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Titan Robotic Mission: Mapping and Sampling of Land and Lake

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Abstract

In quest of exploration and find answers to questions like, Are we alone in the universe? Does life exist anywhere other than Earth? Humanity has sent many deep-space missions beyond the moon and mars to explore unique worlds and perform life sciences. Among such worlds, Titan (Moon of Saturn), having lakes of Hydrocarbon and a possible subsurface ocean, has caught the attention of many planetary scientists to believe in the existence of non-water-based life. To date, Huygens (Probe on Cassini Satellite) is the only probe that successfully landed on the surface of the Titan. This paper walks through a robotic rover mission to explore the surface of Titan with an amphibian boat for methane lake exploration. This rover will be capable of collecting samples from the surface and performing life science to determine composition analysis and relay data back using DTE (Direct-to-Earth) Communication protocol; while the amphibian boat will be able to manoeuvre in the lake and sample liquid methane to determine its chemical compound and possibly find organic life both the vehicle will use RTG (Radioisotope Thermoelectric Generator) for power source and LiDAR for navigation and mapping.

Keywords: Titan Exploration, RTG, DTE Communication Protocol, Sampling, Mapping, LiDAR

Acronyms/Abbreviations

APXS Alpha Particle X-Ray Spectrometer
DTE Direct-to-Earth
DSN Deep Space Network
GCMS Gas Chromatography-Mass Spectrometry
LIBS Laser-Induced Breakdown Spectrometer
LiDAR Light Detection and Ranging
RTG Radioisotope Thermoelectric Generator
UHGA Ultra-High Gain Antenna

1. Introduction

Titan, the largest moon of Saturn, is a world of great scientific and exploration significance. With its dense atmosphere, vast lakes and oceans of liquid methane and ethane, and a surface rich in organic compounds, Titan is a unique and potentially habitable world that has captured the imagination of scientists and the general public alike.

Titan is one of the most intriguing destinations in the solar system, and exploring it can provide valuable new data on the geology, chemistry, and potential habitability of the moon. The data gathered from a Titan exploration mission will contribute to the understanding of the evolution of the solar system, and will provide important clues about the conditions for life in the universe. By exploring Titan, scientists can learn about the role of volatiles and organic compounds in shaping the surface and atmosphere of planetary bodies.

In addition to its scientific significance, Titan is also scientifically important for studying and understanding its contribution to the emergence of life elsewhere in the universe. The moon's unique environment and organic chemistry make it a prime target for searching for signs of past or present life. Furthermore, exploring Titan may provide insights into the early history and evolution of Saturn's system, as well as the formation and evolution of the icy moons in the outer solar system.

2. Previous Missions

Exploration of Titan has been limited thus far, with only a handful of flybys and a single successful landing by the European Space Agency's Huygens probe in 2005. Those handful of flybys were done by the very earlier spacecraft such as Pioneer 11, Voyager 1 and 2, and Cassini-Huygens.

a. Spacecrafts Flybys:

These flybys by Pioneer 11, Voyager 1 and 2 provided valuable information about Titan's atmosphere, geology, and climate and paved the way for more detailed studies of this intriguing moon.

The Pioneer 11 flyby in 1979 was the first ever encounter with Titan and provided initial observation data on the size, shape and atmosphere. The Voyager 1 and 2 flybys in 1980 and 1981, respectively, provided additional information on the atmosphere and surface of Titan and revealed the presence of a thick and mostly nitrogen rich atmosphere, with a haze layer that obscured the surface from view.

b. Cassini-Huygens mission:

The Cassini-Huygens mission was a joint effort by NASA and the European Space Agency, with the goal of exploring Saturn and its moons. Cassini orbited Saturn from 2004 to 2017, conducting numerous flybys of Titan and gathering data on its atmosphere, surface features, and potential for astrobiology.

In 2005, the Huygens probe separated from Cassini and descended to the surface of Titan, becoming the first spacecraft to land on a celestial body in the outer solar system. The probe transmitted data on Titan's atmosphere and surface, including images, temperature and pressure measurements, and data on the composition of the moon's surface. Huygens also discovered liquid methane and ethane on Titan's surface, as well as evidence for possible subsurface oceans. The data collected by Cassini-Huygens has greatly expanded everyone's knowledge of Titan and provided new insights into the conditions necessary for life in the universe.

Although these missions have provided us with a wealth of information about Titan, they have limitations in exploring the lakes and oceans of Titan, which are considered the most scientifically intriguing features of the moon.

