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MACHINE LEARNING FOR MARS EXPLORATION

Abhishek Kumar
Department of CS & IT
Jain (Deemed-To-Be University)
Bangalore, India

Dr. Kamalraj R
Professor
Department of CS & IT
Jain (Deemed-To-Be University)

Abstract- **Machine learning (ML) is a rapidly evolving field of artificial intelligence with the potential to revolutionize Mars exploration. ML algorithms can be trained to learn from data and make predictions, even in complex and uncertain environments. This makes ML well-suited for a variety of tasks in Mars exploration, such as data selection and prioritization, data collection, data analysis, robotic control and navigation, planning and scheduling, fault detection and diagnosis, and science discovery. Although ML has the potential to revolutionize Mars exploration, numerous obstacles still need to be overcome, including the restricted computational capacity of spacecraft, erratic contact with Earth, the unpredictable Martian environment, and ethical issues. ML is a strong tool that can play a bigger role in the future despite these difficulties.**

*Keywords—***Machine Learning, Mars Rover, Mars Exploration.**

I. INTRODUCTION

The study of algorithms that "learn" or "improve" their performance using gathered data is known as machine learning. Machine learning algorithms are a useful tool for researching various phenomena across many commercial and scientific fields due to their capacity to acquire, analyse, and characterise complicated data patterns [1]. As discussed in section 3, machine learning techniques have also been effectively used to analyse data from spacecraft and other spacecraft. Because of the risk to human astronauts, the expense of maintaining astronaut safety and health, and the distance from Earth, space missions are frequently conducted remotely. There are some parts of space that are unpleasant, hazardous, remote, and difficult for humans to explore.

Additionally, long communication distances between spacecraft and Earth result in two obstacles: a limit on the amount of data that can be transmitted due to bandwidth restrictions at long distances results in discarding data in order to make up for the low bandwidth, which wastes time and productivity. Autonomous robotic agents like rovers are desirable for space exploration because of these dangers and disadvantages [2]. Mars exploration is also a data-rich subject, with next missions planned to gather larger and more detailed datasets than ever before, thus boosting the total amount of data already available and the frequency of new observations. Machine learning data analysis approaches can be used to solve these data analysis problems.

Before ML is extensively employed in Mars exploration, a number of issues must be resolved. The limited computational capacity of spacecraft is one issue. It is crucial to create new, more effective algorithms because training and deploying ML algorithms can be computationally expensive. The poor communication link between Earth and Mars presents another difficulty. Sending data back and forth for the purpose of ML model training and evaluation may become challenging as a result. Additionally, because of how unpredictable and tough the Martian environment is, it can be challenging to create ML models that are resistant to unforeseen changes.

In spite of these difficulties, ML has the power to completely change Mars exploration. Future Mars exploration missions should anticipate to use more and more machine learning (ML) as ML methods and technologies advance.

II. LITERATURE STUDY

For establishing a foundational understanding of Mars, this section will present an overview of the planet's fundamental atmospheric and geological characteristics. The introduction will outline Mars' general characteristics or phenomena as well as exploration-impeding barriers. It will be explained why it would be advantageous to resolve uncertainties, or aspects or phenomena of Mars that have not yet been discovered or understood.

2.1 Atmospheric Features

At the surface, Mars' atmosphere is primarily made up of carbon dioxide (95%) along with other gases like argon, molecular oxygen, molecular nitrogen, and carbon monoxide (0.06%). Trace amounts of methane also exist in varying concentrations. These gases have been seen to fluctuate in amount from their seasonal averages depending on the sea son by the Sample Analysis at Mars (SAM) instrument onboard the Curiosity Rover [5], [6], with molecular oxygen fluctuating by an average of 13% [4].

An oxidizing atmosphere characterizes the Martian atmosphere. The iron oxide of the Martian surface material is corroded by O2 in the atmosphere, giving the planet its distinctive red color. Like Earth, the Martian atmosphere corrodes some metals and destroys others. For instance, the Curiosity Rover's wheels deteriorated after landing on Mars in part because of the planet's oxidizing atmosphere [4], [6].

2.2 Oxygen Level Variations in the Martian Atmosphere

The amount of oxygen in the Martian atmosphere fluctuates over the course of a year. In comparison to the 21% oxygen concentration in the Earth's atmosphere, the average oxygen concentration is substantially lower at roughly 0.16%. The seasonal cycle is one of the most important elements that influences the oxygen content of the Martian atmosphere. The oxygen content rises by around 30% over the Martian spring and summer. This is due to the polar ice caps' water ice sublimating in response to sunshine, which releases water vapour into the atmosphere. The sun's UV rays then interact with the water vapour to create ozone, which eventually decomposes into oxygen and other gases [6].

The dust cycle is another element that influences the oxygen content of the Martian atmosphere. The amount of UV radiation that reaches the surface is decreased when there is a lot of dust in the atmosphere because it scatters sunlight. This may result in a decrease in the rate of ozone formation and, consequently, a drop in the oxygen level.

