# STUDY ON SPACE ROBOT’S END-EFFECTOR EXCHANGE MECHANISM

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## ABSTRACT

This paper introduces why it is necessary for space robots to exchange their end-effectors by themselves and summarizes several system requirements for a new end-effector exchange mechanism. Then development of a prototype model (under the support of DLR) with a set of test apparatus, and results of operation tests are stated.

## 1 INTRODUCTION

Future space missions, like construction and assembling of large space structures such as lunar base and space solar power system: SSPS are impossible to be operated by human beings without the support of robots. Those missions need various robots, and in addition, manual operation and maintenance for robots in space is also unavailable so spare components are required. However, rocket is still the only way of transportation to space. The limit of payload capacity of rocket makes us take equipment as few as possible.

This restriction leaded to a concept of dividing robot into robot arm and end-effector. There is no need to take a robot arm for every end-effectors, however, an end-effector exchange mechanism: EEEM is necessary to connect robot arm and end-effector from both mechanical side and electrical side as interface. Hence, Tokyo Tech and German Space Center: DLR started a collaborated research about EEEM.

Actually, several EEEMs have been developed already. The following is detail survey of two previous EEEMs for space robot which are priorities of this study.

ETS-VII which was launched in 1997 is an experimental satellite. For the sake of making its robot arm hold all sorts of payloads, there are three types of grapple fixture between end-effector of robot arm and payloads to play the role as EEEM.

There are three ball-shaped alignment cones on the grapple fixture for misalignment canceling. Three sets of finger covers help the fingers on the tip of end-effector to grasp the grapple fixture accurately. Then three latching mechanisms will hold the grapple fixture. [1][2]

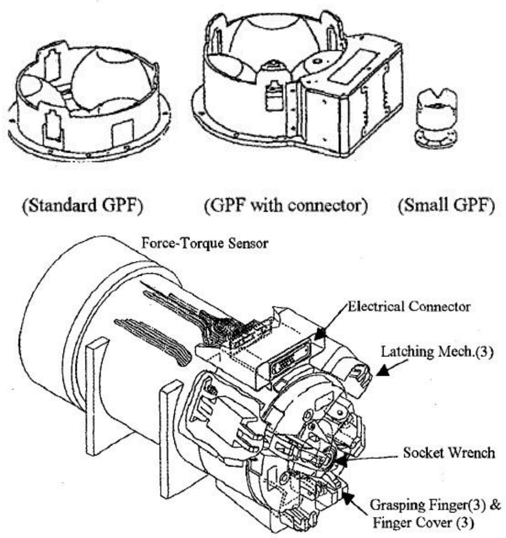

*Figure 1: ETS-VII grapple fixtures(upside) and End-effector(downside) ©JAXA*

The Special Purpose Dexterous Manipulator: SPDM, also called “Dextre”, was launched in February 2008. It is the last component of Canada’s Mobile Servicing System: MSS for the international space station: ISS.

Dextre’s arm can connect to end-effectors through an ORU-Tool Change out Mechanism: OTCM. For example, the OTCM has an internal Gripper Mechanism to drive its two jaws which can capture a standard Micro Interface on the bottom of the Self-Adapting Robotic Auxiliary Hand: SARAH. Then a Socket Head of the OTCM will extend to engage a captive hexagonal bolt head, and thus the OTCM is capable to control the fingers of SARAH through the Socket Head and a switching mechanism. Moreover, there are a pair of lights and a bore sight camera so operators can perform operation with less misalignment. [3][4]

