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Remote Sensing of The Martian Surface: Observation Techniques and Microsatellite Design

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Abstract: *This paper provides a detailed review of methods for remote sensing of the Martian surface and outlines a design for a microsatellite aimed at Mars exploration. By combining past findings from both orbital and Earth-based observations with a new microsatellite structure, we pinpoint key challenges and strategies for understanding planetary surfaces. The study highlights the importance of interpreting thermal, radar, and reflectance data. It also suggests a strong, budget-friendly microsatellite platform that uses commercial off-the-shelf (COTS) technologies for collecting scientific data in Martian orbit.*

Keywords: Mars, remote sensing, microsatellite, thermal inertia, spectral reflectance, radar scattering, deep space communications, attitude control, structural optimization

I. INTRODUCTION

Mars, often called Earth's "sister planet," has fascinated scientists for a long time because it may provide clues about planetary evolution, past habitability, and the necessary conditions for life. As we explore more, remote sensing has become a key method for studying Mars's various surface features without direct contact. Researchers have used data from orbital missions and Earth-based telescopes to gather important information about Martian surface processes, including dust transport, weathering, thermal behavior, and compositional changes.

In the past, large-scale missions have led Martian exploration, relying on complex, expensive spacecraft to collect large datasets. However, recent technological advancements have shifted this approach toward smaller, more affordable platforms like microsatellites. These small spacecraft, equipped with reliable remote sensing tools such as thermal infrared spectrometers and multispectral cameras, can deliver crucial high-resolution data on Mars's surface shape and mineral content at a much lower cost than traditional missions.

This paper combines foundational studies in Martian remote sensing with a new microsatellite design concept meant for planetary observation. It looks at essential observational methods, including thermal inertia modeling, spectral reflectance analysis, and radar-based surface roughness estimation. It also incorporates these insights into creating a lightweight, modular satellite setup. Launched from a mothership, this microsatellite system is designed to operate in Martian orbit and capture valuable data that can greatly improve our understanding of the planet's surface dynamics and geophysical properties.

II. REMOTE SENSING TECHNIQUES FOR MARS

Remote sensing of the Martian surface uses various observational methods to study the physical, thermal, and chemical features of the planet. Since directly sampling the Martian terrain is limited, remote sensing is the main way to investigate large-scale geological and climatic processes. Key techniques include thermal inertia analysis, visible and near-infrared (VNIR) reflectance spectroscopy, infrared emission modeling, and radar-based surface roughness estimation. Each technique offers a unique contribution to understanding the Martian surface environment.

2.1 Thermal Inertia Modeling

Thermal inertia refers to how quickly a surface heats or cools, and it relates directly to the size, composition, and compactness of the surface materials. On Mars, daily temperature changes are affected by atmospheric radiation and surface characteristics. By modeling these temperature cycles, researchers can estimate the thermal inertia of specific areas and, in turn, understand the grain size and physical state of surface materials. Studies indicate that including atmospheric effects leads to lower thermal inertia estimates than previously thought, suggesting the presence of finer-grained surface materials than earlier models proposed.

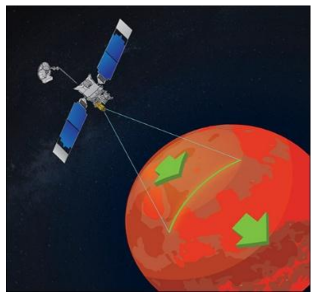

Fig.1:Remote Sensing Techniques

2.2 Reflectance Spectroscopy (VNIR)

VNIR reflectance data help identify mineral compositions by examining how surface materials reflect sunlight at different wavelengths. The reflectance spectra of bright and dark Martian regions show differences mainly due to particle size and scattering behavior, rather than just compositional changes. Using Hapke's reflectance model, researchers simulated how particle size affects observed spectral features. This method showed that correctly interpreting Martian spectral data requires considering the microphysical properties of regolith particles to prevent mischaracterizing surface composition.

2.3 Infrared Emission Modeling

Thermal infrared remote sensing allows for the assessment of surface emissivity, which is essential for determining surface temperature and material properties. A Monte Carlo photon-tracing model was developed to simulate the emissivity of powdered surfaces, taking into account scattering, absorption, and polarization effects. This model accurately replicated thermal emission variations seen in experiments on terrestrial sand surfaces and lunar analogs. The results highlight the need to consider multiple scattering effects and the influence of emission angle in analyzing Martian thermal data.

2.4 Radar Scattering and Surface Roughness

Radar remote sensing provides information about surface roughness at sizes ranging from centimeters to meters. By comparing radar backscatter data with slope distributions measured in the field on Earth, researchers found that common radar scattering models often underestimate the true roughness of Martian terrain. Mixed-terrain radar modeling revealed that the root-mean-square (RMS) slope derived from radar data is a nonlinear average, skewed towards smoother surfaces. These results suggest that radar-derived roughness estimates should be interpreted qualitatively rather than quantitatively.

