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Lunar construction solution: Chinese Super Mason

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Abstract

Supporting the goal to develop the habitat for people to work and live safely and sustainably on the moon, the Lunar construction robot is typically designed with 3D printing system based on laser sintering technique with Lunar soil. Huazhong University of Science and Technology *(HUST)* propose a novel robotic system for Lunar construction entitled ***CSM: the Chinese Super Mason***, combining on-site prefabrication of bricks and arch segments with Lunar soil and multi-structural automated assembly processes. CSM consists of a compound fabrication system composed of 6-axis robotic manipulator and automated sintering fabricator carried on an autonomous limbed vehicle platform. As a case study, a 2.8-m-long, 1.6-m-wide prefabricated structure for Lunar Base was successfully assembled with an experimental platform. Benefits and limitations of CSM and its experimental platform were identified and analyzed. Finally, prospections and exploratory steps toward the future of Chinese Lunar Base are also discussed along with the proposed CSM applications for Lunar construction.

Keywords: Lunar construction; Robotic construction; Prefabrication; Automated assembly; Chinese Super Mason

1. Introduction

With the rapid development of society, the exploration of the living space of mankind has been continuously expanded and deepened to the extreme environment area that is inaccessible. These extreme environmental areas mainly include two types: one is the area beyond the Earth's terrestrial surface such as deep space, deep sea and deep earth, and the other is the special terrestrial land surface such as polar areas, nuclear pollution and major natural disaster sites. In order to support human exploration of extreme environment, new special buildings and structures will emerge, and existing engineering construction theories, methods and techniques will not be applicable in the extreme environment where human beings find it difficult or impossible to reach. Unmanned construction is bound to be the only effective way of building an extreme environment.

For half a century, the exploration of the deep space has been progressively pushed forward by human beings. As early as the 60s of the last century, the United States and the former Soviet Union, based on the purpose of military competition, carried out a great deal of exploration on the moon and successfully implemented a number of plans and in the end stopped them. At the beginning of this century, the United States has restarted explored Mars and even the outside solar system. In recent years, Europe, China, Japan, Korea and India are all involved in the lunar exploration. The construction of the Moon Base has become a great concern of this century.

The research on the construction of the lunar base mainly includes six aspects, such as environment simulation, material preparation, site selection and site planning, architecture design, construction technology, support technology and so on. The first part of this article describes the urgency of the research on the construction of the moon base. The second part introduces the related research at home and abroad. The third part describes our Chinese design of the lunar bas, and is simulated and verified in the fourth part. The fifth part makes a prospect and summary of future research.

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2. Related research

In 2013, NASA proposed that the use of high power laser will be lunar basalt weathering layer and high temperature sintered glass like material, build a lunar base using 3D printing technology[1]; at the same time, NASA designed a multi legged robot platform corresponding to the moon, collecting raw materials, in the process of the construction preparation and construction[2]. In June 30th, 2017, the United States re-established the National Space Committee, which is directly subordinate to the Executive Office of the president. On October 5th, former vice president Mike Burns officially announced that the United States will restart the lunar landing plan. In terms of ESA, in 2014, the lunar basalt weathered rock powder was used as raw material and the binder was solidified by high effective adhesive. The honeycomb wall arched Moon Base was prepared by using the "D-shape" 3D printing technology[3]. KAKI has long been committed to the research of cementing lunar soil with thermosetting polymers, and has collaborated with NASA to carry out 3D printing technology for polymer bonded lunar soil. India Institute of Physics developed a metal container pressure and temperature controllable conditions, used to simulate lunar extreme environment[4]. The following are six aspects of the lunar construction:

2.1. Environment simulation

India, the United States and other countries adopted the experimental simulation and numerical simulation to study the temperature changes of the lunar surface. The India Institute of physics has developed a metal container system that simulates the pressure and temperature conditions of the surface of the moon, the system can achieve some special pressure, and can keep the temperature of the sample in the daytime and night temperature of the monthly table, respectively[4,5]. The University of Connecticut established a general equation based on the thermodynamic principle of thermal flow. The thermal flow environment of the moon and below the monthly table were analyzed to determine the gradient of temperature with time and the depth of the moon and the analysis of the 1 meters of the moon rock wind outside the base of the base structure, the detailed temperature characteristics of the soil protection layer[5].