One of the main limitations of previous missions to Titan has been their limited ability to explore the surface of the moon. The Cassini orbiter was equipped with radar that was able to probe the lakes and oceans, but it was not able to directly sample the liquids. The Huygens probe, which was designed to explore the atmosphere and surface of Titan, was limited by its short operating life and lack of mobility.

Another limitation of previous missions to Titan was their limited ability to study the composition and chemistry of the liquids in the lakes and oceans. The instruments on board the Cassini orbiter and Huygens probe were not specifically designed for this purpose, and as a result, the data collected on the liquids was limited.

3. Proposed Mission

This paper proposes a robotic mission to map and sample titan surface, lake or oceans using semi autonomous robotic rovers and hovercraft boats. These semi-autonomous Rover will be equipped with various sensors and instruments to conduct in-situ analysis and sample collection to determine the composition of surface material. The hovercraft boat would allow mobility into exploration of the moon's vast lakes or oceans of liquid methane and ethane, providing data on the chemical and physical properties of these liquids and their role in shaping the moon's environment.

The paper also discusses an lander used to safely land on the surface precisely near the landing zone as pre-decided, the lander will be used to deploy the rover as well as the hovercraft boat. The lander will act as an instrumentation cluster for hovercraft, as the hovercraft would only be capable to sample the liquids and navigate while mapping the lake or ocean surface. All the samples collected by the hovercraft will be then analysed by the set of instruments present on the lander. Both Rover and the Lander will be powered by Radioisotope Thermoelectric Generator. (RTG), the hovercraft boat will be powered by a small li-ion battery capable enough to provide 2 hours of mission operation per charge. It can also be recharged with the help of the lander to provide mission flexibility for lake or ocean exploration.

Both Rover and the lander will be capable of Direct-to-Earth Transmission using an Ultra High Gain Antenna, which will be used in transmitting real time images, and data from the rover and the lander directly to earth that will be captured by Ground station equipped with Deep Space Network (DSN).

Goal of this mission will be to explore the land using robotic rover while mapping and navigating the terrain and collecting samples will provide information on the distribution of geological features and their relationship to the moon's geological history and evolution. The data obtained from sample collection and analysis will help us better understand the formation of the moon surface and its atmosphere, and the process that shaped it. The chemical present on the surface will give insights into the moon's potential for prebiotic chemistry and the formation of life. Sample analysis will also provide information on the presence of any subsurface oceans or lakes, which may hint about the moon's potential habitability.

Overall, mapping and sample analysis of Titan's surface may provide valuable data for studying the formation, evolution, and potential habitability of the moon and other planetary bodies in the outer solar system.

Lake or ocean samples analysis from Titan can provide information about the chemical composition and behaviour of the liquids present on the moon's surface. This analysis can help us understand the chemical processes occurring on Titan and the nature of the substances present in the lakes and oceans. The study of the samples can also shed light on the potential habitability of Titan, as the presence of certain chemicals and conditions may be indicative of a favourable environment for life.

Exploring the surface and lakes/oceans of Titan through mapping and sample analysis can lead to significant scientific outcomes. This exploration will give us a deeper understanding of Titan's geology, atmosphere, and potential habitability. The analysis of the surface and lakes/oceans will provide insights into the evolution and history of Titan's atmosphere, surface, and potential interactions with liquid. Additionally, studying the organic compounds found on Titan can give us clues about the origin and evolution of life in the universe. The scientific outcomes of a Titan mapping and exploration mission will greatly enhance understanding of the outer solar system and provide valuable information for future missions to other planetary bodies.

4. Robotic Rover Design and Capability

The terrain of Titan is varied and includes vast dune fields, lakes and seas filled with liquid methane and ethane, cryovolcanoes, and large impact craters. The surface is characterised by a mixture of solid and liquid organic compounds, with a temperature that ranges from about -290°F to -180°F. The terrain is also shaped by geological processes, such as erosion, sedimentation, and tectonic activity. It is considered a harsh environment, with a toxic atmosphere, extreme temperatures, and low light conditions.

The proposed Robotic Rover is capable of traversing through titans sandy dune terrain and has a set of instrumentation suits capable of collecting and analysing samples. The rough terrain of Titan will offer many challenges during mobility for which the rover's wheels are made with wedges to overcome the surface challenges.

The Robotic rover is equipped with Radioisotope Thermoelectric Generator (RTG) for generating power to perform science and keep essential electronics running, to survive the coldest night of Titan the rover will utilise heat generated from RTG to keep its essential electronics running. It will be equipped with Ultra-High Gain Antenna (UHGA) to communicate using Direct-to-Earth Protocol. This allows ground stations on Earth to receive live images and data gathered from sensors.