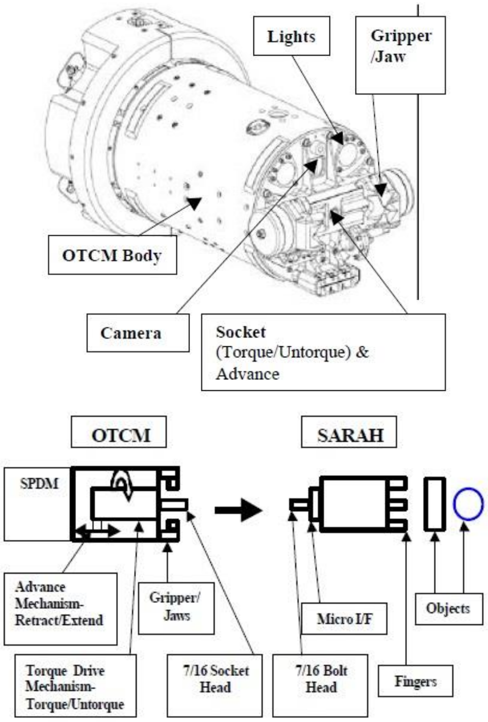

*Figure 2: OTCM(upside) and Interaction of SPDM/OTCM and SARAH(downside) ©CSA*

According to above background of this study, the objectives of this study can be summarized as follows.

- To investigate the system requirements for a new EEEM which should be superior to the previous ones.
- To develop a new EEEM including a prototype model and a set of test apparatus for it.
- To operate function verification test, optimization test, and to study method of misalignment canceling.

## 2 SYSTEM REQUIREMENTS

Requirements for a new EEEM which should be superior to the previous ones will be summarized in this section.

(1)For the sake of cost saving, we will just develop a prototype model whose diameter is required to be less than 100mm at first. It is supposed to be utilized as a assembling robot for a construction mission.

(2)Requirement about misalignment tolerance is that both position misalignment and rotation misalignment should exist without an external force and support of camera feedback during capture.

To meet above requirement, we propose a concept of EEEM by using spring force. A spring-capture mechanism is applied to ensure accurate docking and increasing misalignment tolerance.

Figure 3 shows open mode and close mode of the spring mechanism. Left is the open mode while spring is in natural state. Right is the close mode while spring is restricted by some external mechanism.

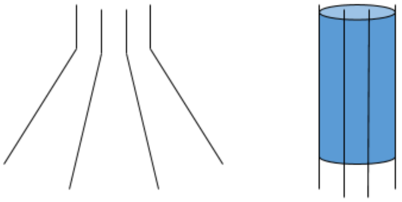

*Figure 3: two modes of spring mechanism*

Figure 4 shows the concept of the new EEEM. Left shows that the spring mechanism gets into open mode and is capable to capture the end-effector with large misalignment tolerance. Right shows that the spring mechanism gets into close mode and is capable to lock the end-effector onto the robot arm.

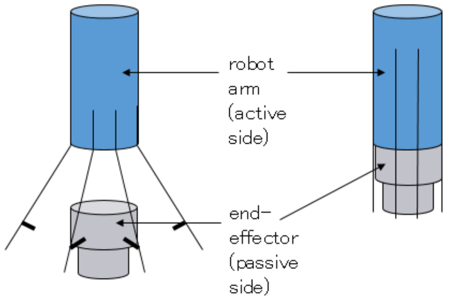

*Figure 4: concept of the new EEEM*

(3)Electrical interface will be set at the center of whole mechanism as minimal solution for Regolith problem.

Otherwise, several electromagnetic mechanisms are proposed to be installed on the docking surface to remove Regolith with the support of physical method. However, this concept is not verified in this paper due to the limited test condition and the author of this paper will continue this study as future research theme.

A comparison with the previous EEEM is given in table 1.

*Table 1: comparison of 3 EEEMs*

| | New EEEM | ETS-VII | Dextre |
|---|---|---|---|
| Operation environment | On-orbit service & planet exploration | On-orbit service | On-orbit service |
| Size (diameter) | Less than 100mm | About 130mm | About 180mm |
| Type of locking | Latching mechanism | Latching mechanism | Bolt/socket & latching mechanism |
| Method of misalignment canceling | Increasing capture range by spring | Ball-shaped alignment cone | Gripper/jaws & camera feedback |
| Position of electrical interface | Center | Outside | Outside |

## 3 DEVELOPMENT OF TEST APPARATUS

After discussion about the concept to meet system requirements, a prototype model is developed.

A prototype model as below is completed. There are two linear motion guides which are driven by motor on active side of EEEM. One guides the holding plate for springs and the other guides the holding plates for fixing-pins. (Fixing-pins play the role as external mechanism to restrict the springs.) First springs come out and open to capture passive side, then fixing-pins come out to close springs, eventually, they are retracted at the same time and lock passive side onto active side.

