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Spherical Mobile Robot for Asteroid Exploration and Defense

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***Extended Abstract*—The asteroid exploration missions not only make contribution to understand the evolution of the solar system and the origin of life, but also provide extremely important material resources for the future long-term large-scale planetary surface exploration, such as the Earth-Moon economic circle [1]. It is of great significance for human beings to carry out asteroid defense and in-situ resource utilization. Mobile robots with relevant payloads are effective means of asteroid surface exploration. However, it is difficult for wheeled or tracked mobile robots to attach and move on the surface of asteroids because of microgravity and unknown terrain. The effective gravitational field of the wheeled mobile traction system is between 1g and 0.1g. The gravitational acceleration on the surface of asteroid is 4~5 orders of magnitude smaller than that of the earth. Foot-legged robots can solve the problem of insufficient friction and traction, but their structures are complex. Especially in the case of uncertain surface contact parameters of asteroid, the design requirements for the end of robot foot structure are strict. The soil splashed on the asteroid surface will jam the joints of the feet and legs, which reduces the motion performance.**

Tumbling and jumping are effective ways to realize the movement of asteroid exploration robots [2]. In 2014, MASCOT [3] carried by Hayabusa 2 realized short-jump movement by using the motor to drive the eccentric rocker arm. The MINEARVA-II robot also carried by Hayabusa-2 used momentum wheels to realize the tumbling motion on the surface of the Ryugu asteroid. The Jet Propulsion Laboratory together with Stanford University have been studying microgravity mobility approaches using hopping/tumbling platforms named Hedgehog[4]. Hedgehog does not have avionics, covers or solar panels. The array of protruding spikes on the Hedgehog surface provide the contact interface with the asteroid surface and protect the platform. The above research is only to enable robots to have the ability to move on the asteroids. However, it is still necessary to study asteroid robots from the perspective of the asteroid exploration mission.

For comprehensive and efficient exploration on the asteroid surface, this paper proposes a spherical mobile asteroid robot (SMART). The missions of the SMART include on-site exploration of the asteroid surface composition and physical properties, the construction of the asteroid local map, and the inversion of the asteroid surface gravitational field. SMART adopts a spherical structure with 8 fixed leg supports, as shown in Figure 1. The symmetrical structure design is beneficial to omnidirectional movement and improve the detection accuracy. The movement of the SMART depends on three orthogonally distributed reaction flywheels. Through the torque vector control of the flywheels, the omnidirectional attitude roll movement of the robot is realized, which effectively solves the problem of microgravity. The payloads deployed on SAMRT include multispectral cameras, APXS, lidar, inertial sensors and multiple visible light cameras.

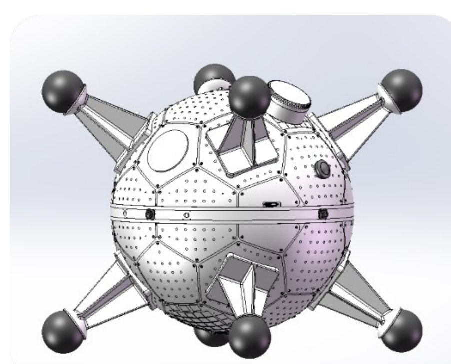


Figure 1 SMART configuration

The mobile exploration on the asteroid surface makes contribution to asteroid mining operations, in situ resource utilization, asteroid defense. There are

three main mission objectives of SMART: (1) On-site exploration of the asteroid surface composition and physical properties. (2) Asteroid 3D reconstruction and local map construction. (3) The inversion of the asteroid surface gravitational field. SMART deploys a multispectral camera and Alpha Particle X-ray Spectrometer (APXS) for asteroid surface imaging and soil composition analysis. The Thermometer and potentiometer probes are embedded on the surface of the SAMRT spherical structure to measure the asteroid surface temperature and potential. Based on the omnidirectional tumbling mobility, the combination of lidar and the symmetrically deployed multi-eye cameras can obtain an accurate map of the asteroid surface for 3D reconstruction. Accelerometers and gyroscopes deployed inside SAMRT measure the inertial information. According to the movement traversal and the force response received, the robot can realize the inversion of the distribution of the gravitational field on the asteroid surface. The mission plan is shown in Figure 2.

