“Skil Mate”, Wearable Exoskelton Robot

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ABSTRACT

A wearable exoskelton robot, Skil Mate, is a new concept that can assist skilled workers in power as well as in skill. Skil Mate is composed of servo mechanisms and haptic devices (tactile or slipping-off sensors/displays), so that it can follow the workers movement. Skil Mate is suitable for works under hazardous environment such as in space, under sea, etc. Goal of the project is to develop a prototype model of the wearable robot for a spacesuit, which consists of an upper torso assembly and a pair of arms with gloves.

1. INTRODUCTION

An Extra-vehicular activity (EVA) robot, Shuttle RMS, has carried out important tasks in space programs, and other EVA robots are under development or under experiment for future EVA tasks. While the number of tasks for EVA robots will increase in the future, there exist inevitable tasks for astronauts.

The astronauts need spacesuit to protect themselves from hazardous environment, such as vacuum, high/low temperature, micro-meteoroids, etc, Because, the space suit is pressurized in 1/3 of atmosphere, it becomes stiff by the tension of space suit fabrics. And, thick fabrics inhibit an astronaut from sensing objects to be handled. The major problems caused by the space suit are [1]:

(i) Hand and shoulder fatigue.

(ii) Lack of sense at fingertips.

(iii) Restriction on range of motion.

Research and developments for the first problem, especially finger metacarpophalangeal (MCP) joint fatigue, have been done as power assisted gloves [2][3][4]. Experimental results of these developments showed that the power assisted gloves could reduce MCP joint torque, but these developments did not deal with the lack of sense at fingertips, which is necessary for skilled works.

One of the solutions for these problems, the authors propose a new concept, "Skil Mate", a wearable exoskelton machine for skilled workers. Skil Mate concept is not just for astronauts but for skilled workers under hazardous environments.

In this paper, Skil Mate concept and its application are introduced, and then prototype development for space suit is outlined.

2. FEATURES OF SKIL MATE

The Skil Mate is a generic name of a machine or a device that moves when the human wears it. And, it is a passive machine having non-autonomous intelligent response incorporated in the human intellectual operation system. Features of Skil Mate are as below.

(1) It is to be worn by a man of skill in case that he should unavoidably work to accomplish tasks as an expert under hazardous environments such as in space. Usually, the man who works under hazardous environment needs protection suit, for example, space suit on orbit or dry suit under the sea. And, these suits restrict the man’s movement and increase his fatigue. Skil Mate allows the man to decrease muscle strain while he works.

(2) It is exoskeletal structure to envelop the man’s body and it does not restrict the man’s movement on joint arrangement and on joint range of motion.

Moreover, haptic receptors or sensors should be mounted as interfaces between the human body and the object to be handled in order to enhance task efficiency. Consequently, it looks like an anthropomorphic robot when it is worn.

(3) It is controlled to follow in response to the man’s

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movement. Its response must be quick enough as the worker has senses without wearing Skil Mate or attached nuisance for their action, supporting his skill as if he is in the most desirable circumstance for his work.

And, as an optional function, it is an exoskeletal shell that allows the worker to protect from hazards. The worker under hazardous environment will get benefits from Skil Mate with the protection shell. Skil Mate may be the inevitable work suit for the works in the environment such as under high water pressure, low temperature and radiation exposure. Even if the protection shell is so thick making human movement slow like a fire-fighting suit, powered Skil Mate will compensate its mass, inertia and stiffness by its servo system. Wearing Skil Mate is to feel wearing no clothes or no working suit at all.

3. SKIL MATE FOR EVA

In November 1997, Dr. Doi, Japanese astronaut, got on board in space shuttle "Columbia". By wearing a spacesuit, he made extravehicular activity (EVA) to two times. The first activity was the capture by handgrip of the Spartan satellite. The second were emission and recovery of the robot camera and the sum total activity hour of EVA exceeded 12 hours. (Figure 1)

