Direction of Construction Robot in Space Development

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Abstract—Mankind has continued challenging to the universe with curiosity since mid-1950s, and, as a result, the mankind could step on the moon and launch the satellites and exploration robots to several planets including Mars to collect desired information. The construction has contributed to the mankind's development and abundant life for a long time. The interests of mankind are focused on the universe, and the mankind set forth expanding their life to the space based on the accumulated information on the universe. To realize these wishes, the mankind has to construction technologies, and the construction engineers of ability shall play a core role for the universal development. This study is to determine the elements to be considered for the space construction through examining the materials of the construction robot and space development. This study is purposed to present the development direction of robots for the space construction.

***Index Terms*—Space Development, Construction Robot(CR), Space Construction, Space Construction Robot(SCR)**

I. Introduction

MANKIND has continued challenging to the universe with curiosity since mid-1950s, and, as a result, the mankind could step on the moon and launch the satellites and exploration robots to several planets including Mars to collect desired information. The construction has contributed to the mankind's development and abundant life for a long time. The interests of mankind are focused on the universe, and the mankind set forth expanding their life to the space based on the accumulated information on the universe. To realize these wishes, the mankind has to construction technologies, and the construction engineers of ability shall play a core role for the universal development. This study is to determine the elements to be considered for the space construction through examining the materials of the construction robot and space development. This study is purposed to present the development direction of robots for the space construction.

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II. Construction Robot And Space Construction Robot

Considering the difference of the constructions on the earth and in space, the construction robot working on earth is to be called 'CR (construction robot)' and the construction robot working in universal space is to be called 'SCR (space construction robot)' in this study.

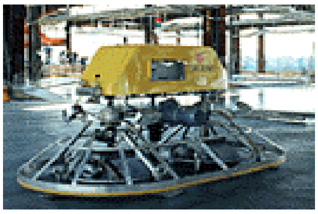
A. Construction Robots

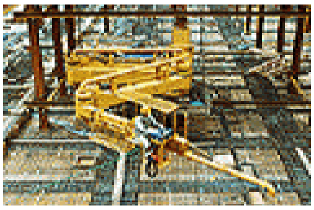
CR has been introduced to ensure the safety and to enhance the productivity and quality on large-sized and complicated construction sites. Recently, CR assumes increasingly the tasks which are hard for people to complete firsthand and on the dangerous and poor-conditioned construction sites. The working scope of CR has developed from simple jobs like earth work, crane work and placing of reinforcement/steel-frame work at the initial stage to the systemized complex processes at the moment.

1) Trend of Construction Robots Development

In Japan, construction robot was came to be used in the 1980s. Then, technology development activities, which had been carried on for automation of construction machinery aimed at improving the efficiency of work at construction sites and for systematization of construction procedures, were given clearly-defined direction of progress toward the development of construction robots, supported by the diffusion of industrial robots and the commercialization of microcomputers. By these results, during some 25 years about 600 systems for the automation, unmanned operation and robotization of construction works have been developed and tried in Japan. Through a period of progress from single-function devices to multifunction ones, research activities are now focused on developing a total system of construction technologies covering all aspects of construction management. These activities feature the basic principle that "construction" works, which have been centered around construction sites for decades, be dealt with as a total system of works comprising not only the procedure for building new structures but also tasks for repair and replacement of structures in service at the maintenance and management stages. In addition to the provision of artificial intelligence for construction robots themselves, research projects have been launched recently to find new types of construction robot system.[2]

The U.S.A. develops not only robot that emphasize in total system automation, but also for single work. Specially, they are inclining effort to develop robot that is fit in underground, bottom of the sea and environment of space as well as ground space. Recently, construction robots based on simulation and control technology that utilize remote control and automatic position revision system are for utility phase.


a) Con'c Surface Finishing Robot


b)Con'c Placing Robot


c) Steel-frame welding robot

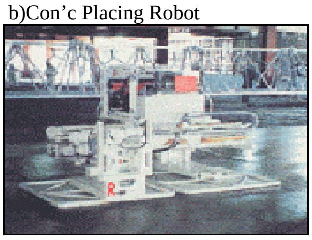

d) Water absorption robot

Fig. 1. Construction Robots(Japan)

Korea set forth the research on robot motivated by the government to cope with the necessity on the construction automation in 1980s. Currently, piping robot and robot for the bridge safety diagnosis are commercialized on the basis of the outputs from KICT's(Korea Institute of Construction Technology) and some university annex R&D centers. Intelligent robot is forecast to be commercialized for ensuring the construction safety in 2010-2012, and measuring robot is for the purpose of the maintenance in 2010. Then, 5-10% of construction facilities are predicted to be replaced by construction robot.[4]

B. Space Construction Robots

The most distinctive difference between CR and SCR is the workplace. The SCR works on a planet or in universal space. The robot developed to build ISS (International Space Station) is an SCR, and the true SCR similar to the CR is not available because there is no space construction project under progress. Exploration robot sent or to be sent to a planet may be specified into SCR if the exploration is regarded as a basic activity for the construction, but its exclusion is normal due to the difference between exploration and general construction works.

