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The Receipt and Analysis of Weather Data in a Simulated Martian Environment

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Abstract

Mars' first colonies could interact with a network of weather satellites orbiting the Red Planet to receive real-time weather data and be warned about incoming atmospheric and weather conditions. Currently, Martian weather information is only provided by the Mars Reconnaissance Orbiter. In the near future a constellation of Martian weather satellites, discussed in this paper, will have to be established to adequately provide weather data to incoming habitants. By adapting and miniaturising the Earth weather communication technology of Automatic Picture Transmission (APT) and High Resolution Picture Transmission (HRPT) for Martian weather satellites, this paper proposes an adaptive communication system to distribute and analyse Martian weather data. Trials designed to be conducted at Flashline Mars Arctic Research Station, a Mars analog habitat, assess the feasibility of using proposed APT and HRPT ground stations on Mars.

Since the invention of APT, ground station technology has greatly improved. While APT receiving technology is typically more robust relative to HRPT receiving technology, the HRPT technology provides higher resolution images. An amalgamation of adaptive APT and HRPT receiving technologies allows for the use and deployment of different antennas for various weather conditions such as dust storms and thermal tides. After reception of weather data, machine learning algorithms are used in the analysis and prediction of future hazardous weather events on Mars.

By tracking spacecraft that employ APT and HRPT transmission, terrestrial ground stations can be tested as they would be on the Red Planet. By tracking NOAA weather satellites, which transmit both APT and HRPT signals, this paper explores the use and deployment of adaptive APT and HRPT receiving ground stations to receive weather data from orbiting satellites within a Martian environment. Studying the difficulties encountered through the testing proposed in this paper leads to an augmented understanding of weather data receipt, processing, and analysis on Mars.

Keywords: Mars, weather analysis, machine learning, ground station, risk mitigation

Acronyms/Abbreviations

Automatic Picture Transmission (APT)
High Resolution Picture Transmission (HRPT)
Solar Particle Event (SPE)
Ultra High Frequency (UHF)
Low Mars Orbit (LMO)
EELV Secondary Payload Adapter (ESPA)
Evolved Expendable Launch Vehicle (EELV)
Galactic Cosmic Ray (GCR)
Short-term Prediction of Research and Transition (SPoRT)

1. Introduction

Humanity is progressing towards Martian civilization; however, if humanity intends to survive on Mars they must be readily informed of hazardous phenomena on the red planet. From solar particle events (SPEs), to dust storms, the Martian environment contains unpredictable challenges for human activity. It is apparent that future Martian civilizations will need a suitable telecommunications infrastructure to notify citizens of hazardous environmental phenomena.

While this infrastructure has been considered in the past [1], further research must be explored to ensure adequate risk reduction. The receipt and analysis of environmental data from Martian orbiters is of utmost importance for future Martian civilizations and these systems will have to be adequately tested on Earth to ensure their efficiency on Mars. These systems will aid in risk mitigation by enabling the prediction of future environmental and weather hazards in a Martian climate.

2. Future Martian Satellite Systems

While telecommunications protocols will be necessary on Mars, they may be less effective without a satellite system to capture and relay environmental data.

Currently, there are eight active Martian orbiters. Most of these satellites communicate with surface landers and rovers via the Ultra High Frequency (UHF) band, and with Earth via the X band (shown in Table 1) [2].

Table 1. Active satellites in Martian orbit

Agency	Satellite	Downlinks
CNSA	TianWen-1 orbiter	Orbiter-lander: UHF Orbiter-Earth: X-band
NASA	Mars Reconnaissance Orbiter	Orbiter-lander: 435-450MHz Orbiter Earth: ~8GHz
NASA	Mars Odyssey	Orbiter-lander: 435-450MHz Orbiter Earth: ~8GHz
NASA	MAVEN	Orbiter-lander: 435-450MHz Orbiter Earth: ~8GHz
ESA	Mars Express	Orbiter-lander: UHF Orbiter-Earth: X-band
ESA	ExoMars Trace Gas Orbiter	Orbiter-lander: UHF Orbiter-Earth: X-band
ISRO	Mars Orbital Mission	Orbiter-Earth: S-band
UAESA	Mars Hope Orbiter	Orbiter-Earth: X-band

While this infrastructure works for sending Martian data to Earth, transmissions between the Earth and Mars take four to twenty four minutes[3]. If humans intend to colonise and explore Mars, a self-sustained telecommunication system must be implemented around the red planet.