Additionally, it has been noted that the oxygen content of the Martian atmosphere changes throughout time. For instance, data collected in 2009 by the Mars Reconnaissance Orbiter revealed that the oxygen content has dropped by 10% since the early 1990s[2]. The causes of this persistent decrease in oxygen levels are still a mystery to scientists. A variety of consequences for Mars exploration result from fluctuations in the oxygen content of the Martian atmosphere. For instance, humans on Mars have trouble breathing due to the low oxygen levels. The performance of scientific instruments and spacecraft systems can also be impacted by variations in oxygen levels.

To better understand its variability and the consequences for Mars exploration, scientists are still investigating the oxygen content of the Martian atmosphere.

2.3 Methane's origins in the Martian atmosphere is unknown.

One carbon atom and four hydrogen atoms combine to form the simple organic molecule known as methane. It is a far more potent greenhouse gas than carbon dioxide and can act as a precursor to more intricate organic compounds.

The Martian atmosphere has been shown to contain methane, but its origin is still a mystery. There are several plausible theories, including the following:

Geological activity: When water interacts with ultramafic rocks, a process known as serpentinization occurs, which can result in the production of methane. Methane can be created via this procedure by reacting hydrogen gas with carbon dioxide.

Microbes: Microbes like methanogens can also create methane. Methanogens are a particular kind of bacteria that can create methane from a range of organic substances, such as carbon dioxide and hydrogen gas.

Comets and asteroids: Both of these bodies have the potential to bring methane to Mars. Methane and other organic chemicals are present in these frozen bodies, and when they collide with the surface, they can release these molecules into the Martian atmosphere.

Which of these sources is the most plausible source of methane on Mars? Scientists are still attempting to answer this question. Measuring the methane's isotopic makeup is one approach to do this. The various isotopes of the constituent elements are referred to as a substance's isotopic composition. Measuring the isotopic composition of methane can help to determine its source because different sources of methane have different isotopic compositions.

Searching for other indications of life or geological activity is another method for figuring out where the methane on Mars comes from. For instance, it would be more plausible that the methane is originating from a biological source if researchers were to discover methanogens on Mars.

Since methane could be an indication of life, scientists have been intrigued by the discovery of the gas on Mars. A biosignature is an element created by living things, such as methane. Methane can also be created by non-biological mechanisms, it's vital to remember that. Methane is not a sign of life, hence its finding on Mars does not prove it.

2.4 Distribution of clouds on Mars

The coldest period of the Martian year, when the planet is in its eccentric orbit and is farthest from the sun, is when Martian clouds normally occur. The Opportunity rover's cameras, however, have recently recorded Martian clouds at higher heights and earlier in the Martian year than expected [4]. Understanding the spatial distribution and time of Martian clouds would lead to a clearer understanding of the Martian hydrological cycle and how the Martian atmosphere functions because the positioning and timing of Martian clouds are presently different from predictions.

The Martian spring and summer are when water ice clouds are most prevalent because sunlight causes the polar ice caps' water ice to sublimate, releasing water vapour into the atmosphere. The resulting ice crystals from the condensation of the water vapour give rise to clouds. The dust cloud is another form of cloud that can be seen on Mars. Tiny dust particles that have been carried into the sky by the wind or other mechanisms make form dust clouds. The southern hemisphere summer is when Martian dust storm season occurs, and at this time, dust clouds are most prevalent on Mars in the equatorial and low-latitude regions.

The climate of Mars may be significantly influenced by the dispersion of Martian clouds. By absorbing and reflecting sunlight, clouds can change the Martian atmosphere's temperature. The quantity of UV light that reaches the Martian surface can likewise be impacted by them. The Martian water cycle may also be influenced by clouds. The Martian atmosphere may be exposed to water vapour when clouds precipitate, which may then condense and create fresh clouds. Polar ice caps may also be formed as a result of clouds.

III. DATA ANALYSIS OR MARS EXPLORATION USING MACHINE LEARNING

To find, evaluate, and prioritise data for downlinking to Earth, the Onboard Autonomous Science Investigation System for Opportunistic Rover Science (OASIS) framework is used by Mars rovers. Three key functions of OASIS are featuring extraction from images, data analysis and prioritisation, and planning and scheduling new sequences based on the analysis of the data [5]. Using machine learning methods, terrain features are found in photos [5]. Following the determination of the terrain target, the physical characteristics of the terrain are categorised using elements including albedo (a metric for surface reflection), size, and form variation.

After analysing rover Navcam imagery of dust devils and clouds, the OASIS programme (also present in AEGIS, Mars Exploration Rovers (MER) downlinks sections of images or whole images only having targeted or desired elements [7]. Before installing OASIS on the MER rovers, the rovers downloaded the whole image sets after capturing sets of photographs at predetermined intervals. Due to image collecting at set periods, there was little possibility for data acquisition of specified, and typically uncommon, occurrences like dust devils or clouds. Intense bandwidth reductions were made possible by the adoption of this command, known as WATCH, which extended the time window for recording the desired phenomenon and reduced the number of sent photographs [6].