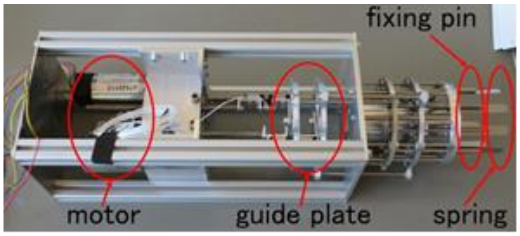

*Figure 5: mechanism of the prototype model (active side)*

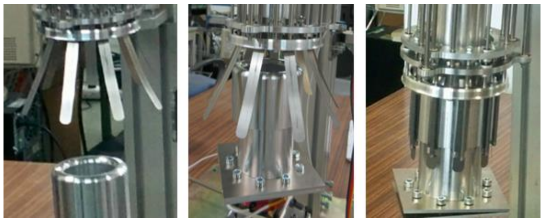

*Figure 6: capture process of the fingers*

Main parameters of the prototype model (active side) are given in table 2.

*Table 2: main parameters of the prototype model (active side)*

| | |
|---|---|
| Size (springs and pins are retracted) | 131mm×140mm×405mm |
| Maximum length (springs and pins are deployed) | 475mm |
| External diameter of capture portion | 90mm |
| Internal diameter of capture portion | 38mm |
| Weight | 3437g |
| Motor type | Maedler 47520113 |
| Motor power | 36W |
| Maximum distance between two guide plates | 74mm |

A set of test apparatus for the prototype model is also developed.

A compliant base connected to the passive side using spring and spherical joint to provide capability to rotate for several degrees at 2 axes is fabricated. And a roll stage connected to the active side introduces rotation misalignment while a Y stage connected to the passive side introduces position misalignment.

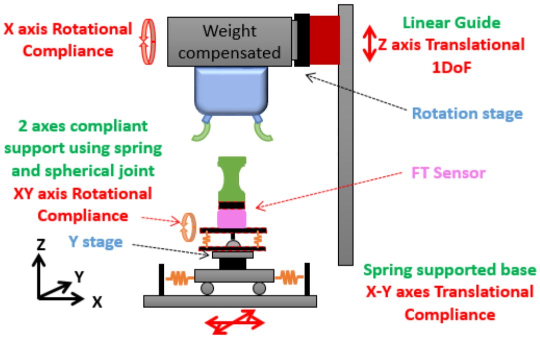

*Figure 7: concept of test apparatus*

An electrical control circuit is developed as figure 8.

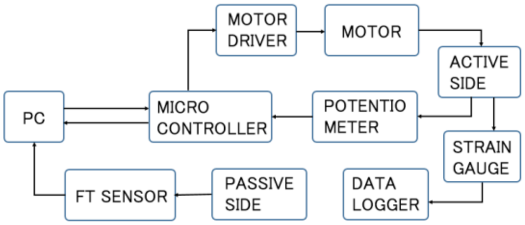

*Figure 8: block diagram of electrical control circuit*

An H-bridge motor driver and an Arduino microcontroller board are inserted into the control circuit to control the motor direction and the motor speed. Two potentiometers are installed to monitor the movement of the guide plates to avoid collision. Two strain gauges are installed to measure force acts on the motors and we read the data by a data logger. A capacitive 6 axes force-torque sensor is used to measure force and torque loads on the passive side under docking conditions.

The whole test apparatus is shown as figure 9.