2.2. Material preparation and site planning

The Hanyang University and University of New South Wales have made use of simulated lunar soil as the main raw material to prepare lunar construction materials by sintering, bonding, dry mixed pressure, and geological polymerization[6,7]. Based on the constraints of lunar environment, the United States and France have studied the location of lunar bases and the planning of base construction sites. The site plan of the moon base proposed by University of Southern California, including landing pad, connecting land location and base passageway, and transportation system[8]. The French International Space University has proposed the overall infrastructure and site layout of the "LB10" moon base, including the spacecraft landing field, the launching station, the power station, the base building and the scientific telescope[9].

2.3. Structure design and construction technology

The United States, Italy and other countries have studied the architectural design of the lunar base[10,11,12], which can be divided into three categories, including: 1) inflatable structure, 2) rigid structure, 3) mixed structure. The United States and ESA have studied it. From the point of view of material sources, the current construction technology of the lunar base can be divided into two categories, including: 1) the earth's raw materials, transport to the moon 3D printing robot, 2) the moon on the ground, and the 3D printing robot.

3. Conceptual design

3.1. Overall plan of the scheme

In this paper, we proposed a CSM application for the Lunar construction. We will build the theory, method and technology of the unmanned moon base in the whole process of Perception - Decision - Design - Construction - Operation and maintenance of special structure, material and performance. The CMS includes two core parts: robot operating system and program execution setup. According to the automated construction path optimization algorithm, robot operating system could convert the Building Information Modeling (BIM) model into a series of coordinates that the robot could match with different path (Fig. 1).

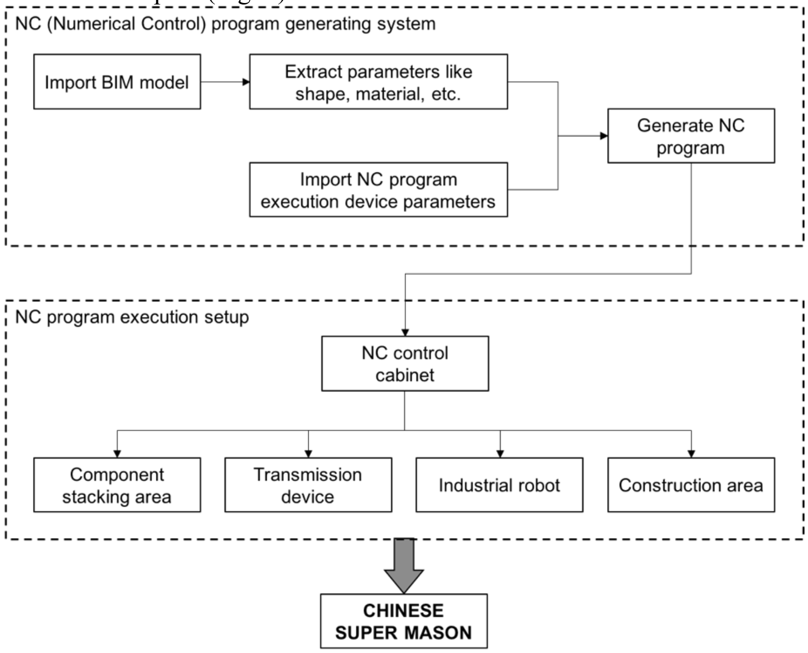

Fig. 1. Composition diagram of CMS

3.2. Conceptual design

The main function of the moon base is to achieve temporary or permanent base facilities in the lunar environment. During the construction of the lunar base, the moon environment, such as gravity, air pressure, temperature and earthquake, should be taken into account. The moon is rich in lunar soil and lunar rocks, and the compressive strength and tensile strength of lunar rocks are 10 times that of the earth. Therefore, the use of local materials, the construction of practical structure, modular, light construction equipment.The scheme to reduce the cost of launch and launch is more appropriate.