The environment on Titan is quite challenging and offers a wide range of hurdles, to cope up with its corrosive environment the rover will be equipped with a good amount of anti-corrosive steel to protect its instruments and essential electronics. To collect samples it is equipped with a small Robotic Arm that will assist in collecting and precisely dropping samples in the sampling sections. The Robotic rover offers a wide range of operation and ability to collect and analyse samples from various areas on Titan.

Instrumentation on the rover includes:

1. *Alpha Particle X-Ray Spectrometer (APXS) and Laser-Induced Breakdown Spectrometer (LIBS) -*
   Inspired by NASA's Mars rover missions and ISRO's Pragyaan Rover, APXS is selected to perform an analysis of Titan's surface. The scientific objective of APXS is to determine the major and minor elemental composition of the soil, rock, and other geological material. APXS will search for traces of elements like Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, Cr, Mn, Fe, Ni, Zn, and B. This will help us to determine elemental diversity on the surface by the rover.
   LIBS uses a laser to perform spectroscopy analysis, LIBS will focus on different sets of elements. LIBS will be used to characterise elements like H, Be, Li, C, N, O,Na, and Mg. It uses a high-energy laser pulse to excite the atoms.
   As the content on the surface of Titan is still unknown, APXS and LIBS instrumentation will help us to determine the elemental composition of a particular area on the Titan.

2. *Gas Chromatography-Mass Spectrometry (GCMS) -*
   To narrow down on the gaseous content in Titan's atmosphere. The resulting graph produced by the mass spectrometry will distinguish and quantify the abundance of the elements detected. Gas Chromatography will generate a gradient based on the chemical nature of the impurities inside the spiral tube.

3. *Aerosol Collector -*

The aerosol collector will help us to collect and determine the chemical composition of the aerosol in different regions of the titan. This particular instrument is used on drone boat as well as on the rover, which will help us to identify characteristics of aerosol in both of these locations
The following images in figure 1 shows different views of the Robotic Rover.

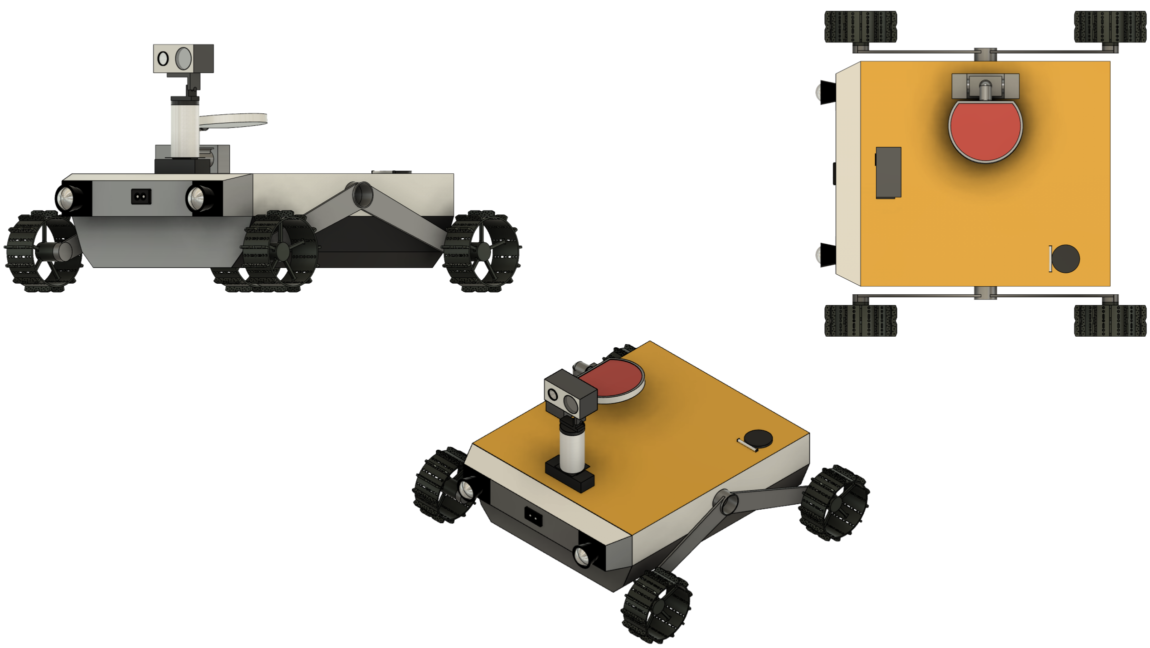

Fig.1. Side, top and front views of the robotic rover

Hovercraft Boat Design and Capability

The hovercraft boat is capable of collecting liquid samples of the lake or ocean while smoothly gliding over the surface of the titan lake or ocean. To do so it generates thrust using the propellers at the bottom of the Hovercraft boat design, it uses one more propeller at the back for navigation and traversing purposes.