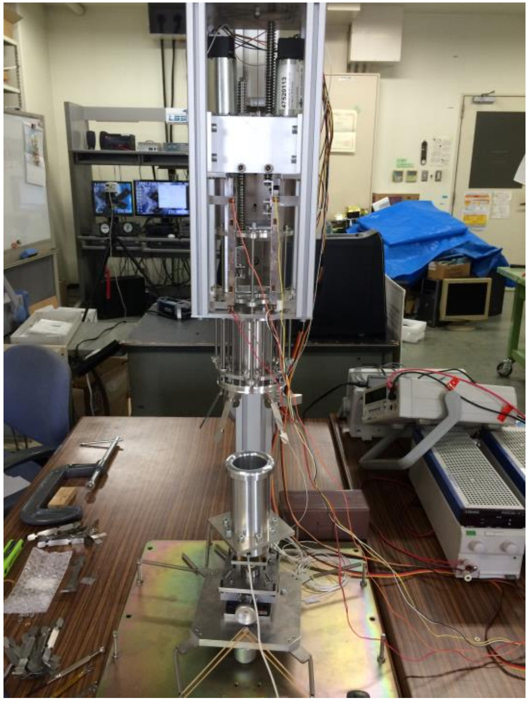

*Figure 9: the whole test apparatus*

# 4 OPERATION TEST RESULTS

## 4.1 Function Verification Test

(1)A maximum force load of 200N which the prototype model can withstand is confirmed.

(2)A maximum torque load of 5N・m which the prototype model can withstand is confirmed.

(3)A maximum position misalignment of 21mm which the prototype model can withstand is confirmed.

(4)A maximum rotation misalignment of 5° which the prototype model can withstand is confirmed.

(5)The velocity of springs during deploying is 9.3mm/s, the velocity of fixing-pins during deploying is 9.0mm/s, the velocity of springs and fixing-pins while they are retracting simultaneously is 8.9mm/s.

## 4.2 Optimization for End-Effector Exchange Mechanism

(1)Three types of springs with different thickness (0.3mm, 0.2mm and 0.1mm) are tested.

(2)Three patterns of number of springs (9, 6, and 3) are tested.

(3)Two types of passive side with edges of different thickness are tested.

(4)Two different positions of latching points were tested.

According to comparison of above test results, a set-up with 0.3mm of spring thickness, 6 springs, thin-edged passive side, and high latching position was selected as the best combination.

Optimization of the prototype model can also be generalized to other EEEMs of this spring-capture type. They will be summarized as below.

- Type of springs.

If there is no plastic deformation on the springs when closed by external mechanisms, springs as thick as possible which means springs with coefficient of elasticity as large as possible are desired.

- Number of springs.

Angle between misalignment and spring should not be too large leads to an ideal number of springs of 6 or 7.

- Shape of passive side.

Thin-edged passive side is preferred because of the better docking performance and less weight than thick-edged passive side.

- Position of latching points.

Higher latching position is preferred because of the better docking performance but it should be calculated to satisfy system requirement of misalignment tolerance.

- Shape of latching mechanisms.

Furthermore, additional improvement for latching mechanisms should be taken into account in order to increase misalignment tolerance.

## 4.3 Study of Relation between Docking Force and Misalignment

(1)Docking force and torque acts on passive side which is got with position misalignment of 0mm, 2mm, 4mm, 6mm, 8mm, and 10mm and rotation misalignment of 0°, 1°, 2°, and 3° is compared.

(2)Maximum docking force and holding force acts on motors which is got with rotation misalignment of 0°, 1°, and 2° is compared.

Test results are shown as below.

