Efficient exploitation and collection of lunar resources

I. Background of the project

1. Resources on the Moon

Lunar exploration is the starting point for mankind to move towards the sea of stars. The focus of lunar exploration in the new era has shifted to the development of lunar resources and the establishment of lunar bases. Many countries in the world have listed the development and utilization of lunar resources and the construction of lunar bases as important strategic goals in the new round of lunar exploration planning. The U.S. even passed the Commercial Space Launch Competition Act as early as 2015, stipulating that any resources discovered by U.S. individuals or companies on asteroids or the moon, including minerals, water, etc., should be owned and disposed of by the discoverer. In 2016, Luxembourg promulgated the "Law on the Development and Utilization of Space Resources", and China also announced in 2019 that it would open up the Earth-Moon Economic Zone, the main purpose of which is to develop and utilize lunar and space resources. It can be seen that the competition for lunar resources among countries around the world will inevitably become more and more fierce.

1.1 Helium-3 Resources

First of all, helium-3 resources must be No.1 among the lunar resources that have attracted much attention. Helium-3 is an efficient, clean, safe and cheap nuclear fusion power generation fuel that has been recognized worldwide. According to calculations, 10 tons of helium-3 can meet all the energy needs of my country for one year, and 100 tons of helium-3 can provide the total energy used by the world for one year. But the reserves of helium-3 on earth are very small, only a few hundred kilograms. The preliminary results of lunar exploration show that the lunar soil contains millions of tons of helium-3. This news can be described as exciting and exciting, because it means that after the deuterium-helium-3 nuclear fusion reaction is achieved, such abundant helium-3 on the moon can continue to provide human beings with fuel for more than 10,000 years of energy needs ! This is bound to have a significant and far-reaching impact on human economic and social development, and can effectively solve the energy crisis faced by human beings.[1]

1.2 mineral resources

There are also rich mineral resources on the moon, of which ilmenite and krippite have attracted much attention. The Moon Sea Basalt is rich in ilmenite resources. It is estimated that the total resource of ilmenite in the Moon Sea Basalt is about 1000-2000 trillion tons. After mining and beneficiation, ilmenite is not only the main component of the building materials required for the preparation of the lunar base, but also the raw material for extracting metallic iron and titanium, and can also be used as an important raw material for the production of water and rocket fuel liquid oxygen. Krippite is a special kind of rock on the moon, named for its richness in K (potassium), REE (rare earth elements) and P (phosphorus), and also rich in radioactive elements thorium and uranium. It is estimated that the total amount of rare earth elements in the Kripp rocks in the lunar storm ocean area is about 20-45 billion tons, which is much higher than the total reserves of rare earths in the world. How to carry out efficient mining and beneficiation on the moon, and how to comprehensively develop and utilize these abundant mineral resources are bound to be important issues that need to be solved urgently at present.[1]

1.3 lunar soil

Lunar regolith refers to the weathered material with a particle size of less than 10mm in the regolith on the lunar surface. Its particles are fine, with an average particle size of about 100 μm. The composition of lunar soil is closely related to the composition of the lunar rocks in the area where it is located, and basically includes mineral debris (pyroxene, olivine, plagioclase, ilmenite, etc.), primitive crystalline rock debris (basalt, plagioclase, etc.), angular Conglomerate debris, glass, cementitious agglomerate, meteorite debris (troilite, olivine, pyroxene, conestone, etc.), the chemical composition is mainly silica, titanium oxide, aluminum oxide, iron oxide, Alumina, calcium oxide, etc.

Lunar soil is the most important in-situ resource. Untreated lunar soil is mainly used to cover the building surface to maintain temperature, shield radiation and resist meteorite impact. The cured lunar soil can be used as a structural material.[3]

1.4 water resources

At present, there is no direct observation or acquisition of water ice resources on the lunar surface, but it has been proved by means of spectral detection and other methods that the moon is likely to have water ice resources, which provides the possibility of water use for construction on the lunar surface. In terms of water resources exploration, NASA's lunar orbiter found that there are water ice resources in the permanently shadowed area of the moon on the surface, and the analysis of lunar soil samples also showed that there is water inside the moon.[3]

It is expected that the lunar south pole will be a very important target in future lunar exploration and lunar base construction missions. In addition to the important scientific value of the water ice distributed there (by analyzing the potential water ice distribution at the lunar north pole (left) and south pole (right), a hypothetical map of the water ice distribution in the Sheckleton crater near the moon's south pole, near the moon's south pole .The hypothetical map of the water ice distribution in the Sheckleton impact crater The isotopic composition of hydrogen and oxygen in the water ice can help us understand the source of lunar water, the composition and evolution of water in the early solar system, etc.), or provide water and oxygen resources for astronauts Important Guarantee.[2]