1) Space Construction Robots Development Example

a) ROKVISS & ROTEX

ROKVISS is developed in German. It was installed on the surface of the service module Zvezda, which stands for Robotics Component Verification on the ISS, consists of a small double-jointed manipulator arm, an illumination system and a power supply. ROKVISS is a fifty centimeter-long robotic manipulator with two hinges, a controller, lighting system, metallic fingers and two built-in cameras.

ROKVISS will be commanded by operators on the ground at the German Space Operations Center outside Munich, or the German Aerospace Research Institute -- which has six facilities at separate locations -- during periods when the ISS is flying over the country. The space station crew also can operate it.[14]

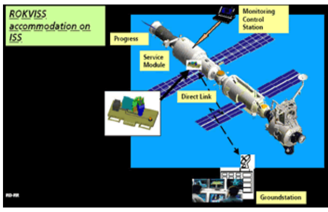
b) EMR(Mr. E)

A robot arm made in China is trying to earn a placement on the International Space Station (ISS) and participate in the construction of the large multinational orbiting outpost. The mechanical arm is part of China's continuous research effort on robotics that has spanned more than a decade. The robotic system has two "limbs" connected by a joint in the middle. At the end of each "limb" is another joint, which connects a smaller mechanical section that acts like the "hand" of the robot arm.

There are a total of nine joints and 14 pairs of sensors on the robot arm, which has a formal name of "EMR" and a nickname "Mr. E". These grapple devices are equipped with various sensors and will behave like "digits" of a hand, which could perform precision operation.[17],[18]

c) Canadarm2

The Canadarm2, or Space Station Remote Manipulator System (SSRMS) is a new generation Canadarm, the first component of the Mobile Servicing System (MSS) was launched on STS-100 early in the station's assembly sequence. The Canadarm2 is a large machine. It's 17.6 meters (57.7 feet) long when fully extended, weighs 1,800 kilograms [kg] (3,968 pounds [lbs]) and can work with up to 116,000 kg (255,736 lbs) of work. The structure is made of 19 layers of high-strength, temperature resistant carbon fiber called thermoplastic. The robotic arm has force-movement sensors that provide a sense of touch so that astronauts can tell the force with which the arm comes into contact with various objects. There are four cameras, located at each side of the elbow and on the LEEs. This enormous moving crane can be controlled autonomously or by astronauts. Canadarm2 receives its power from Power Data Grapple Fixtures (PDGF) on the ISS, which are much like electrical outlets spaced throughout homes on Earth. Canadarm2 can move anywhere that a PDGF is available. Because it uses the PDGF for power, the arm isn't permanently mounted to one particular spot on the Station.[15],[16]



(a) ROKVISS


(b) EMR

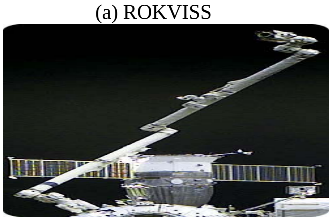

(c) Canadarm2

Fig. 2. Space Construction Robots

III. SPACE CONSTRUCTION

A. Necessities of Space Construction

Stressed on the significance of environment while the growing needs on the development from the increasing population and improved living quality, the construction business faces a lot of restrictions. The environment can not be perfectly conserved by the current technology if both construction and environment conservation are pursued, so the change of the development objects can be taken into account as alternatives such as skyline building, development of underground space and development of oceanic space and so on. Now, many people are thinking the universe as a future alternative.

B. Type of Space Construction

The space construction is split into the works on a planet and in the universal space. The work on a planet is carried out on the planet with the ground as same as on the earth, and one case is the construction of large-scaled living space like the moon station. Building structures without the foundation like ISS under construction can be taken as an example for the work in the universal space. Strictly speaking, ISS is different from the original concept of construction because it is made in the assembly of the pre-made modules on the earth, but it may be classified into the construction in that there are structures made in the assembly of pre-made parts on the earth, and that ISS is to build the structures for multiple purposes including residence. The construction on a planet's ground is supposed to be conducted in similar ways as on the earth, but we may not jump to the conclusion because not a detail blueprint is available yet.