Since its launch in 2004 [2], the Mars Express (MEX) spacecraft of the European Space Agency has been exploring the surface of Mars and carrying out science operations from orbit, including locating evidence of the existence of subsurface Martian water using its Mars Radar for Subsurface and Ionospheric Sounding [1]. Electricity produced by the solar panels on the MEX orbiter and stored in batteries allows it to operate even when the sun isn't shining [2], [4]. Only a small percentage of the total electric power generated is left over for scientific activities since the autonomous thermal system of MEX requires most of it to keep all the instruments onboard MEX at the proper temperature.

The power consumption of the thermal system, which varies depending on elements like spacecraft heat and instrument heat, must be predicted to distribute the total energy between the planned scientific procedures and the thermal system effectively. Reference [5] describes a machine learning model that was trained using data from the thermal system and three Martian years of telemetry, including the thermal system's measured electric current, to forecast the values of the electric current required by the thermal system. However, because the raw data contains data in formats that machine learning algorithms cannot interpret and has incompatible temporal resolutions, it cannot be used to train machine learning algorithms at first.

Onboard the Mars Reconnaissance Orbiter, the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) employs detectors to look for aqueous mineral residue. For a better understanding of Mars, the previous CRISM discovery of water minerals on the planet's surface were crucial [5].

However, CRISM primarily found common minerals and mineral phases, not secondary or accessory phases [7]. The Northeast Syrtis region and the Jezero crater landing location have both been linked to mineral findings that indicate the presence of water. Reference [7] have created machine learning methods for automatic mineral discovery of less frequent minerals in CRISM collected data.

IV. FUTURE APPLICATIONS OF MACHINE LEARNING FOR MARS EXPLORATION

Autonomous exploration and discovery**:** By deciding where to go and what to look at, rovers and other spacecraft might explore Mars autonomously using ML algorithms. In comparison to the current capabilities of human-controlled rovers, this would enable them to explore more areas and make more discoveries.

Making decisions in real time**:** Using ML algorithms, rovers and other spacecraft may be able to decide in real time how to react to environmental changes. They would be able to respond to unforeseen situations more skilfully as a result of being nimbler and more adaptive.

4.1 Human-robot collaboration

Human-robot collaboration (HRC) is a form of cooperation in which robots and people cooperate to accomplish a common objective. Space exploration, industrial, and healthcare are just a few of the applications for HRC. It can be applied to Mars exploration to boost mission efficacy and efficiency. Humans can concentrate on activities that call for creativity and problem-solving abilities while robots can be deployed to carry out dangerous or repetitive duties.

A third strategy is to employ a hybrid strategy that blends autonomy and teleoperation. A robot, for instance, might be trained to do a task on its own, but a human operator might be on hand to take over if necessary. Mars exploration could undergo a huge transformation thanks to HRC. Humans and machines can do more together than they could separately.

The following are some instances of how HRC might be use in Mars exploration:

Robotic exploration of dangerous or inaccessible locations: Lava tubes and canyons on Mars are examples of dangerous or inaccessible regions that can be explored by robots. This would enable people to gain more knowledge about these areas without endangering themselves. Robots can be used to do scientific analysis, including sample collection and testing. Human astronauts may then concentrate on other responsibilities, like planning and exploration, because of this.

Construction and upkeep: On Mars, rovers, habitats, and other infrastructure can all be built and maintained by robots. This would make it possible for people to settle permanently on Mars.

Although HRC is still in its infancy, it has the potential to completely change Mars exploration. Humans and robots can do great things when they cooperate. Future rovers and other spacecraft could explore Mars independently, decide in real-time how to react to environmental changes.

V. CHALLENGES & SOLUTIONS

Spacecraft have limited processing capabilities, which can make it challenging to run sophisticated machine learning (ML) algorithms. Communication with Earth is unreliable, which might make it challenging to develop and use machine learning (ML) models. The uncertain Martian environment can make it challenging to build machine learning (ML) models that can generalise to new conditions. A variety of ethical issues need to be considered while using ML to explore Mars, such as the possibility of prejudice and the requirement to make sure that ML systems are in line with human values.

Here are some possible answers to these problems:

Creating more effective machine learning (ML) algorithms is one solution to the problem of limited computational resources on spacecraft. Another strategy is to use distributed computing, where the ML algorithm is executed on various computers or spacecraft. One solution for Unreliable communication with Earth is to train machine learning models on Earth before deploying them to spacecraft. A different strategy is to employ federated learning, in which the ML model is trained using data that is dispersed over numerous computers or spacecraft.

VI. CONCLUSION

This paper has highlighted the benefits of applying machine learning techniques to Mars exploration. Machine learning is already being used by a number of spacecraft intended for Mars exploration to prioritise data selection, gather data, and analyse data. Furthermore, machine learning techniques are used on Earthbound computers to analyse raw Martian data. Further application of machine learning techniques in Mars spacecraft could potentially boost the capabilities of present and future Mars exploration missions by enhancing path-planning to conserve spacecraft energy and energy prediction to improve spacecraft path planning. Further applications of machine learning techniques to analyse Martian data will expedite the study of Mars imagery or samples collected on Mars, lowering unproductivity, and saving time because automation would eliminate the need for manual data analysis.

The problem of human risks for Mars

exploration is mostly resolved by additional applications of machine learning techniques for in-situ Mars exploration.

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