According to the international principle of building "local material" for the moon base and the design of the arched structure of the ground base, we compare the following four possible construction schemes for the 3D printing robot of the lunar base: 1) NASA's laser layer by layer sintering method for lunar soil accumulation; 2) Formation of adhesive bonded layer by layer bonding method for lunar soil consolidation in ESA and other agencies; 3) Layer by layer extrusion molding for microwave melting of California Institute of Technology; 4) Laser sintering masonry of lunar soil blocks at Huazhong University of Science and Technology, China.

	Indicator	1	2	3	4
Raw material system	Complexity of raw materials	★	★★	★	★★★
	Lunar soil utilization	90~100%	70~80%	90~100%	80~100%
Technical equipment	Equipment complexity	★★	★	★★	★★★
	Technical maturity	★	★★	★	★★★
Construction process	Energy requirements	★★	★	★★	★★
	Construction efficiency	★	★★	★★	★★★
Application performance	Material and structural strength	★★	★	★★	★★★
	Durability	Further study			

Fig. 2. Comparison of base construction schemes

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From the above table (Fig. 2), the " Laser sintering masonry of lunar soil blocks" scheme has high technical maturity (long history masonry), high construction efficiency (large scale layer thickness), good strength of material and structure, and is proposed as a proposal, named " ***CSM: the Chinese Super Mason*** ".

3.3. Construction equipment

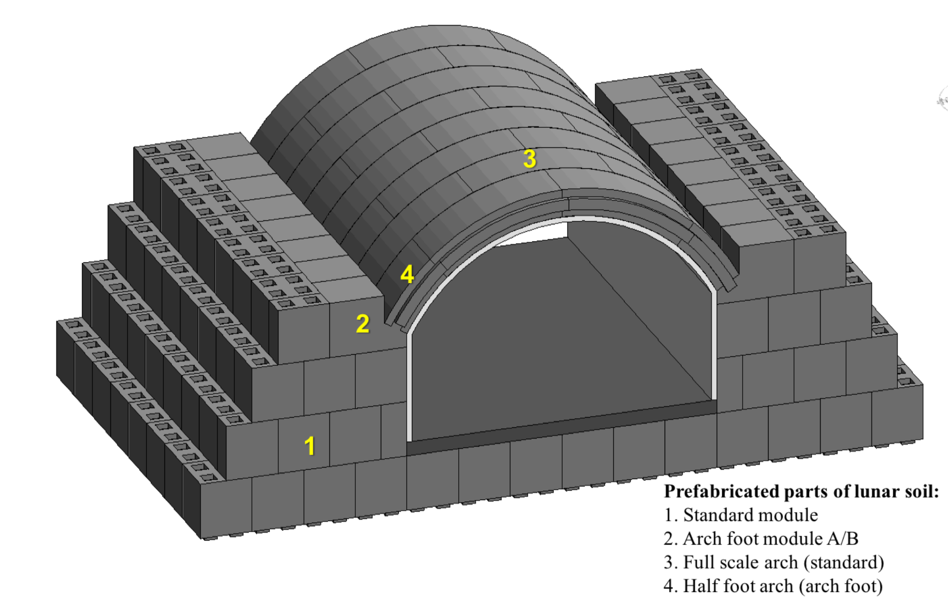

Fig. 3. Structure scheme of lunar loam module arch

In view of the above recommendation, we designed the structure scheme of lunar loam module arch (Fig. 3). The construction plan of the lunar base is characterized by the establishment of an integrated construction system and matching of different construction tasks. The core of the technology comes from three aspects: 1) design and manufacture of the acquisition module for raw materials (lunar soil); 2) design and manufacture of terminal modules for carrying out construction tasks (masonry, sintering, melting, etc.); 3) design mobile robot platform suitable for lunar environment and develop adaptive technology.

4. Simulation: the Chinese Super Mason indoor

4.1. Model design and construction preparation

In view of the plan design in the third chapter, we simulated the experimental scene in the laboratory. The execution setup consists of a component stacking area, transmission device, industrial robot and construction area (Fig. 4).