III. MICROSATELLITE DESIGN FOR MARS REMOTE SENSING

The design of a microsatellite for remote sensing of Mars' surface combines miniaturized technology, mission-specific instruments, and cost-effective deployment methods. Given the challenges of interplanetary travel, like high ΔV requirements, harsh conditions, and limited payload capacities, microsatellite platforms provide a flexible solution for scientific exploration. This section describes the overall structure and subsystem integration of a microsatellite designed for polar orbit around Mars. Its main goal is to observe the surface using imaging and spectroscopic techniques.

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Fig.2:Remote Sensing

3.1 Mission Architecture and Deployment Strategy

Microsatellites have limited propulsion capabilities and cannot achieve interplanetary transfer on their own. A mothership serves as the delivery vehicle, transporting one or more microsatellites to Mars orbit. The mothership carries out the heliocentric transfer, Mars orbital insertion, and subsequent deployment. This approach improves mission reliability, allows for the deployment of multiple satellites at different angles, and adds a safety backup in case of satellite failure.

3.2 Payload Configuration

Mars Colour Camera (MCC): This device maps polar caps, geological features, and surface details by capturing multispectral images.Thermal Infrared Imaging Spectrometer (TIS): It measures heat emissions to determine surface temperature, emissivity, and mineral composition.

3.3 Propulsion Subsystem

The microsatellite uses a monopropellant chemical propulsion system with FLP-106, an environmentally friendly alternative to hydrazine. This system offers a higher specific impulse (260 seconds) and helps with orbit maintenance and adjustments. The propellant and pressurant tanks, made from Ti-6Al-4V titanium alloy, are built into the structure to improve the strength-to-weight ratio. A set of 1-N thrusters provides precise ΔV for periapsis correction due to atmospheric drag.

3.4 Power Subsystem

To meet the satellite's energy needs (~155 Wh/day), the design features:

- 18 Gallium Arsenide (GaAs) triple-junction solar panels, designed to efficiently collect energy in low solar conditions (~493–550 W/m^2 in Mars orbit).
- Lithium-ion battery packs with a capacity of 12,800 mAh for power storage during eclipses.
- Solar Array Drive Assemblies (SADA) for sun tracking and optimal orientation.

3.5 Communication Subsystem

For Earth-Mars communication, the satellite includes:

- IRIS V2.1 Transponder, operating in the X-band (8.4 GHz), developed by NASA for deep-space CubeSats.
- A high-gain reflectarray antenna for long-distance data transfer.
- During planetary eclipses, a low-gain dipole antenna will relay data through existing Mars orbiters.

3.6 Attitude Determination and Control System (ADCS)

The 3-axis stabilized ADCS consists of:

- Star and sun sensors for determining attitude.
- Reaction wheels arranged with redundancy for controlling attitude.
- A 3-axis gyroscope-based inertial reference unit (IRU) for measuring angular velocity.

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- Monopropellant thrusters for handling disturbances and desaturating reaction wheels.

This system ensures the precise pointing of the payload, which is crucial for imaging and spectroscopy.

3.7 Structural Design

The satellite's structure is made from Aluminum 7075-T6 and optimized using Finite Element Analysis (FEA) in ANSYS to endure launch loads (~15 g) while minimizing excess weight. Modal analysis confirms the satellite's natural frequencies do not match those of the launch vehicle, preventing resonance. An iterative topology optimization process reduced the structural mass from 5.37 kg to 3.02 kg.

3.8 Assembly and Mass Budget

The satellite measures 680.73 × 772.85 × 2269 mm³ and has a total launch mass of 21.7 kg, which includes fuel. The weight distribution among subsystems is carefully balanced to ensure stability, effective thermal management, and optimal space utilization. The dry mass is 15.7 kg, providing enough propellant margin for a five-year operational lifespan.

IV. RESULTS & ANALYSIS

The microsatellite design meets all mission requirements for Martian remote sensing.

- Mass & Volume: The total mass is 21.7 kg. Structural optimization reduced the weight by 40% to ensure launch compatibility.
- Structural Integrity: Modal frequencies range from 125 to 345 Hz to avoid resonance. The maximum stress is 2.16 MPa, which is well below the material limits.
- Propulsion: The satellite uses FLP-106 monopropellant. It requires 63.78 g of fuel for each orbit correction, which is enough for a 5-year mission.
- Power System: Eighteen solar panels generate 734 Wh per day, which covers the 155 Wh per day demand and provides a strong eclipse margin.
- Communication: The X-band transponder ensures a link to Earth. The low-gain antenna supports a range of 725 km for relaying data.
- Attitude Control: A 3-axis system with star trackers and reaction wheels provides more than 50 times the required torque authority.

The results confirm that the satellite is lightweight, power-efficient, structurally sound, and able to communicate. This makes it ideal for affordable and reliable Mars surface monitoring.

V. CONCLUSION

The proposed microsatellite provides a small, affordable option for remote sensing of the Martian surface. It combines important subsystems and scientific instruments to gather thermal and visual data while in Mars orbit. With reduced weight, effective power generation, and reliable communication and control systems, the design shows great promise for future low-cost interplanetary missions and educational research projects.

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