The Following design prototype in figure 2 gives away the jist of what the model would look like:

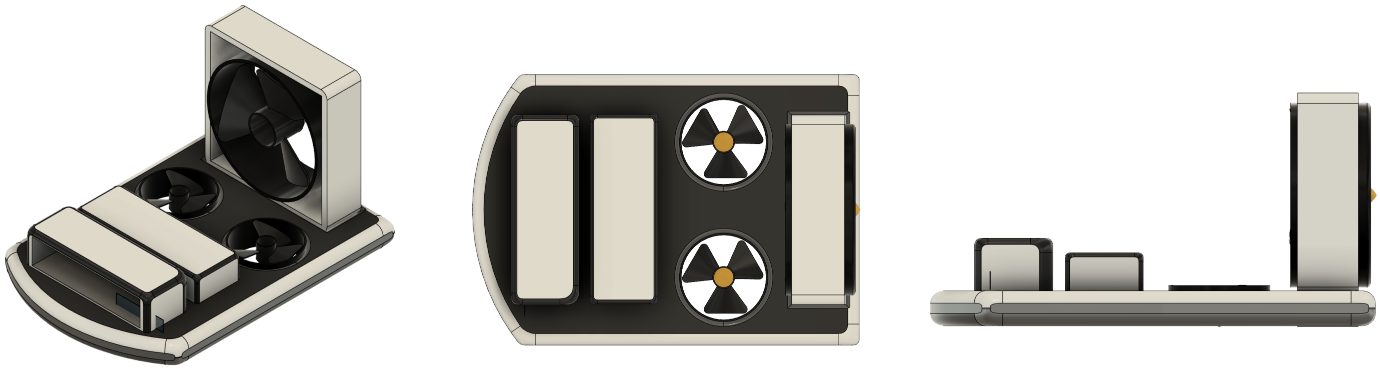

Fig.2. Side, top and angular view of hovercraft boat

6. Lander Design and Capability

The lander plays the most important role right from the initial stage of the mission, after re-entry in Titan Atmosphere the computer on board will be responsible for taking decisions while landing the lander safely and precisely. To do so it is equipped with a camera, lidar and laser based distance sensor to accurately map and fetch distance from ground while selecting the least rough surface possible, for safe landing.

The lander has the robotic rover at the top and the hovercraft boat at the bottom, the robotic rover will make use of tracks to alight from the platform, over the top platform the lander is equipped with its own Radioisotope Thermoelectric Generator (RTG) to generate energy and support essential electronics and instruments to support sample analysis and data transmission of those sample gathered by the hovercraft boat. The bottom platform is used to carry the hovercraft boat, it is purposely placed at the bottom for easy access to the surface without having to use wheel based assist to alight from the lander.

The ideal landing site for the lander will be near the lake or ocean (shore area) after which the robotic rover will traverse to the dunes and the hovercraft boat will have easy access to the lake or oceans of the Titan.