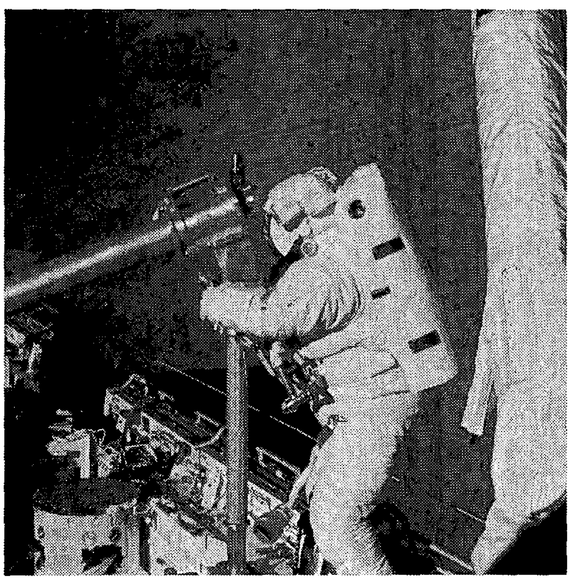

Figure 1. EVA (Japanese Astronaut Dr. Doi)
NASDA Photo No: DOI-141CD0494-053 [6]

The authors discussed EVA experience with Dr. Doi. And he pointed out the space suit problems as below :[1]

(1) Hand fatigue: The space suit glove was stiff because of pressurization with 1/3 of atmosphere and the astronaut need more finger force to overcome the stiffness. Still more EVA tasks included frequent grasping motion, for instance, grasping the handrails for moving himself, grasping hand tools. He also mentioned that mainly thumbs, forefingers and middle fingers were used for grasping motion.

(2) Difficulty in complex and sensitive tasks with fingertips: Fingertips of the space suit glove were covered with rubber and this did not interface slipping nor holding sense. He carried out this kind of tasks mostly by using his vision not by his sense of the fingers.

(3) Restriction of motion: The space suit had one bearing joint at the shoulder and if shoulder movement was not along the bearing joint, shoulder muscles may fatigue. If there were two bearing joints at the shoulder, this problem will be improved. And, he added that waist and hip flex was poor and this made him difficult to see switches at his chest.

From above discussion, application of Skil Mate to the space suit will have following features.

(a) Skil Mate provides force/torque to the space suit joints to cancel the stiffness caused by the pressurization. Skil Mate also detects astronaut's movement for servo mechanism.

(b) Skil Mate detects/displays force, pressure and slip sense at the fingertips, which allow the astronauts to accomplish complex and sensitive tasks.

4. PROTOTYPE MODEL

Development of the prototype model started in the summer 1998. In the FY, we focused on hardware design and assembly. This section shows our project status of the prototype model development.

Actuator

McKibben artificial muscles have been adopted as one of actuators for Skil Mate. Major advantage of the actuator include:

(1) larger power/weight ratio than electro-magnetic motors;

(2) major charactoristics of the actuator is similar to human muscles [6][7].

The prototype actuators for Skil Mate, shown in Figure 2, is 8mm (5/16 inch) diameter and 150mm (5.9 inch) long which generate more than 200N at 400kPa (58 psi). Force measurement of the actuator is shown in Figure 3. From the measurement, model of the actuator is shown as below.

$$F = P\{a(1-\varepsilon)^2 - b\} - c \tag{1}$$

Here

F : Output Force in (N)

P : Pressure in (kPa)

ε : Strain

a : Constant (1.568 N/kPa)

b : Constant (0.7696 N/kPa)

c : Constant (86.0 N)

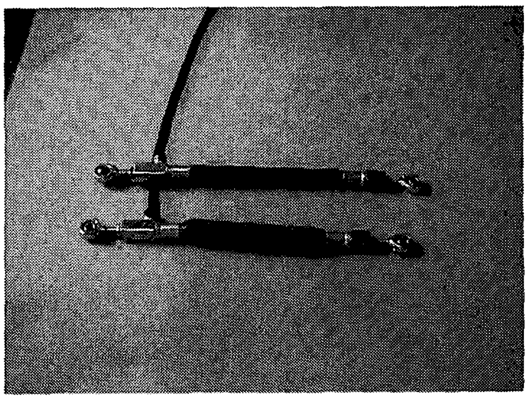

Figure 2. McKibben Artificial Muscle for Skil Mate

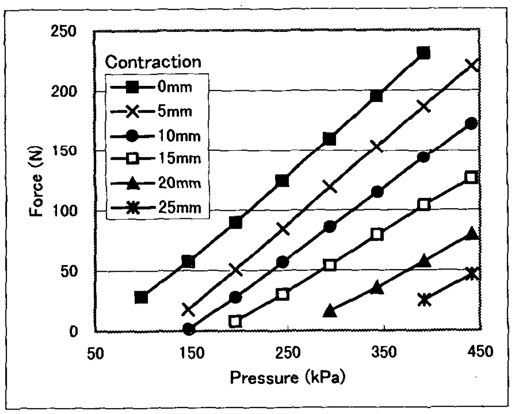

Figure 3. Actuator Output

Elbow Joint

Prototype elbow joint is composed of two artificial muscle actuators and an incremental encoder (shown in Figure 4). The actuators are placed as tendons for the elbow joint and generate joint torque. Electro-pneumatic regulators and a PC computer control the actuators. The weight of this joint is 376g.

