In-Situ Mechanical Probing Technology for Lunar Regolith (Postprint)

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Abstract

The Moon contains abundant mineral resources such as titanium, thorium, and uranium, as well as new minerals including triclinic pyroxene and zircon that have not been discovered on Earth. Developing lunar resources is expected to address Earth' s resource depletion, and securing a technological advantage to acquire more resources has become imperative. China plans to achieve manned lunar landing by 2030, concurrently conducting in-situ scientific experiments on the Moon, with in-situ acquisition of lunar regolith mechanical properties being a prerequisite for scientific research and construction activities on the lunar surface. The Soviet Luna missions and the U.S. Apollo missions conducted in-situ mechanical tests on lunar regolith in the 1970s; however, the equipped penetrometers were rudimentary, and limited by the sensor precision and technological level of that era, resulting in limited penetration depth and low data accuracy. In view of the current development status and trends of in-situ mechanical detection technology both domestically and internationally, a significant gap exists in China' s development of lunar regolith in-situ mechanical detection payloads and technical capabilities. Although China has conducted extensive ground mechanical testing and research through returned lunar regolith samples, and has performed inversion calculations of lunar regolith physical and mechanical properties via photogrammetric methods, in-situ mechanical detection of lunar regolith has yet to be achieved. To address the requirements for lunar scientific research station construction and in-situ resource utilization, the Institute of Mechanics, Chinese Academy of Sciences, has conducted a series of pre-research efforts on lunar regolith in-situ mechanical detection payload development and detection technologies. Based on lunar scientific detectors, penetrometer design schemes including cone-type, harrow-type, blade-type, and vane-type have been successively proposed, realizing miniaturization, lightweight design, low power consumption, and intelligent capabilities, while key technical challenges requiring focused efforts have been identified. Demonstration results indicate that through the construction of lunar regolith penetration resistance models and

research on neural network and artificial intelligence parameter interpretation algorithms, an interpretation methodology suitable for lunar regolith mechanical property parameters can be established, thereby enabling precise detection of lunar regolith cohesion and internal friction angle, and providing technical support and reference for China to successfully accomplish lunar regolith in-situ mechanical detection missions and fill the gap in this domain.

Full Text

Research on In-situ Mechanical Detection Technology for Lunar Regolith

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Abstract

The Moon harbors abundant mineral resources, including titanium, thorium, and uranium, as well as novel minerals such as tranquillityite and zircon that are not found on Earth. Exploiting these lunar resources offers a potential solution to Earth' s resource depletion, making the competition for technological supremacy in this domain an urgent imperative. China aims to achieve manned lunar landing by 2030 while concurrently conducting in-situ scientific experiments. Obtaining the mechanical properties of lunar regolith in situ constitutes a prerequisite for scientific research and construction activities on the lunar surface.

The Soviet Luna and U.S. Apollo missions conducted in-situ mechanical testing of lunar soil in the 1970s; however, their penetrometers were rudimentary, and limitations in sensor accuracy and overall technological capabilities of that era resulted in shallow penetration depths and low data precision. A comprehensive review of current in-situ mechanical detection technology reveals a significant gap between China' s payload development capabilities and international standards. Although China has performed extensive ground-based mechanical testing on returned lunar samples and derived lunar soil physical-mechanical properties through photogrammetric methods, in-situ mechanical detection of lunar regolith remains unrealized.

To meet the requirements of lunar base construction and in-situ resource utilization, the Institute of Mechanics, Chinese Academy of Sciences, has undertaken a series of development and pre-research initiatives for lunar regolith in-situ mechanical detection payloads. Building upon lunar scientific exploration platforms, we have proposed penetrometer designs including cone-type, rake-type, blade-type, and vane-type configurations, achieving miniaturization, light weight, low power consumption, and intelligent operation while identifying key technical challenges requiring focused breakthroughs. Our feasibility studies demonstrate that constructing lunar regolith penetration resistance models, combined with research on neural network and artificial intelligence parameter interpretation algorithms, can establish an effective methodology for interpreting lunar soil mechanical parameters. This approach enables accurate determination of cohesion and internal friction angle, providing technical support and reference for China to successfully accomplish lunar regolith in-situ mechanical detection missions and fill this critical capability gap.

Keywords: Lunar exploration; Lunar regolith; In-situ mechanics; Cone penetration test