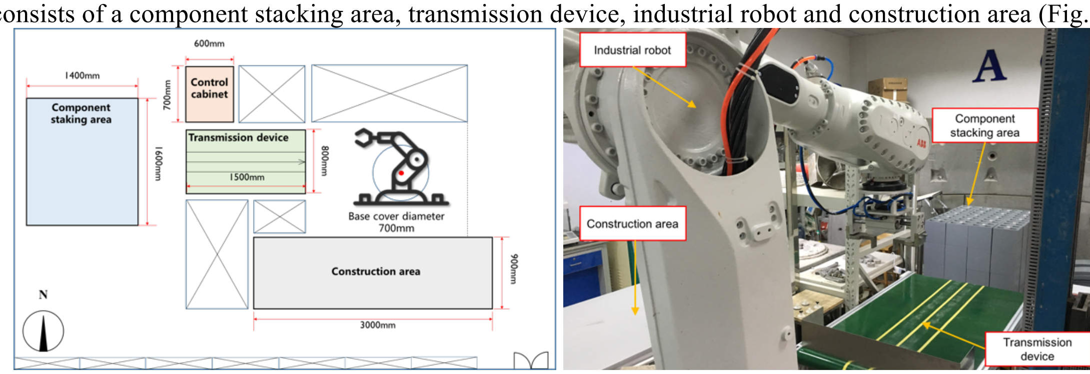

Fig. 4. NC program execution setup of CMS

In the staking area, each component has a code which follows the construction order that we have optimized in the BIM (Fig. 5a) and the tramsmission device (Fig. 5b) delivers the component to the industrial robot (Fig. 5c) which is controlled by the control cabinet (Fig. 5d) to catch the component with the functional fixture (Fig. 5e) to the construction area (Fig. 5f).

The related parameters of some machines of the NC execution systems are listed as the following:

- The industrial robot and the control cabinet are the ABB IRB 6700-235, whose movement of the arm is 2.65m, 235kg load and 0.05mm repeat positioning accuracy.
- The transmission device is 0.8m high, 1.5m length and 0.8m width, over 8kg weight nagative, 1m/min minimum speed and 5m/min maximum speed.
- Functional fixture is drived by a MHL2-40D cylinder with the same size of the component.

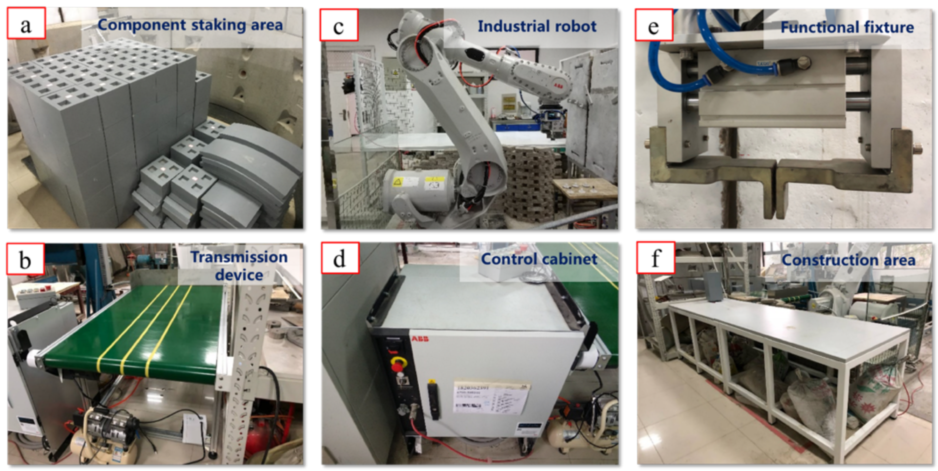

Fig. 5. Distribution composition of CMS

4.2. Module design and production

As we all know that most of the moonbase has an arch structure which has a good performance in high strength and shockproof. In Chinese traditional bridge structure, stone arch bridge is pretty universal. According to this, we design the Chinese Super Mason (CMS) plan which is a prefabricated assembly structure consisting of six diferent basic elements, 8.0m high, 14.0m length and 8.0m width. Because of the limitation of site condition, we manufactured these six different components reducing the size of 5 times, 150 in total. Comparing three construction sequences in Naviswork, we choose the plan A down to top (Fig. 6) to implement in our case study.

