optimization Algorithms
Choosing Mars-Time: Analysis of the Mars Exploration Rover Experience [7]	Statistical Analysis, Data Mining

According to Table 1, Techniques Used, many papers apply deep learning (especially CNNs and LSTMs) for image classification, object detection, and anomaly detection. These techniques are particularly useful in handling large datasets and are commonly used in robotic vision (e.g., rock hunting, crater detection). Swarm intelligence is employed in the coordination of multiple robots (e.g., the robotic swarm concept), while data mining and clustering techniques are used for geological feature extraction and analysis, like in rock detection. Predictive modeling and optimization algorithms are used for Mars flight vehicle designs and rover health monitoring (e.g., anomaly detection and predictive maintenance).

III. AGENT DEFINITION AND TYPES

An agent in artificial intelligence refers to an entity capable of perceiving its environment and taking actions to achieve specific goals. In the context of Mars exploration, these agents are typically embodied as rovers or robotic systems that autonomously perform tasks such as data collection, navigation, and sample collection, among others. According to [17], an agent can be defined as an autonomous system that perceives its environment through sensors and acts upon it using actuators to achieve specific objectives. These agents are essential for tasks that are difficult or impossible for human operators, especially on distant planets such as Mars, where communication delays and environmental constraints complicate human intervention [18].

An agent (shown in Fig. 1) in artificial intelligence refers to an entity that can perceive its environment and input environment data from sensors, and take actions

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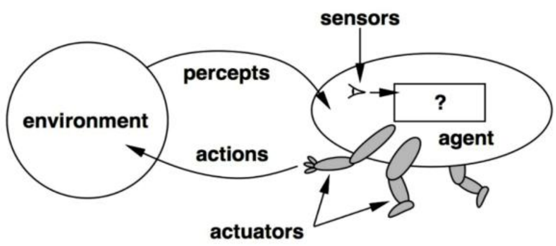
according to reasoning, and finally reach goals. On the other hand, agents of Mars exploration are embodied in rover systems that perform tasks such as data collection, navigation, and sample collection etc. According to Russell and Norvig, rational agents make the best decision to achieve the best outcome with the information collected from their environments, rather than relying on perfect knowledge. In the context of Mars exploration, rational agents could be assigned tasks such as navigating challenging terrains or determining the right time to collect samples, all while considering mission objectives and limitations [19].



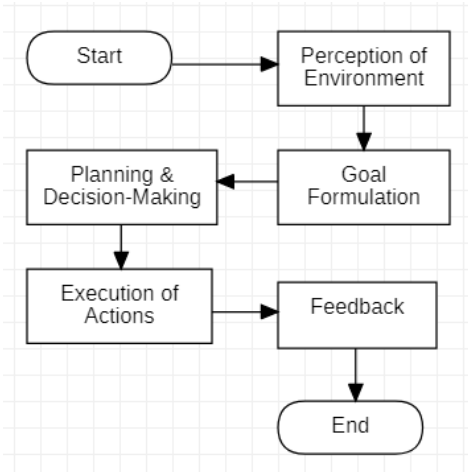
[Fig.1: Rational Agent and its Environment [17]]

An autonomous agent is an agent that can perform tasks and make decisions independently [17]. Autonomous agents are designed to observe their environment and get its as input data from the sensors, then reason about it, and finally make actions to reach their goals. An autonomous agent is described as one that "perceives and acts on the environment independently in pursuit of its objectives." Without human interaction, autonomous agents can change behavior according to changes in's environment. Be this feature, the autonomous agent is the best choice for the Mars exploration [20].

The decision-making in a rational agent is a making of structuring process (gathering information, reasoning [21], and action (based on the current state and its knowledge)). These processes are shown in Fig. 2 and with the following [22]:

- **A. Perception**: Sensors are an input method to the agent, which is used to sense its environment and collect information about it.
- **B. Goal Formulation**: The agent determines the goals based on the information in perception. These goals reflect that the gent wants to achieve it.
- **C. Planning**: The agent then formulates a plan or strategy to achieve its goals. This step involves evaluating possible actions and their outcomes.
- **D. Execution**: After planning, the agent executes the chosen actions.
- **E. Feedback**: The agent receives feedback from the environment and adjusts its decisions or plans as necessary.

A rational agent's decisions are typically based on a utility function that quantifies the desirability of a particular outcome [21]. The agent chooses actions that maximize its expected utility, aiming to achieve the most favorable outcome according to its goal [22].



[Fig.2: Flowchart of the Process of Decision-Making [21]]

IV. MARS EXPLORER EXPERIMENTS

In [23], Steels (1990) proposed the subsumption architecture agents, which combine the cooperative and non-cooperative agents.

Problem: Work together to efficiently gather rock samples from the Mars surface.

Solution: Subsumption architecture is proposed with two mechanisms. First (non-cooperative), in order that the agent's communication with the mother ship lies and knows in which direction, the mother ship generates a radio signal. The second mechanism (cooperative) enables agents to communicate with one another.

Idea: is that agents will carry 'radioactive crumbs'.