One proposition has been to establish an areostationary satellite above the surface of Mars to relay communications with Earth. On top of this, due to its stationary nature, an areostationary satellite could provide real time environmental and weather data immediately. However, areostationary satellites would have to operate at 17030 km above the surface of Mars [1]. Due to this, larger slant ranges would affect surface-orbiter links, requiring higher frequency transmission, possibly in the Ka band [1]. This poses attenuation problems due to dust storms which are discussed further in section 4.2. To combat this, a combination of Low Mars Orbit (LMO) satellites and areostationary satellites may be a best choice to ensure adequate data transmission at all times. With regards to LMO satellites, multiple proposals have been suggested. Notably, a constellation of microsatellites or nanosatellites could provide numerous daily profiles of the red planet [4]. Currently, a constellation of 2-6 microsatellites appears feasible for an ESPA (EELV (Evolved Expendable Launch Vehicle) Secondary Payload Adapter) launch platform [4]. Sun-synchronous orbit is possible about Mars [5]. This orbit would provide great benefit in allowing the observation of the entire Martian surface. These satellites would aid in the prediction of future environmental and weather events by providing environmental data of the entire Martian surface. Hazards such as dust storms and SPEs could be predicted well in advance, a concept discussed in section 5.

3. Threats to Future Martian Civilizations

There are many weather phenomena which must be tracked and predicted to minimise risk imposed on crew exploration on the red planet. Through use of Martian orbiters and ground telecommunications systems, the risk of the following hazards may be mitigated.

3.1 Dust Storms

Dust storms on the red planet are much more severe than those on Earth and they pose many problems for future Martian settlements. The largest of these problems is the reduction in solar power caused by the obscuration of the sun for solar cells. Although nuclear power is feasible, humans would still have to clear dust from thermal radiators on a regular basis [6]. Dust has also been known to interfere with fans, filters, and regenerative air and water systems which poses a threat to life support systems on Mars.

Other problems may arise when considering the deployment of Martian rovers. Rovers are not able to store as much electrical energy as a stationary habitat due to storage constraints. The use of solar power could mitigate this load, though the problems with solar-powered rovers would be similar to the problems with solar-powered stationary facilities . While fuel-cell powered rovers have been flown before, they pose other problems such as overheating, as was seen on the Apollo rover [6].

The ability to predict incoming dust storms would aid in exploration preparation to reduce the time in dust storms and increase time in the sun. Additionally, hazard detection and route navigation could be optimised for exploration over large distances. Navigation equipment will be especially useful for manoeuvring over terrain during low visibility dust storm conditions. These surface navigation systems as well as hazard detection and avoidance, could be provided by Martian orbiters.

3.2 Radiation

On Mars there are two main sources of radiation: galactic cosmic rays (GCRs) and solar particle events (SPEs). SPEs are the most significant radioactive threat to future Martian settlements. They have been known to fluctuate with the solar cycle, and are generally unpredictable. As well, they develop rapidly, and generally last no more than a few hours [7]. Radiation exposure would increase the risk of cancer and could even lead to bone marrow syndrome or acute radiation sickness [7]. In worst-case scenarios, SPEs could emit particles with several giga electron-volts of electricity per atomic mass unit which would be immediately lethal in free space [7]. Due to this, steps must be taken to ensure adequate radiation risk mitigation. These steps are further discussed in greater detail in section 6.

4. Telecommunication Hazards

While it's clear that telecommunications will be required on Mars to mitigate environmental hazards to humans, one must also look at the hazards posed on said telecommunications systems to ensure proper use and deployment.

4.1 The Ionosphere

While the ionosphere does pose a threat to wave propagation, they tend to affect lower frequencies more than higher ones. It has been noted that the Martian ionosphere affects frequencies below 450Mhz, above this the ionosphere is almost transparent [8]. Seeing as the orbiter-lander communications will take place around 440Mhz, in accordance with the Proximity-1 Space Link Protocol [9], communications may be slightly affected.