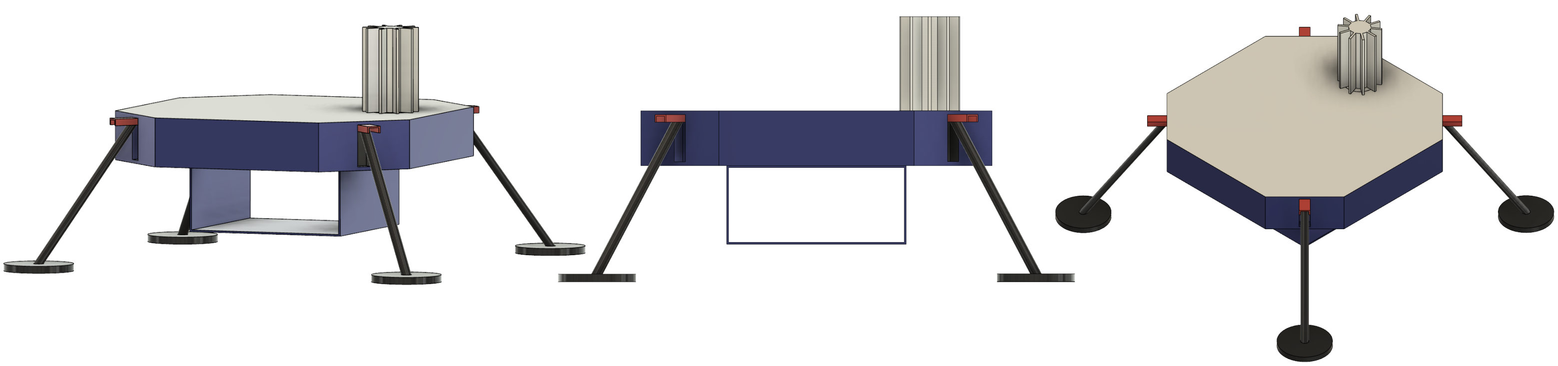

Fig.3. Side, back and angular view of the Lander

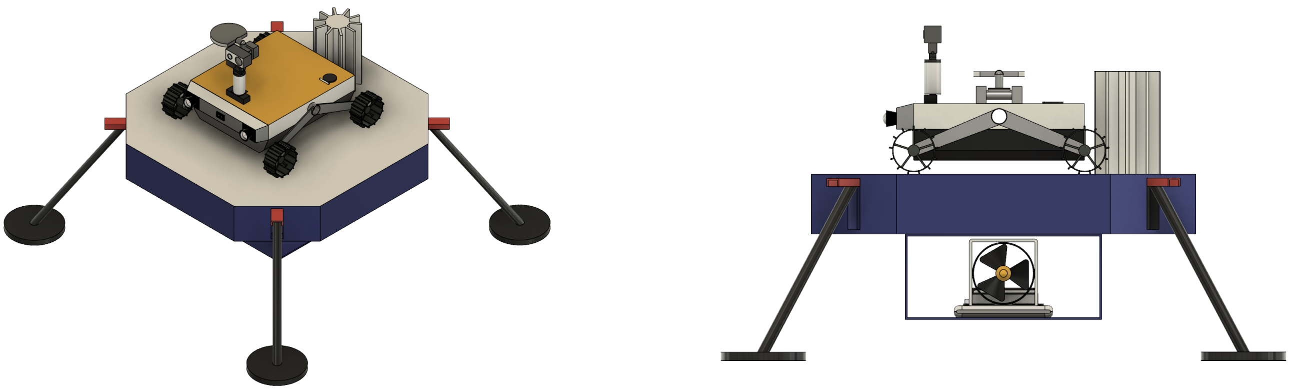

Fig.4. Orthogonal and Side view of final lander assembly with the hovercraft boats

7. Scientific Significance

The robotic rover and hovercraft-based mission to Titan have significant scientific significance as they allow us to explore and study the surface and potential subsurface of Titan in detail. The rover will be equipped with a suite of instruments and tools to perform surface analysis and obtain samples, providing new information about the composition, geology, and potential habitability of Titan.

The hovercraft boat will allow us to study the methane lakes and oceans, providing insights into the hydrocarbon cycle and possible geologic processes that might be shaping the surface of Titan. This proposed mission will also contribute to the understanding of the role of volatiles and organic compounds in shaping the surface and atmosphere of planetary bodies, and their potential for supporting life.

8. Challenges and Limitations

Previously, mobility and operation time was the issue as part of the Cassini - huygens mission which has been significantly overcome by the robotic rover. The main technical challenge presented by this paper is in terms of landing, deployment and operation of the hovercraft boat. The hovercraft boat requires generating lift to move around and as it is going to transverse over the methane lake or ocean manoeuvring will be difficult. Due to the possibility of the liquid motion controlling the boat is a major challenge. Apart from that returning boat back to the lander by locating the land is the challenge with the hovercraft.

Another Major Challenge faced will be with connectivity with earth to continuously relay data back to ground stations. The distance between Earth and Titan, as well as their orbital positions, can pose a challenge in maintaining a direct communication link between the robotic rover or hovercraft boat and Earth. The communication lag time increases with the increasing distance, which can negatively impact the real-time control and data transfer between the spacecraft and ground stations.

9. Conclusion

In conclusion, mapping and sample analysis of the Titan's surface and its lakes and oceans play a crucial role in understanding the formation and evolution of this unique world. By exploring the surface and subsurface of Titan with a robotic rover and hovercraft boat, valuable data can be gathered on the distribution and composition of its surface materials, including ices, organics, and liquids, and how they interact with each other. This data can also help us to understand the role of volatiles and organics in shaping planetary bodies, as well as shed light on the potential habitability of the moon and the possibility of life elsewhere in the universe. The proposed robotic rover and hovercraft boat-based mission to Titan is an exciting opportunity to expand knowledge and answer many of the questions that remain about this fascinating world.

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