Behavior Rules:

detect function = d(), carrying function = c(), drop function = dr(), change function = ch(), travel up gradient function = tug(), pick up function = pu(), move randomly function = mr(), obstacle = o, direction = di, samples = s, mother ships = b,

This behavior can be represented in the rule:

If d(o) then ch (di). (5.1)

Another behavior, any samples collected by the agents are returned to the mother ship:

If c(s) and in b then dr (s) (5.2)

if c(s)and not in b then tug(). (5.3)

Behavior (5.3) guarantees that agents load the samples and return to the mother ship. The behavior:

if d(s) then pu(s). (5.4)

Final behaviour, when the agents have no choice but to do so, the agents move random direction:

if true then mr(). (5.5)

Hierarchy behaviours:

(5.1) < (5.2) < (5.3) < (5.4) < (5.5).

All implementations of Steel's Mars [1990] are available in [24] using the Java programming language.

V. MARS AGENT FROM DATA MINING POINT OF VIEW

Data mining is the process of extracting knowledge or useful information from large datasets (such as raw data) using many methods, such as statistical, Artificial Intelligence, Deep Learning

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[25], and computational methods, applied to structured, semi-structured, or unstructured data stored in various forms [26]. The goal of data mining is to uncover hidden patterns, information, knowledge, and relationships for informed decision-making and predictions through techniques such as clustering algorithms [27], classification algorithms, regression algorithms, association rule mining algorithms, anomaly detection algorithms, and reinforcement learning [28]. Applications of data mining are marketing, finance, healthcare, and telecommunications [29], discovering disease, web mining, Sentiment analysis, Spam Filtering, etc [30].

This section will describe the agent from a data mining point of view (problem, solution, discussion) [31]:

A. Non-Cooperative Agents

i. *Problem:* There are many problems in this type of agent, such as Data Availability, which collects data about the environment. Noisy Data, Data collected may contain noise or be incomplete. Exploration and Sample Discovery, Agents have limited data about where the rock samples are located.

ii. *Solution:* The solution may be such techniques as clustering: group terrain data and identify regions with a higher likelihood of finding samples. Anomaly Detection: used to identify unexpected obstacles. Exploration Strategies: reinforcement learning can be employed where agents learn from their previous exploration outcomes.

iii. *Discussion:* after problems and solutions, the discussion: Limitations of No Communication, which can lead to the same exploration areas. Minimize overlap in agent exploration using Clustering and pattern recognition. Decisions are less reliable in terrain due to the Data Inaccuracy. To reduce this, less reliable filtering or smoothing approaches can be used. Agents can optimize the utility values based on the historical data from previous missions (past data).

B. Cooperative Agents

i. *Problem:* There are many problems in this type of agent, such as: agents communicate and share data effectively, communication limitations may prevent real-time?. Is it important to avoid redundancy and ensure all areas are explored? (coordination between agents).

ii. *Solution:* Pattern Mining is applied to help in detecting the area for exploration. Reinforcement Learning is used to dynamically learn from interactions with the environment and other agents. Communication and Data Sharing: Clustering and classification techniques can be used to categorize regions based on the likelihood of finding rock samples.

i. *Discussion:* The Effect of Cooperation on Data Quality depends on the reliability of the data shared between agents. Data fusion can combine data from different agents, improving the overall understanding of the terrain. Optimizing Data Flow, to avoid data overload, agents can use filtering algorithms to prioritize communication and only share crucial data (e.g., when a sample is found or a new obstacle is discovered). Scaling Cooperation: As more agents are added, the amount of data shared increases exponentially. *Distributed* learning techniques can be used to handle large-scale coordination while minimizing communication overhead.

C. Subsumption Architecture (for Both Cooperative and Non-Cooperative Agents)

ii. *Problem:* Multiple Objectives, Agents have multiple competing goals. Balancing these goals in a dynamic environment is challenging. Limited Data on the Terrain, agents must rely on real-time sensory data, which can be sparse and noisy.

iii. *Solution:* Reinforcement learning can be applied to allow agents to learn from their environment. *Clustering* algorithms can help classify areas into safe and unsafe areas, also the clustering algorithms can determine the regions with high or low probability of rock samples. Data fusion techniques can be used to combine their knowledge of the terrain.

iv. *Discussion:* Priority Conflicts between agents in Dynamic Environments allow for quick prioritization. We can improve the system by predicting obstacles or samples. Reinforcement learning can adapt an agent's behaviors over time to collect more rocks. We can increase the effective exploration over repeated missions and using the combination of pattern recognition, prediction, and subsumption architecture.

VI. CONCLUSION

Incorporating data mining algorithms into 'Mars exploration experiments' shows a hopeful way to boost the performance and decision-making abilities of autonomous agents on Mars. Such techniques as these Techniques: clustering, reinforcement learning, and pattern mining are used to solve challenges such as navigating unfamiliar terrain. The data mining algorithms allow agents to process large data collected from sensors and then apply a processing step to make real-time decisions, even with incomplete and noisy information. Data mining can help in communication between agents, resulting in more effective sample collection and a greater chance of mission success. Thus, data mining algorithms are not just beneficial but essential in developing intelligent, cooperative, and autonomous systems for Mars exploration vehicles.

DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

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