C. Plans of Space Construction

The United States published the 3-stepped space development projects in 2004, which included the space construction plan. The second step from 2015 to 2020 comprised the construction program of a manned station which might enable the astronauts to live there for a long time. Many experts foresee this program to come true around 2030. This can be an example for the space construction.[13]

Japan has a plan to set up an airbase on the moon with 3 trillion-yen investment by the government and large-sized construction companies in 30 years and a colonial city accommodating 10,000 in 2050. Japanese colonial city is projected to be furnished with power plant, farm and leisure facilities as well as resident districts. The research for this has been processed for more than 10 years.

Chinese manned space projects released in 1999 included the building of a moon station to mine the lunar minerals. China is anticipated to publish the concrete scheme sooner or later by considering their recent investment on space development.

D. Considerations for Space Construction

The space construction shall be processed in the direction of building the resident space and the other needed facilities. The space construction can not be materialized without diversified essential technologies. The concrete plan for the space construction is prerequisite for the development of these technologies. The concrete plan means here classifying the working scope of the space construction and helps clarify the development direction of SCR. The following factors based on the findings from the collected information on space should be reflected in the space construction plan.

TABLE I
FEATURES OF PLANETS

Planet	Surface gravity (Earth=1)	Surface temperature(℃)	MASS (10^{24}KG)	ATMOSPHERE
Mercury	0.38	-173 ~ 427	0.3302	-
Venus	0.91	482	4.8690	CO_2
Earth	1.00	15	5.9742	N, O_2
Mars	0.38	-140 ~ 20	036419	CO_2
Jupiter	2.37	-121	1898.8	NH_3
Saturn	0.94	-125	568.5	H, He
Uranus	0.89	-193	86.625	H, He
Neptune	1.11	-193 ~ -153	102.78	H, He
Pluto	0.07	-230 ~ -210	0.015	-

Firstly, the dynamics of the universe is different from that of the earth. Every planet has its own gravity, and the space is in a gravity-free state. This must make an impact on the structural features. Therefore, the design should be based on the structural formula reflecting this point, and the details of the design including the structure type can be varied depending on the interpretation.

Secondly, the different environmental factors like temperature, and climate should be taken into account. There is no wind or rain on the moon, which makes a significant influence on the material features. The material options should be made considering the materials' intensity, chemical and physical reaction to the air components and to the different temperatures.

Thirdly, the planets are composed of different components from the earth. Earth-typed planets like Mercury, Venus, Mars and Pluto as well as the earth mainly are mainly made of rocks. Juniper-typed planets are filled with gases like hydrogen and helium, and the site construction is impossible as they have no ground. The structure materials of the earth-typed planets are diversified and should be taken into consideration at the foundation works, one of the major construction phases.

Fourthly, the construction management including the facility choice, material transportation and storage must be flexible in accordance with the workplace at space. In particular, the space construction needs enormous investment, so the management plan should be set up by reflecting the life cycle.

Finally, the construction method may be the key factor. The construction of the structures as figure 2 may require not so many constructive factors, but the manual works are hardly possible owing to the limitation of space suit if they are assumed to be done in the same way as on the earth. In other words, many parts of jobs are expected to be relied on the SCR. But there is a limit in size and shape due to the shipping space shuttle. The construction methods should be projected by considering these restrictions.

TABLE 2
AREAS OF SPACE CONSTRUCTION

Mechanics & Structure	• Aerodynamic • Dynamics & Controls • Dynamic analysis • Dynamic response • Structure integrity • Structure design • Thermomechanical response • Impact safety, etc.
Ground	• Ground property • Engineering properties of regolith • Ground stability • Foundation Design, etc.
Environments	• Engineering in extreme • Gravity environments • Environmental effects, etc.
Materials	• Soil properties of each planet • Concrete reaction & crack • Steel corrosion • Water reaction • Thermomechanical response • Welding, etc
Construction & Project management	• Project economic analysis • Related law review • Project planning • Construction method • Project support, • Procurement management

IV. DEVELOPMENT OF SPACE CONSTRUCTION ROBOT

A. *Works of SCR*

The construction on the planet is anticipated to be processed in general order of exploration, survey and measurement, excavation and assembly as do on the earth. But, the space construction shall be nearer to the parts' assembly rather than construction. So the SCR specialized in the examination and repair as well as the assembly needs to be developed.