In a word, there are abundant resources on the moon, which can not only solve the increasingly scarce resources and energy problems on the earth, but also have great significance for the sustainable development of mankind. As Germany's "Science" weekly said: Today, as the earth's resources are increasingly depleted, the moon and other planets have become the targets of concern for countries around the world, including the United States. From the perspective of sustainable development, the energy and resources on the earth will be exhausted sooner or later, and human beings will sooner or later fly to the solar system and go to outer space.[1]

2. Influencing factors of resource extraction and collection on the moon

However, the exploitation and collection of resources on the moon is also faced with many problems. There are many factors that affect the exploitation and collection of resources on the moon. If we want to realize the exploitation and collection of resources on the moon, we must overcome these influencing factors.

Table1 Lunar environmental impacts

影响因素	分析	影响
真空	月面无大气	无风荷载（有利） 需要封闭结构
微重力	月球表面重力加速度 $1.62 m \cdot s^{-2}$	降低自重荷载（有利） 降低结构稳定性 降低振捣密实程度和水泥水化速率
辐射	包括宇宙辐射、月球辐射和二次辐射 宇宙辐射最强，约每年 300mSv 月球地磁场弱，不能屏蔽宇宙辐射 辐射区工作者最大允许辐射量每年 50 mSv	危害人员健康 影响仪器精度
温度	一个月球日等于 28 个地球日，昼夜时间长 赤道温度 95K~387K，极地温度 50K~200K 温度变化快，最高一小时上升 150K	增加结构温度内力 降低材料耐久性
微陨石	直径 1mm 微流星体通量为 $1.35\times10^{-3}/m^2 year$ 陨石平均速度 $20 km \cdot s^{-1}$ 陨石平均密度 $0.5\sim2 g \cdot cm^{-3}$	危害结构安全
月震	平均每年月震 500 次 最大震级里氏 5~6 级	需要抗震措施和结构验算
月尘磨蚀性	月壤风化层颗粒粒径小于 100μm 月尘吸附在建筑表面将造成破坏	需要防尘除尘措施
月尘带电性	月尘带电，其电荷可能来自连接键断裂或太阳风 带电粒子易悬浮，悬浮性质随昼夜交替而改变 太阳高能粒子活动期间（SEPs），负电荷可达到 $10^3 V$	需要防静电措施

Table 1[3]

Regarding the use of solar energy on the lunar rover: Although the moon is bright, it does not emit light. Like our earth, the side of the moon that is illuminated by the sun is day, and it is bright from the ground; the side that does not illuminate the sun is night. Whether or not a spot on the moon will be illuminated by the sun depends on the moon's own rotation -- the moon rotates about every 27.3 days, so day and night are about a little more than 13 days. Therefore, how to make the lunar rover work for a long time when there is no light on the moon is also a major problem that needs to be solved.

II. Research content

1、What resources should we explore on the moon?

2、What kind of resource detection tool should we choose?

3、How to make the lunar resource extraction machine work for a long time on the moon?

III. Research objectives

1. In view of the special space environment of the moon, such as ultra-high vacuum, no atmospheric activity, ultra-clean, weak gravity, no magnetic field, and stable geological structure, research the way to enable the robot to run smoothly and at high speed on the moon, so that the robot can complete the collection at the end of the collection. The required resources can be smoothly transported back to the base for storage.

2. Carry out a mechanical analysis for the mechanical structure of the appropriate resource mining and collection we have selected, and select appropriate materials to improve the feasibility and practicability of the robot.

3. Finally, make a three-dimensional model that meets the requirements of the robot that can complete the collection and collection of lunar resources, and enable the robot to initially achieve the desired effect through dynamic testing.

IV. Key issues and solutions

1. Regarding the utilization of solar energy on the lunar rover: Although the moon

is bright, it does not emit light. Like the earth, the side of the moon that is illuminated by the sun is day, and it is bright from the ground; the side that is not illuminated by the sun is night. Whether or not a spot on the moon gets the sun depends on the moon's rotation -- the moon rotates around every 27.3 days, so day and night are about a little more than 13 days. Chang'e-4 can stay overnight on the moon because of the characteristics of the batteries it carries, but Chang'e-5 cannot - Chang'e-4's lunar rover Yutu carries nuclear batteries, while Chang'e-5's power supply system is powered by solar cells array and lithium-ion battery pack. Nuclear battery is also called "radioisotope battery", which is manufactured by converting the thermal energy of isotope radiation with thermal energy into electric energy through semiconductor transducer. The appearance and internal structure of the nuclear battery are as follows:

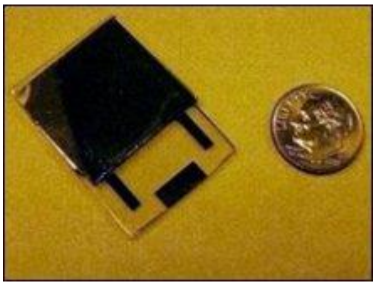


figure 1

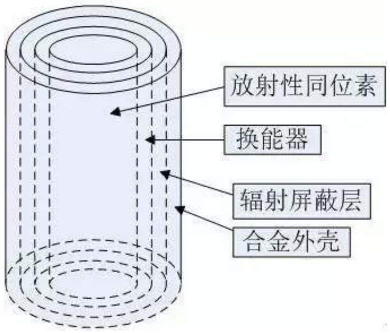


figure 2

The principle of "thermoelectric power generation" of nuclear batteries is to use the properties of semiconductors. When the temperature of the two ends of a doped semiconductor material is different, the charged "carriers" on the side with the higher temperature have higher energy and will flow to the side with the lower temperature. The electric field prevents the carriers from continuing to diffuse. Therefore, there will be electrical related processes on both sides of the temperature. It is also based on this characteristic that the "nucleus" of the nuclear battery on Chang'e-4 uses radioactive isotopes, which will undergo the decay process as shown below:

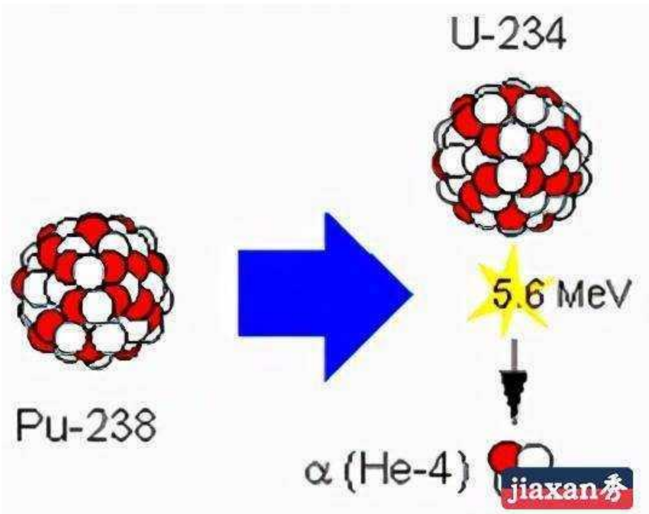
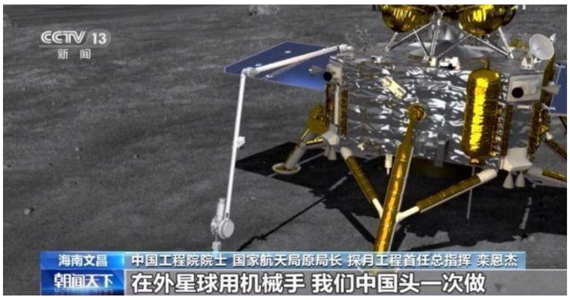


figure 3

Therefore, when Chang'e-4 with a nuclear battery is turned off at night, the center of the nuclear battery is still releasing heat, which can maintain the temperature of

Chang'e-4. The solar cell panels produced have various shapes such as triangles and polygons, which make the fabric efficiency reach more than 91%, which is 5% to 10% higher than that of conventional products. At the same time, Chang'e 5 chose higher-efficiency solar cells, increasing the efficiency of converting light into electricity to more than 31%. Therefore, here we can choose to combine the nuclear battery on Chang'e 4 with the power supply system on Chang'e 5 to form a new power supply system, so as to achieve uninterrupted work throughout the day and not be restricted by day and night, thereby improving work efficiency.

2. The robotic arm that can be used for sampling: The robotic arm has been used on Chang'e 5 to sample the surface of the moon. Generally speaking, we can continue to use the robotic arm of Chang'e 5, but due to the different working objects, we need to measure the robotic arm. Make certain modifications. We can install a positioning monitoring system on the robotic arm[4] . The positioning monitoring system is mainly composed of two parts: the vision system and the target. It can be installed on the arm or on the surface of the spacecraft to establish a space coordinate system, calibrate the motion of the manipulator, and monitor the motion process of the manipulator. At the same time, we can establish an inverse kinematics model for the robotic arm [5], as shown below:



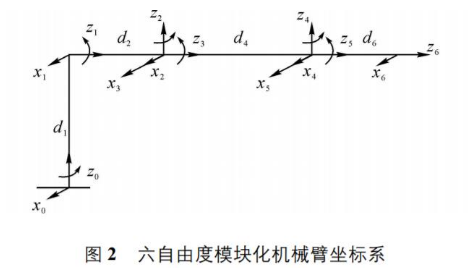


Figure 4 Figure 5

As a result, the robotic arm can actively sense the environment of the sublunar strata, achieve accurate sampling, and improve work efficiency.