4.2 Dust Storms

Dust storms have been known to affect wave propagation, however, in contrast to the Martian ionosphere, this tends to affect higher frequencies rather than lower ones. It has been found that large dust storms can cause attenuation of at least 3dB to Ka-bands or higher [8]. An adaptive system is required to mitigate attenuation during dust storms; This is discussed further on in section 6.

5. Hazard Prediction

Hazard prediction will be crucial in risk mitigation on the red planet. Through use of machine learning, it is possible to predict most Martian hazards. Despite this, work still needs to be done to ensure the adequate prediction of all environmental threats on Mars.

5.1 Dust Storms

NASA's Short-term Prediction of Research and Transition (SPoRT) has worked with the NOAA to develop systems for determining dust storms on terrestrial surfaces. Using the GOES-R satellite, they have been able to develop composite RGB images of atmospheric phenomena [10] (see Fig. 1.). Using these images, one can predict dust storms. However, it is somewhat difficult to distinguish clouds or smoke from dust storms in the images [10]. Furthermore, if surface temperatures and dust temperatures are equivalent, such as at night, it becomes increasingly difficult to distinguish dust storms [10].

Machine learning solves these problems by looking for relationships humans would otherwise not notice. By analysing large volumes of data neural networks can effectively find trends in data from which they can better predict dust storms.

The random forest model used by SPoRT was able to correctly label 85% of dust pixels and 99.96% of no-dust pixels in a validation data set [10]. With this software, humanity will be able to predict most Martian dust storms, ultimately decreasing risks for future settlements on Mars.

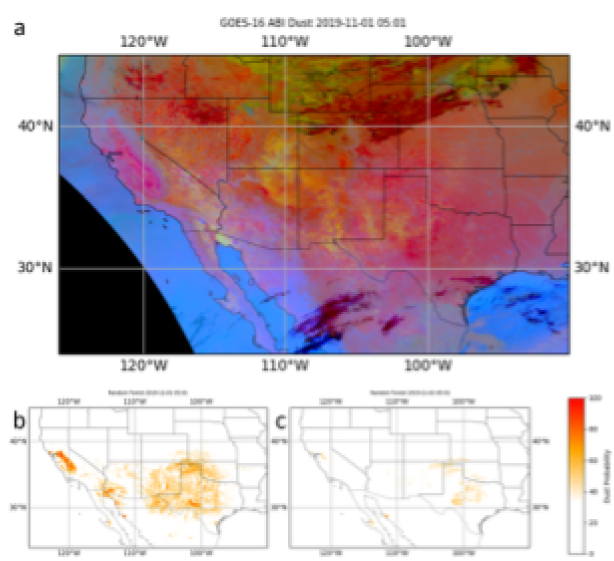

Fig. 1. An RGB image of atmospheric phenomena [11]

5.2 Solar Particle Events (SPEs)

Solar Particle Events are large increases in particle flux produced by the sun. These contribute to radiation on Martian surfaces and pose many risks to humans, as discussed in section 3.2. If humanity can predict the occurrence of SPEs, they can mitigate radiation risk for future Martian civilizations. Machine learning has been proposed as a method for determining the likelihood of SPEs. Through use of a neural network, it is possible to predict solar flares (eruptions of electromagnetic radiation often accompanied by SPEs) to an accuracy of 89% [11]. Ultimately higher accuracy is required to reduce Martian risk.

6. Proposal

A future Martian colonisation will require an adaptive telecommunications system to communicate with Martian satellites. One proposition is to have antennas in three bands: Ka-band, X-band, and UHF.

Seeing areostationary satellites as a likely element of future Martian satellite constellations, the construction of an antenna capable of receiving in the Ka band for use in communicating with areostationary weather satellites around Mars will be important. While X-band transmission is possible between an areostationary orbiter and a surface antenna, the Ka-band offers data rates more than 10 times higher [12].

The X-band can however be used when dust storms cause sizable attenuation in the Ka-band. While data rates would be lower, they would still get through the dust storms and provide continuous data from an areostationary orbiter.