B. *Considerations for SCR Development*

Many portions of the construction works in the space have no choice but to depend on the SCR because of the workplace's danger and specialty. As aforementioned, there are many factors to be considered in the space construction projects, and the follows should be noted in the development of SCR.

1) Materials

The temperature of the SCR's workplaces shows a dramatic fluctuation, and the non-existence of the atmosphere can make the SCR exposed easily to the harmful rays emitted from the sun. So the SCR's outer cover' and the parts' materials should be resistant to these conditions.

2) Transportations

Two alternatives can be taken into account for the SCR shipment. The one is to deliver the finished body from the earth to the workplace, and the other is to manufacture each part into module, and transport the modules and assemble them at the workplace. The SCR is purposed to undertake dangerous and hard works and to enhance the productivity as it is expected to complete much more works than the human workforce. Therefore, the SCR shall be made in the size and shape to maximize the productivity, and the shipment in the state of modules will be preferred except the case of the availability of the space shuttle which is big enough to transport the desired SCR.

3) Operations

The operation part with no relation to the actual working should be minimized by virtue of the mobility. In other words, the SCR should be unmanned robot controlled remotely. In this case, the feasibility of control time gap depending on the location and distance with the controller and of missing control information should be predicted.

4) Power Supply

One of the SCR's mechanical specifications is a motor for the operation. It is hard to supply with the power directly in space in contrary to the earth where the energy resources are supplied firsthand. Due to this fact, the most idealistic power resource might be the solar heats. But the solar battery has to have the capacity to cover the SCR's consumption for the works, and it can bring about some obstacles by considering the current technology level. To fix this problem, recharging technology should be promoted to charge the battery during the non-operation as desired. A kind of generator can be built in, but in this case, it might restrict the mobility and working scope owing to the connection between the power resources and the equipment.

5) Maintenance

The SCR has the mechanical and electrical features and should be maintained properly for the extended utilization. It might not be a big problem if the operator can always stay near to the equipment, but the unmanned robot should carry out a self-repair or self-maintenance, and the operation should not be influenced by minor troubles. It should be designed solidly at the development stage and developed in the orientation of minimizing the maintenance causes and of self-maintenance function.

6) Construction Methods

The actualized space constructions are not under process except ISS at the moment. Accordingly it is limited to map out the construction methods clearly. The decision on the construction method is a crucial factor to determine the overall space construction and the development type of the SCR. The structure type and the construction method are decided prior to getting into the robot development projects as shown in ISS.

TABLE 3
CONSIDERATION WORKS AND NECESSITY TECHNOLOGIES OF SPC

	WORK PLACE	CONSIDERATION WORKS	NECESSITY TECHNOLOGIES
Space Construction	Work on Planet ex) Lunar city	Inquiry Measurement Excavation Construction Assembly Maintenance/repair Inventory management Material conveyance	Sensing Controlling Communicating Monitoring Moving Armor materials User Interface Power Supplying
	Work in Space ex) ISS	Assembly Checking/Inspection Maintenance /repair	

C. Technologies for SCR Development

The technologies demanded for the SCR development are sensing technology, mobility, operation technology and communication technology as same as the existing CR (see table 4). But the workplace of the universal space needs more in-depth research than that of CR, and some specific areas including the aforesaid power supply should be studied with completely new approach. The necessary technologies and the significance of the SCR development should be embodied to practice the space construction projects. In particular, putting the preference per each technology may be very meaningful for the future SCR development, but not at the moment when a lot of uncertain factors exist. Currently, the realizable technologies are asked to be developed within predictable scope.

V. Conclusions

The space construction has more uncertain factors than certain ones, but it is sure that this is an area the construction engineer should undertake. A number of studies on space construction are available for the moment, but its actualization should be assumed by the construction engineers and is expected to need the aids of a robot appropriate to the construction works. It is anticipated to be realized in near future as the interests in the space development get higher. Fixing the detail scheme for the space development is above all fundamental to the development. If the location of the structure, structure type and construction method are mapped out, the needs on SCR should be figured out to plan the details. At the current stage, it is possible to predict the demanded technologies to build up the lunar station and Mars city based on the experience with the SCR used for ISS construction. And the research can be conducted in this direction. In addition, an organization has to be set up to link the experts of various fields and to integrate the outputs of every field's independent research.

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