3. Detection and development of water resources and metal ores: Like the earth, the temperature of the north and south poles of the moon is much lower than that of the equator. Because the lunar surface is covered with large and small impact craters, some of the low-lying terrain makes it impossible to see sunlight all year round. These are called permanently shadowed areas. Temperatures in these regions can reach as low as -250°C, and if water is present, it will be stably preserved in the form of water ice. These theoretical assumptions were put forward by scientists in the 1960s and gradually recognized by the scientific community. It is generally believed that the water ice in these areas mainly comes from comets or meteorites containing water ice, which land in the permanently shadowed area and are preserved. For example, scientists used lunar remote sensing satellites to find that there is a very strong laser reflection signal in the Sheckleton crater near the South Pole, which may be caused by the presence of water ice on the surface. [6]

If we can detect, develop and utilize the water resources on the moon, it will undoubtedly provide great convenience and life support for us to solve the lunar space station or astronauts' long-term life on the moon in the future, and can reduce the weight of the rocket's burden, It can free up more weight and space to carry more other necessary items and resources. The ability to obtain oxygen through electrolysis of water is also an important guarantee for providing water and oxygen resources for astronauts. To determine the content and area of lunar water resources, the most direct method is to dig out the soil in these areas, and then measure the content of water ice. It is expected that the lunar poles will be an important target in future lunar exploration and lunar base construction missions. The water ice distributed there is not only of important scientific value (by analyzing the isotopic composition of hydrogen and oxygen in water ice, it can help us understand the source of lunar water, the composition and evolution of water in the early solar system, etc.), it also provides water for astronauts. and an important guarantee of oxygen resources.

Considering the extreme low temperature of the moon, our group hopes to heat the lunar soil through the decay of radioactive elements to generate heat or solar energy and to use the remaining heat generated while drilling the ore, so that the solid ice or magma water on the surface (when it leaves the lunar surface) will be heated. After the magma is diffused and degassed, it crystallizes to form glass beads, and strongly bound H or OH (magma water) is formed around the glass beads minerals.

For the mining of metal ore, the experience of Chang'e 5 can be used for reference. The sampling on the lunar surface of the Chang'e-5 spacecraft launched by my country is divided into two modes: drilling and surface sampling. Drilling is to drill to a depth of two meters below the lunar surface through the coring mechanism of the hollow drill pipe to obtain the bedding information of the deep samples. Surface sampling is to use a fixed shovel-type sampler at the end of the robotic arm to collect the surface and subsurface lunar soil to achieve multi-point and multiple sampling. [7] Because this is the first time humans have landed on the back of the moon, large-scale sampling is essential. In this case, the combination of surface and drilling will undoubtedly allow Chang'e-5 to obtain more valuable sample, but based on the topics we are studying, among the resources on the moon, helium-3 resources must be No.1 among the lunar resources that have attracted much attention. Helium-3 is an efficient, clean, safe and cheap nuclear fusion power generation fuel that has been recognized worldwide. Preliminary results from lunar exploration indicate that the lunar soil contains millions of tons of helium-3. There are also rich mineral resources on the moon, of which ilmenite and krippite have received much attention. The Moon Sea Basalt is rich in ilmenite resources, and it is estimated that the total resource of ilmenite in the Moon Sea Basalt is about 1000-2000 trillion tons. After mining and beneficiation, ilmenite is not only the main component of the building materials required for the preparation of the lunar base, but also the raw material for extracting metallic iron and titanium, and can also be used as an important raw material for the production of water and rocket fuel liquid oxygen. Krippite is a special kind of rock on the moon, named for its richness in K (potassium), REE (rare earth element) and P (phosphorus), and also rich in radioactive elements thorium and uranium. It is estimated that the total amount of rare earth elements in the Krippite in the lunar storm ocean is about 20-45 billion tons [1]. It is impossible to collect helium-3 and these metal resources simply through surface sampling, so in the next development of lunar resources, we can abandon the surface sampling technology adopted on Chang'e 5, so that Chang'e 5 can be collected. The space originally used to carry surface sampling devices can be used to carry more deep drilling tools, of which hollow outer auger rods are a good choice. And through the conceived hollow PDC drill bit and drill pipe, the dual purpose of collecting ore and collecting water resources can be achieved.