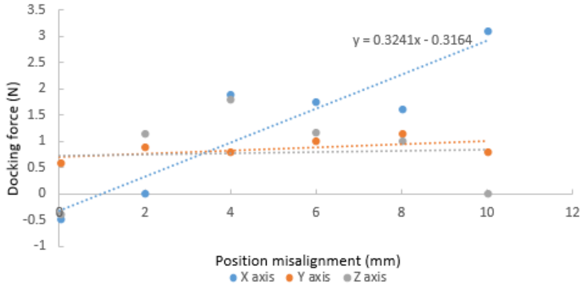

*Figure 10: relation between docking force and position misalignment*

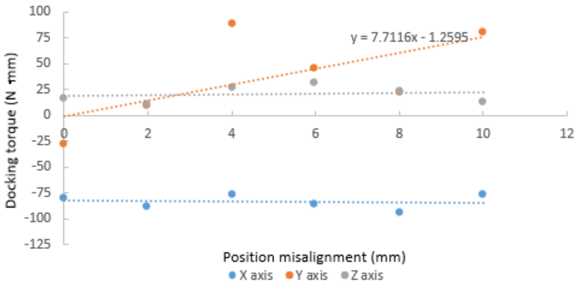

*Figure 11: relation between docking torque and position misalignment*

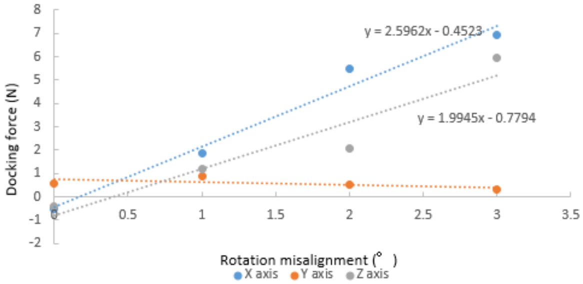

*Figure 12: relation between docking force and rotation misalignment*

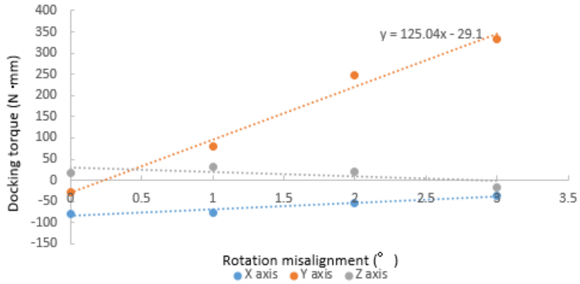

*Figure 13: relation between docking torque and rotation misalignment*

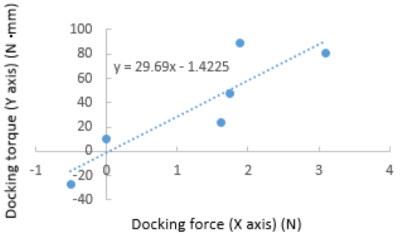

*Figure 14: relation between docking force and docking torque (with position misalignment)*

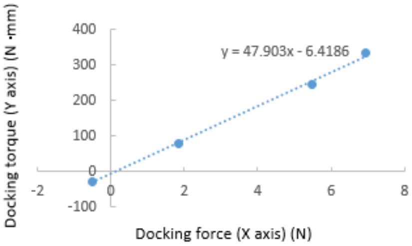

*Figure 15: relation between docking force and docking torque (with rotation misalignment)*

Docking force at direction of X axis and docking torque at direction of Y axis increase linearly with both position and rotation misalignment. And if comparing relation between docking force at direction of X axis and docking torque at direction of Y axis with two types of misalignment, it can be found that proportional coefficient with rotation misalignment is larger than that with position misalignment.

*Table 3: force acts on motors with different rotation misalignment*

| Rotation misalignment (° ) | 0 | 1 | 2 |
|---|---|---|---|
| Maximum docking force(spring) | 51.87 | 55.92 | 58.79 |
| Maximum docking force(fixing-pin) | 35.45 | 36.76 | 36.81 |
| Holding force(spring) | 21.69 | 26.25 | 30 |
| Holding force(fixing-pin) | 31.22 | 31.89 | 26 |

There is no linear relation between force acts on motors and rotation misalignment. The reason is considered as that when misalignment gets large (in this test, it means angle of rotation misalignment is 2° ), several degrees (in this test, it is 0.5° ) of back angle occurs on the rotation stage.

Based on above test results, a method of misalignment canceling for robot arm control is proposed. For a known misalignment at the passive side (end-effector side), the active side (robot arm side) is able to cancel it as below.

- For position misalignment.

A horizontal locomotion is enough to cancel position misalignment.

- For rotation misalignment.

In practice, rotation misalignment occurs at the passive side instead of the active side in the test. So horizontal locomotion as well as rotation is necessary and displacement of locomotion should be calculated in advance.

- Back angle occurring on rotation stage

Relation between back angle and original misalignment should be studied further.

## 5 CONCLUSION

This paper supposed a space construction mission and the end-effector exchange mechanism: EEEM of robot arm which is necessary for it. A new concept of EEEM is proposed, a prototype model is developed and operation tests are done. Further study will be extended on method of robot arm control, and solution for Regolith problem.

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