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RECONFIGURABLE HABITAT SYSTEMS FOR LUNAR LAVA TUBES BASED ON QUASI-SPHERICAL UNITS

Abstract

Constructing long-term habitats in uncertain environments like lunar lava tubes, makes it difficult to fully grasp the internal spatial configuration beforehand. In such environments, an adaptive process is required— one that evaluates each action before determining the next step—rather than linear construction following a single master plan. Simultaneously, considering transportation costs and payload constraints, construction robots and building components must be standardized and capable of long-term, versatile operation. Reconfigurable robotics has garnered attention as a technology addressing these demands, but often, the Builder robot and the target structure are designed separately. This separation tends to fix structures as dedicated components for predefined purposes and limits transport materials to specific applications. Consequently, diversity in configuration shapes and freedom in redeployment decrease, restricting adaptability in long-term, phased operations. This research adopts a unified approach, designing the robot body and building components under a unified geometric unit and realizing both the locomotion mechanism and assembly action principles through the same mechanism. By minimizing the geometric and kinematic differences between the Builder and the Building, it aims to enhance material transport efficiency and realize a cyclical and adaptive construction process. The proposed system is characterized by its architectural modules and robotic components being composed of identical quasi-spherical polyhedral units. The unit shape maintains a degree of sphericity while possessing standardized joint surfaces, selected based on geometric conditions enabling filling of three-dimensional space at a constant density. Each unit incorporates an effector and rotation mechanism on its joint surface, enabling rotation about its normal axis while connected. This allows multiple units to form a kinetic chain, enabling movement across terrain via rolling. Units are detachable, functioning as single or multiple robots by connecting or separating from 2 to N units. This rotational mechanism also functions as the principle for altering the geometric configuration of structures, not just for movement. The units are both mobile entities and spatial structural units; rotating their joint surfaces enables the expansion, contraction, and reorganization of structures. This facilitates spatial renewal tailored to terrain conditions and required performance. This paper presents (1) Geometric parameters for selecting the shape of quasi-spherical polyhedral units (2) Modeling of the kinematic chain in the connected state, physical simulations on uneven and sloped terrain, and motion planning (3) A configurable living space prototype, presenting a framework for lunar architecture that views the structure as a system capable of updating itself in uncertain environments.