Collection of metal ore: [8] Hollow outer auger pipe is the most commonly used and most reliable drill pipe configuration, and its load, drill pipe parameters and total drilling pressure during the working process are also higher. Compared with the smooth involuted body, when there is a micro-groove structure on the surface of the involuted body, the extremely low total pressure areas near it are concentrated into the groove, so that the overall low total pressure layer on the surface of the involuted body is smaller than that of the smooth surface. The total resistance reduction effect is the most obvious when only the rear 1/3 of the surface is the micro-groove surface, followed by the full-groove surface model. When the Mach number increases, the relative drag reduction or drag increase of these models decreases, and the change of lift-drag ratio is similar. The front 1/3 and rear 1/3 surfaces are groove surfaces at the same time, which can significantly reduce the viscous friction resistance of the rotating body, followed by only the front 1/3 surface being the groove surface, and when the angle of attack and the incoming Mach number increase The drag reduction effect is more obvious, only the rear 1/3 of the surface is the groove surface, which will increase the viscous resistance of the revolved body. The mechanical model of the interaction between the hollow outer helix and the lunar soil is as follows:

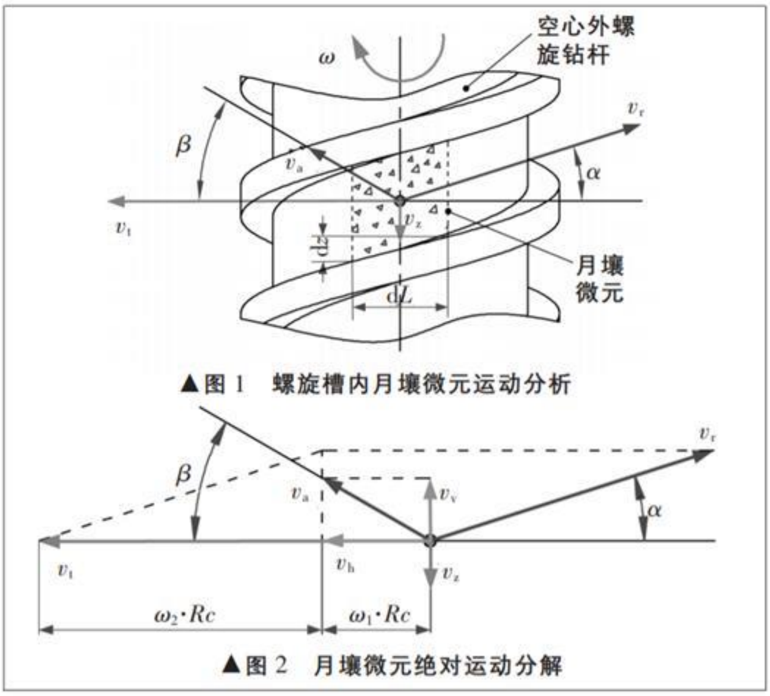


Figure 6

Taking water resources: We can punch holes on the drill pipe in Figure 6, change the blade in Figure 7 to a spiral groove, enter the hollow groove through the small hole on the drill pipe, and apply impact load and rotational moment to the drill pipe, using the cutting edge of the PDC bit to drill, and the rotating groove to drill the surface extra-terrestrial soil; when the lower section of the drill pipe is completely drilled into the surface soil, the flexible sealing cover is closely attached to the surface soil; the light concentrating device at the top of the drilling tool introduces focused sunlight , through the light-guiding mirror at the top of the drill pipe to the hollow cavity inside the drill pipe; the lower drill pipe is heated by solar energy and transfers heat to the superficial soil through the thermal conduction of the blades (rotating grooves); the flexible sealing cover and the surrounding frozen soil are separated Heat and sealing, water and other volatiles enter the hollow cavity inside the drill pipe through the air hole and rise to the gas outlet, enter the condensation separation and detection processing module, and complete the single volatile extraction task.

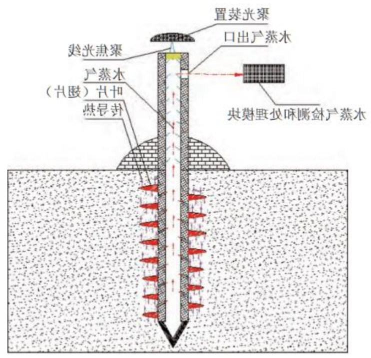


Figure 7

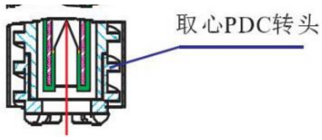


Figure 8[9]

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