This joint has been PID controlled for basic data acquisition. Experimental result of PID control without load is shown in Figure 5.

Tactile sensors (pressure sensitive conducting rubber) are going to be attached to detect human movement.

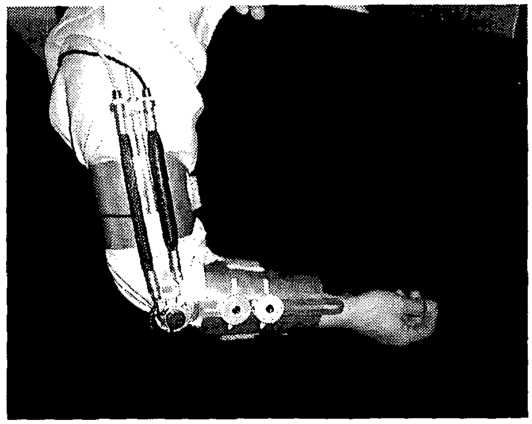

Figure 4. Elbow Joint with artificial muscles

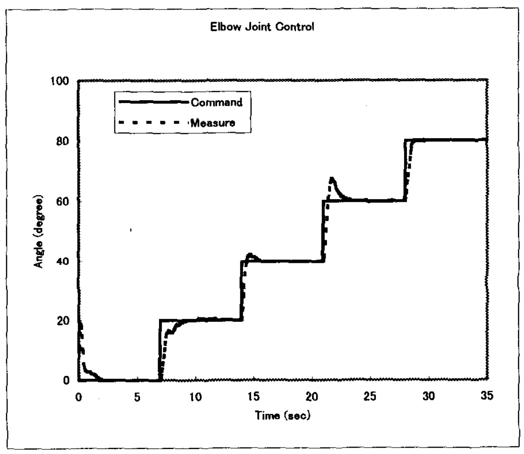

Figure 5. Elbow position control example

The elbow joint with pneumatic cylinders (shown in Figure 6) has been also built for comparison with the artificial muscle actuators.

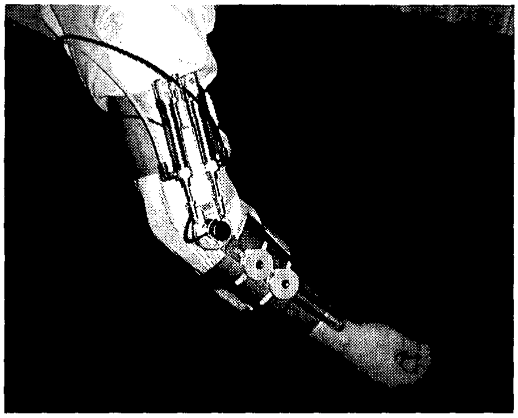

Figure 6. Elbow joint with pneumatic cylinders

Wrist Joints
The wrist joints have also been designed and built. The wrist joints have 2-DOF that are the roll and the pitch. Components of the joint are almost same as the elbow joint. The wrist joints have already assembled with the elbow joint then the joints plan to be tested and improved. The assembled joints are shown in Figure 7.

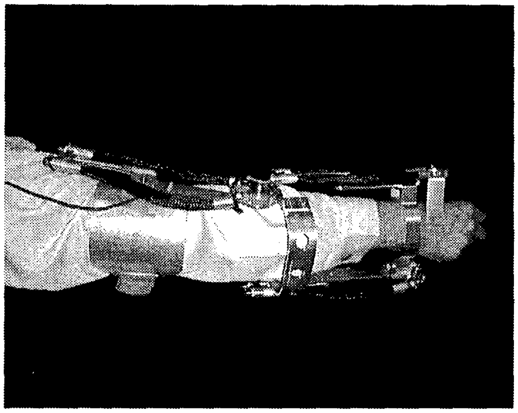

Figure 7. Assembled joints

Fingers
The finger joints are shown in Figure 8 and Figure 9. The finger joints are composed of the thumb, the pointing finger, and the middle finger. The pointing finger and the middle finger has 2-DOF each, that are the MCP and PIP (proximal interphalangeal) joints. The thumb has 3-DOF, which are the CMC (carpometacarpal), the MCP, and the IP (interphalangeal) joints. The small pneumatic cylinders drive each joint.