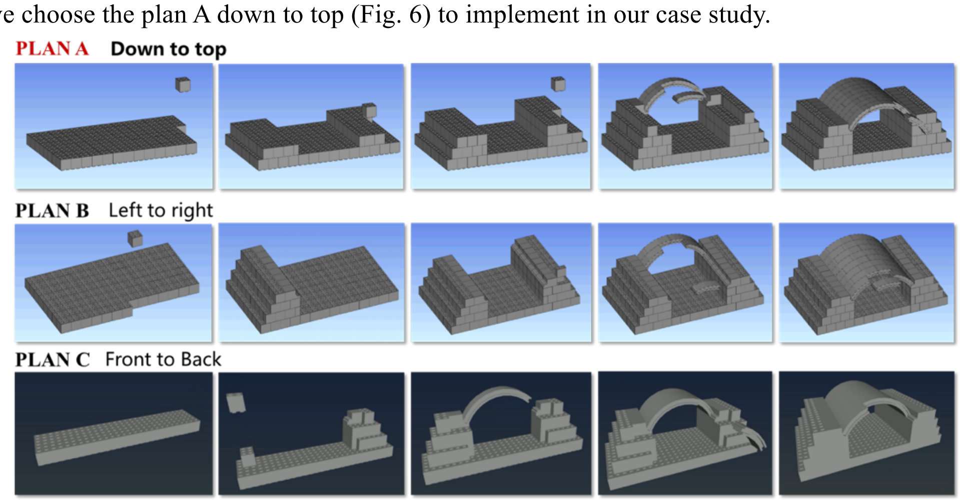

Fig. 6. Simulation of the construction sequence

4.3. Automated construction process

For the construction path optimization algorithm, we designed this from one feeding palce where the transmission device work and changeless to different construction point. The coordinates of these points we have calculated before will be compared to these we got from the process simulation of the robotic Moon Base construction using the teaching apparatus. We use the ABB programming language having a good encapsulation to control the robot (Fig. 7).

Fig. 7. Construction process of the Moon Base

5. Future directions and conclusion

Prospections and exploratory steps toward the future of Chinese Lunar Base are discussed along with the proposed CSM applications for Lunar construction in this part.

- New construction material. The biggest problem for automatic construction technology to face with is the material problem. The next step, we will use the automated sintering fabricator technology to manufacture the simulated lunar soil components.

- Accuracy issue and new fuctional fixtrue. There are many factors affecting the accuracy of automatic construction, mainly including site layout, design of the fuctional fixture, location precision of components, etc. Wherein the design of the fixture is one of the most important problems, or rather, the more meticulous the fixture, the higher the accuracy, yet the lower the construction process speed at the same time. Therefore, it needs to take comprehensive consideration of the accuracy and speed of construction to set proper fixture size.
- Algorithm development and process control. Optimized construction sequence algorithms are critical in that the time of machine running can significantly be reduced. This paper provides some simple robot moving algorithms, which may cause time waste due to many invalid paths. So the optimization of the construction sequence algorithms is very important. Furthermore, the development of hierarchical algorithm of BIM model is also important to reduce manual operations and improve the efficiency of NC programs. CMS provides a good foundation for multi-equipment collaborative construction and the next step is to design a fuctional fixture for different components corresponding to construction sequence.

The further research about Lunar Base construction is presented above. While still in its prospections and exploratory, this research has the potential to improve the traditional automatic construction methods, and solve problems like high accident, low quality, loss of skilled workers, and so on.

In the case of construction equipment, construction of artificial intelligence technology, advanced manufacturing technology, and other digital technology research provide technical support for the development of equipment in extreme environments and possible major scientific technical breakthrough in the field of special unmanned equipment. Lunar construction in extreme environments as a subversive construction model to devote to the new construction organization plan and management model will greatly expand, enrich and reform the construction management theory and method.

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