An antenna in the UHF band will be used to communicate with LMO satellites. The largest benefit of these satellites will be their ability to provide high resolution images of the Martian landscape for use in environmental analysis. As well, as the satellites are orbiting Mars, they can capture images from different sides of the planet, allowing for the prediction of oncoming dust storms before settlements are struck.

Carleton University's ground station (see Fig. 2.) has been testing these concepts on Earth by receiving signals from NOAA satellites. A homebrewed ground station incorporates a multitude of subsystems to track satellites and receive transmissions. These include a pointing subsystem for controlling azimuth and elevation, and an adaptable radio frequency subsystem, among other things. The pointing subsystem makes use of stepper motors for precise pointing and is controlled with self-made software, NeedleGUI, built in Python. With two line elements imported from GPredict, the Carleton team is capable of tracking low earth orbit) and geosynchronous equatorial orbit) satellites across the horizon, allowing us to capture transmissions from the satellites below.

In selecting a directional antenna for pointing, a Yagi antenna configuration was chosen to reduce cost. To receive HRPT transmissions, a 20-element horizontally polarised Yagi antenna was chosen. The antenna is centred around 1702.5 MHz, has a gain of 17.54, and a 3 dB beamwidth of 23.4 degrees. When receiving HRPT signals a low noise amplifier is employed with a centre frequency of 1688 MHz with an 80 MHz bandpass region. The minimum gain in the bandpass region is 30 dB[10]. For receiving HRPT signals a Hack RF is the software defined radio used. The Hack RF has a frequency range of 1 MHz to 6 GHz and supports bandwidth as high as 8 MHz[12].

To simulate the receipt of areostationary orbiters, a challenge was taken on to receive a signal from GOES-16, a geostationary weather satellite deployed by the NOAA. The satellite broadcasts high resolution images as well as instrument data for use in environmental analysis. Using an in-house developed ground station with commercial-off-the-shelf hardware and open-source software, the Carleton team successfully received and decoded the signal broadcasted by GOES-16. The decoded information can be used for weather and dust storm predictions as demonstrated by SPoRT [10].

To simulate the receipt of LMO satellites, the team has been receiving signals from NOAA-15, 18 and 19 satellites which transmit Automatic Picture Transmission (APT) and High Resolution Picture Transmission (HRPT) weather images. The ground station is capable of tracking these satellites across the

Fig. 2. Carleton's ground station with a 20 element Yagi, 4 element Yagi, and a parabolic dish

sky, allowing us to receive high resolution imagery. The downside of this though is that there is not always a satellite above. Frequently, one has to wait not only for a satellite to pass over their position, but for one to pass at an elevation high enough for adequate reception. To further an understanding of Martian satellite communication, tests in a Mars analog habitat have been proposed. The main objective would be to explore unforeseen events and hazards which could be posed by a Martian environment. Tests at this Mars analog will help ensure proper ground station deployment and signal receipt to minimise the risk of problems on the red planet. Currently, the Flashline Mars Arctic Research Station is a favourable prospect for testing. Located in the Baffin region of Nunavut, Canada, the Mars analog presents geological and temperate conditions similar to those on Mars.

7. Conclusion

Future Martian settlements have many environmental hazards to be concerned about. With a satellite constellation and adequate telecommunication systems, these hazards can be monitored to reduce their impact on life on the red planet. This study delved into the problems faced on Mars, both for humans and telecommunications systems, and how best to address them in future missions.

It is evident that a satellite constellation is required to suit needs for future Martian civilizations. This constellation includes areostationary orbiters for constant data transmission, and LMO satellites for use with UHF antennas. To receive signals from these satellites, adaptive telecommunications will have to be constructed.

The main threat to Martian signal reception is dust storms. Unfortunately high frequency signals experience loss in dust storms and seeing as one would be communicating with an areostationary orbiter in the Ka band, dust storms may break this connection. In these times UHF antennas would have to be used, demonstrating the need for adaptive ground stations.

If one can receive environmental data from orbiting Martian satellites, one can mitigate risks involved by predicting and foreseeing disasters before they happen using machine learning. Ultimately, the receipt and analysis of weather data on Mars will help progress human exploration of the red planet.

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