The pneumatic cylinders generate the flexion forces of the fingers and the extension forces are generated by the passive coil springs. The artificial muscle actuators are going to be attached to the glove for extension force if the spring forces are not sufficient.

Pressure sensitive conductive rubbers are attached to the fingertips to measure the force between the fingers and the gloves. Induction position sensors are to be attached to measure the finger joint angles.

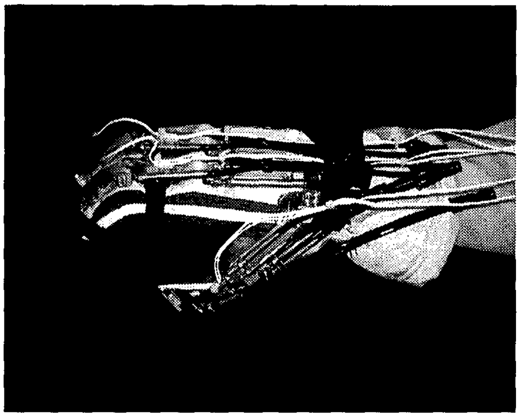

Figure 8. Prototype glove

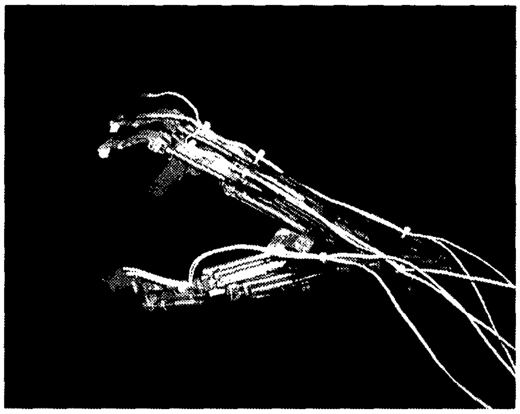

Figure 9. Finger joints without glove

Future Works
Next step of the prototype development is to assemble the fingers, the wrist joints, and the elbow joint. And, haptic devices are planned to attach the fingers.

Goal of the project
Goal of the Skil Mate project is to develop a prototype exoskeletal machine for a spacesuit. The prototype model will consist of an upper torso assembly, and a pair of arms with gloves. This prototype model will be placed between pressure garment and insulation layer.

The arms of the prototype have shoulder joints, an elbow joint, and wrist joints. Each joint is driven by pneumatic actuators and can sense joint angles. Tactile sensors are to be attached to detect human motion, so that the machine can follow the astronaut's movement. Because the prototype model is always interfaced to human, impedance control will be appropriate for man-machine cooperation. A Force-Torque sensor will be need between the wrist and the glove to accomplish the impedance control.

The structure of the glove itself and the interface between astronauts' hand and the glove will be studied and carefully designed. Haptic devices such as tactile or slipping-off sensors and displays will be need to accomplish skilful tasks.

5. APPLICATION FOR CONSTRUCTION WORK

Nowadays, "industrialized" and/or "advanced" construction systems are more popular in Japan and in the world. These systems realized effective production in shorter term and less labor power that caused better business profit to construction industries. On the systems, major work is done by construction machines supervised by a high performance information networks with a lot of computers. Automatic systems and robots are participating to the construction sites. Reducing the labor cost on the construction sites make more business profit.

On such construction sites, human workers are going to be one of the construction system components as a machine operator, or an intelligent transportation device, or a flexible handling machine. Modern and advanced construction systems, such as automated and robotic construction systems, are transplanted high-level skill from human workers.

While a lot of automated systems have been developed and practically used for construction work, human participation to the construction work is inevitable. The reasons are as below:

(1) There are hundreds of tasks in one construction site so that it is not realistic to apply automated systems to every task.

(2) Each construction site has different condition, which comes from design of the structure, environment of the site, etc.; as a result, one particular automated system is not always applicable to the other construction sites.

(3) Some of the human's skill has not been realized by automated systems. Of course, there exist tasks that can not be done without automated systems.

Application of Skil Mate to the construction work site is one of solutions to human-machine cooperation. The Skil Mate allows the worker to accomplish various tasks that human skills are need.

6. CONCLUSION

A concept of Skil Mate and its application for EVA are introduced. And, development status of the prototype model for a space suit is outlined. The first goal of the prototype development is to assemble the shoulder, the elbow, the wrist, and the glove. Future work includes haptic device development and impedance control of the joints.

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