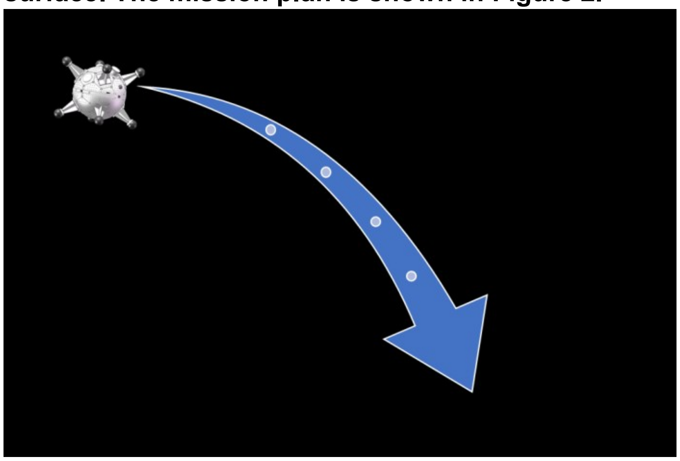


Figure 2 The mission plan of SAMRT

SAMRT adopts a spherical configuration. The diameter is about 200mm and the weight is about 15kg. There are 8 leg supports fixed on the spherical surface of SAMRT. The movement of the SMART depends on three orthogonally distributed reaction wheels, as shown in Figure 3. The torque vector of the reaction wheels can control the motion and attitude of the robot at the same time. This drive device will avoid failures caused by splashed soil. The surface of the robot sphere is attached with solar cells and solar sensors[5], which can be used for energy supplement and attitude determination. Three optical proximity sensors (OPS) are deployed on the robot surface. They are used to measure the robot's relative orientation to the asteroid ground by the obtained reflecting light.

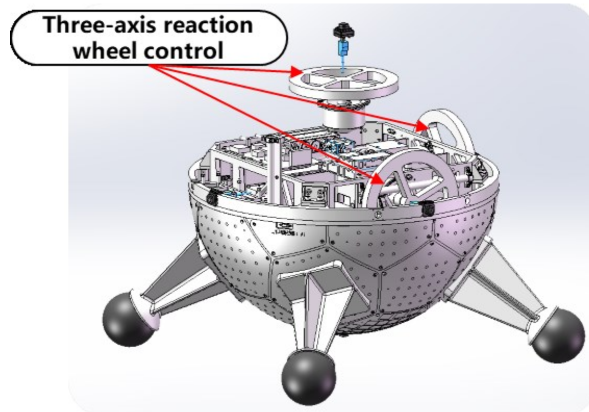
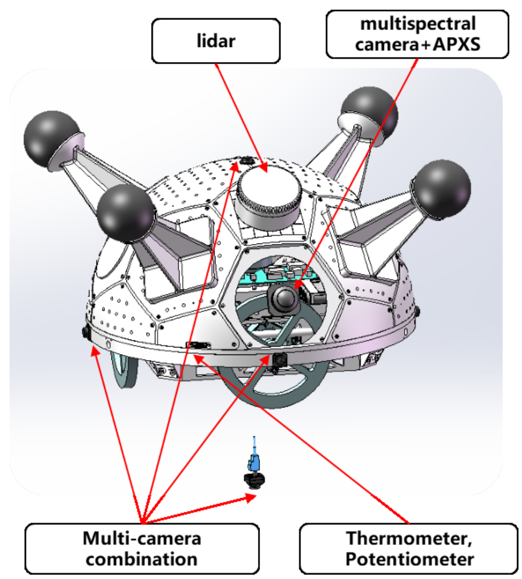


Figure 3 Movement and attitude control by reaction wheels

The payload of SAMRT includes visible light camera, laser radar, multispectral camera, APXS, etc. The payload of the robot includes visible light camera, laser radar, multispectral instrument, APXS, etc., as shown in the figure. SAMRT is equipped with 6 visible light cameras, which are symmetrically distributed. A laser radar is configured on the top. A multi-source fusion sensor system consisting of visible light cameras and laser radar is used to achieve 3D reconstruction and mapping on the asteroid surface.



The power supply of the robot uses the graphene supercapacitor battery with high current and high reliability[6]. Solar cells mounted on the surface improve sun light utilization. The SAMRT uses the computing module based on an embedded GPU with a 1.3RFLOPS AI computing power. The mass of the computing module is 800g. it has an AI computing power of 1.3RFLOPS at the power consumption of 7.5.

As an important component of the main spacecraft, the asteroid exploration robot is of great significance for human beings to understand asteroids and carry

out deep space exploration operations. The goal of SMART proposed in this paper is to conduct on-site exploration of asteroid surface composition and physical properties, asteroid 3D reconstruction and mapping, asteroid surface gravitational field measurement inversion. The SAMRT adopts a spherical configuration to improve the detection field of view and inversion calculation accuracy. In the future, we will continue to improve the design and control capabilities of the robot, so that it can be applied to actual missions on asteroids as soon as possible.

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