

WEARABLE EXO-SKELETAL ROBOT, SKILMATE, AND ITS APPLICATION TO EVA SUITS

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Abstract

The authors propose a new concept "SkilMate", a kind of wearable robot, in order to reduce the fatigue of astronauts and to demonstrate their skill in EVA. This paper describes an outline of the SkilMate project. They also discuss the concept in view of the man-machine system, the configuration design, the control system, and the final target of the project.

1. Problems on Workability of Spacesuit.

It has been already reported that the operation performance of EVA in space is very bad and that the fatigue of the astronaut is intense. It is because that the comfort of the spacesuit is very terrible. This fact becomes a large problem which should reach solution for future space development.

There, we have the following three problems which must be cleared in order to improve the operation performance in this spacesuit wear and in order to demonstrate skill of the EVA work acquired by intense training of the astronaut.

- (1) Attaching servo-actuators on each joint of the spacesuit to make it actively controlled.
- (2) Controlling the position, the posture and the impedance of the whole movement system as the astronaut efficiently carries out the

mission.

- (3) Applying the compound haptic device on the finger palm to detect force, pressure, and slip senses.

Hence we denote that such machinery as satisfied with these three items should be a robotized machine. The spacesuit mounted with such three kinds of functional ability described above should work for the skilled astronaut to accomplish EVA activity skillfully.

2. Concept of "SkilMate".

The authors propose a new concept named SkilMate. SkilMate is defined as a generic name of machines or devices characterized 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 a hostile environment.
- (2) It is preferably exo-skeletal structured to envelop the man's body, and it is movable enough flexibly as the man is able to move as his will. Therefore, it should be mounted with haptic receptors or sensors in order to enhance intelligent workability. Consequently it looks move like an anthropomorphic robot when it is worn.

SkilMate is nothing but a wearable exo-skeletal

machine for the skilled worker to move maintaining his skill. It assists him in power as well as in skill due to the servo mechanisms of SkilMate.

The benefit of SkilMate will arise in the case where the worker should need to slip on some clothes to protect himself from a hazardous environment.

3. Features of “the SkilMate” as New Concept.

By inventing various kinds of machine, the human, being were able to expand the functional ability. Especially, the human is able to convert the intelligent function into automatic machines or robots recently. However, in spite of the effort of the conversion, human skill is still difficult to convert even if we use the most advanced intelligent robot technology. The advanced skill of the worker remains, therefore, very important and the conversion of such talent as veteran engineer executes the mission under the ultimate environment is also important.

In this research project, we assume that the astronaut wears a spacesuit in which a servo-actuated skeletal structure mounted with haptic sensors is attached, as if the handicapped wears artificial limb or hand. Thus we propose a new concept called SkilMate. Therefore, “the SkilMate” is a generic name of the machine with such effect, as described above. It can be sufficiently demonstrated that a skilled worker is able to perform his tasks most efficiently, when the worker wears it. He is also amplify the range and speed at work. In addition, the fatigue is drastically reduced by the wear.

The SkilMate is also defined as a wearable robot, because it shows its functional ability in case that it is worn by a skilled worker.

The machine of the resemblance to the SkilMate was proposed in 1960 generation.[1] The foreseeability must be evaluated. However, it was not successful by lack of the generic technology and the uncertainty of its concept.

The SkilMate defined in this paper is a well-defined machine, employing the most advanced robotic technology. It never moves as far as it is driven by the wearer even if the power is turned on. It moves, only if the human wears and drives it. The SkilMate is just an instrument in a sense. It is neither a powered machine nor automatic machine. And we say, it is not a robot standing alone. However, it moves on as the wearer’s intention, if he once fixes it and manages the body. It demonstrates the function which dynamically exceeds the human ability. It is able to attain controllability for stabilizing the movement and the posture of its own body. The skill in manual working is as efficient as that in bare hand. Therefore, it accomplishes the work as an intelligent machine. However, it has nothing on the autonomous function. It is just a passive machine having non-autonomous intelligent response incorporated in the human intellectual operation system. It is a uniquely defined machine that we have never experienced until now.

4. Compensation of Ballooning Caused by Spacesuit.

When an astronaut wearing a spacesuit bends the joint (elbow joint, for example) during performing a task in the extravehicular activity (EVA), the vacant volume contained inside between the arm and the spacesuit decreases, then the air in this vacancy is compressed. The compressed air causes a spring effect on the spacesuit which extends the bent astronaut’s joint back to its extended posture.[2] This spring-like

effect is known as “ballooning”.[3] The ballooning fatigues the astronaut in a short term and reduces efficiency of the task during the EVA, because he has to keep exerting the bending moment on the joint in order to hold it in the bending posture.

It is considered that the above disadvantages of the current spacesuit can be improved by compensating the ballooning with the SkilMate. However, the following problems are anticipated for the compensation:

- (1) The spring effect caused by the ballooning will be nonlinear. Moreover, it will be difficult to identify the model of this effect accurately.
- (2) The ballooning effect will vary according to the astronauts, because the shape and volume of the air space is different among them. This anticipation can be supported by an investigation on the EVA glove which reported that the hand of the astronauts is, the more the grip drops compared to the bare hand.[4]

5. Tuning of Control Parameters.

Not only compensating the ballooning, but also an ability to help the astronaut to show the skill is necessary for the SkilMate in order to improve the performance of the EVA. Therefore, the SkilMate is needed to determine its own control parameters so as to realize this ability. This is the second control problem of the SkilMate. In this paper, we consider this problem as a parameter tuning one on mechanical impedance of the whole system including the spacesuit, the SkilMate and the object handled by the astronauts. According to this consideration, the problem can be specified as follows:

- (1) How does the SkilMate determine the ideal inertia and viscous coefficients?

- (2) Does the SkilMate fix these parameters all over a task, or set them as time is varying?
- (3) Whether does the SkilMate append the spring effect or not? If the spring effect is preferred, where should its equilibrium point be located?

In order to solve this problem, we need an experimental study to find out the ideal impedance for tasks performed in the EVA. Since it is desired that the SkilMate works well under variation of conditions such as a motion velocity, and an initial and terminal postures of the task, this variation should be taken into account in our study. It is finally needed to express the ideal impedance quantitatively so that they can be referred by the controller of the SkilMate.

If we consider that the SkilMate is a robot cooperating with a human, a previous study on a cooperative task to carry an object can be referenced.[5] However, this study focused only the viscous coefficient, and has not dealt with the variation of the task conditions.

6. Goal of SkilMate Project.

SkilMate project was put into practice in August 1998. This project aims to manufacture mainly an exo-skeletal structure assembly to be worn by the astronauts for EVA (Extra-Vehicular Activity).

This structure assembly will consist of three parts, the upper torso, the lower torso assembly, and the pair of arms with gloves. Similar to SSA (Space Suit Assembly), these parts are able to be assembled when it is put on. The movement of every joint (shoulder, elbow, wrist, and so on) is controlled with servo-actuators which assist in the intentional movement of the astronaut.

The structure of gloves are most carefully designed, and the haptic devices such as tactile or slipping-off sensors/displays are indispensable to

maintain the skillness of the astronauts.

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