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Power Pedal as a Man-Machine Synergy Effector — Bipedal Walking with Human Skill and Robot Power —

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***Abstract*— We have proposed the concept of *Man-Machine Synergy Effectors*. These are high-performance tools for human use, which are realized by introducing robot technology. It becomes possible to perform conventionally impossible tasks by human alone or robot alone, because the system synergizes better assets of both parties. In this paper, the concept of Man-Machine Synergy Effector is described. Then, the *Power Pedal* is introduced as a prototype of Man-Machine Synergy Effector for human lower extremities, which amplifies human leg power intuitively.**

I. Introduction

It is generally dangerous for human to hold high-power robot directly. In the case of human power amplification by such a robot, there is a trade-off between stability and performance. That is, the greater amplification, the inferior is the stability of the system [1].

Although this trade-off is unavoidable in the human power-amplifying systems, it is not a serious problem. The really serious problem is that the instability is unpredictable without a precise dynamics model of the human-robot-environment system. Therefore, the only strategy is to reduce the performance low enough to secure the stability in any case.

Kosuge *et al.* [2] proposed *virtual tool*, in which an efficient closed-loop dynamics is realized. The virtual tool needs no dynamics model of human and environment. However, there are two assumptions to guarantee the stability of the whole system: 1) human and environment are passive, and 2) a desired closed-loop dynamics (*virtual tool dynamics*, which should be strictly positive real) is realized by control.

Although it seems a reasonable assumption that human and environment are passive, it can be an insecure assumption in a system which amplifies human power hundreds of times stronger. Human can act to be passive against the input of external force. But, even in the case that human become active on purpose to excite the instability of the system, the whole system is never allowed to go unstable, never allowed to cause harm to human.

After all, it still has several problems to be overcome, in order to realize the man-machine synergy at practical level by the existing methods, especially in the human power-amplifying systems.

II. Man-Machine Synergy Effector

Here *Virtual Power Limiter System* (VPLS) [3] is adopted to solve the problems. The VPLS monitors the physical interaction between human and robot. Usually it only monitors the power flow, but once it detects an excessive power inflow from robot to human, the VPLS intervenes in the robot control to limit the excessive power inflow to human.

This asymmetrical power transfer between human and robot solves the existing problems. The excessive power inflow to human are regulated and the harm to human from the interaction to robot, and from environment via robot, are avoided. Since the VPLS needs none of human passivity, robot passivity, nor environment passivity, human safety will be secured even if human tries to make the system unstable intentionally.

Unlike the case of symmetrical power transfer in which the physical interaction of human and robot is both regulated, the power flow from human to robot is not regulated in the asymmetrical power transfer. So the operativity by human is not spoiled and human safety is also secured simultaneously.

The VPLS is a core technology for realizing the man-machine synergy. It never replaces some existing control systems, but it is attached to the existing systems. We consider that the elemental technologies to realize man-machine synergy are all come out now. We call the robots which have all the elemental technologies, Man-Machine Synergy Effector (MMSE) [4].

III. MMSE Prototypes

We have developed three prototypes to show the validity of our MMSE concept. They are described here: *Power Finger*, *Power Effector*, and *Power Pedal*.

A. Power Finger

In order to express our MMSE concept, we have developed Power Finger first. Power Finger is a simplified version of MMSE with some practical use. It is shown in Figure 1.

The Power Finger is an MMSE, which maintains the dexterity of a human finger, while delivering a powerful grip which is impossible by human. The VPLS is also implemented in this Power Finger.

The Power Finger can easily crush a walnut with its finger tips, as well as perform delicate tasks like holding a raw egg without cracking it. The maximum finger force is 100.0 [kgf], the maximun finger speed is 99.0 [deg/s].

B. Power Effector

The Power Effector [5] is a dynamics converter which the user can actually "hold and use." The dynamic conversion is a human arm power amplification. The Power Effector is also shown in Figure 1.

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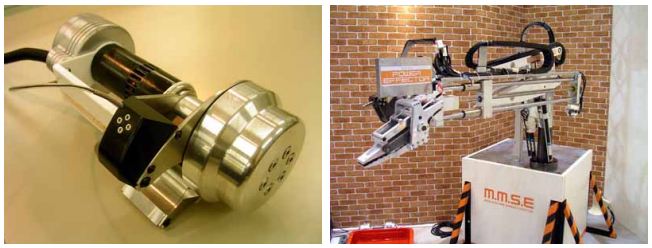


Fig. 1. Power Finger (left) and Power Effector (right)

The Power Effector can exert the translational force around 50 [kgf] in maximum, and the grip force around 500 [kgf] in maximum. Furthermore, it is realized the intuitive operativity to follow human operational motion without delay. It means that human power-amplifying gain can be from 100 times to 1000 times.

Although the Power Effector has no force sensor between the effector and environment, it can handle a raw egg without breaking. That is a result of man-machine synergy, realized by the intuitive operativity.

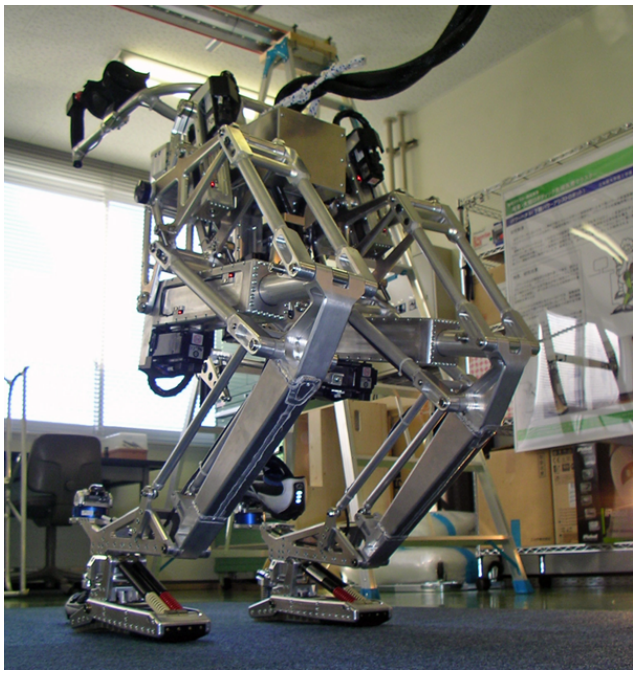
C. Power Pedal

Here we disclose a new prototype of MMSE for human lower extremities. The Power Pedal has been developed as the device to realize the synergy of human skill and robot power in lower extremities. The Power Pedal is composed of a pair of pedals (powered robotic legs) shown in Figure 2.

A 6-axis force sensor is equipped with on the step of each pedal. Operator's feet are fixed on the force sensors, so that the operational forces are measured in all translational directions on each foot. The handgrips are just for the fixation of the operator's body, not for the operation.

Each pedal has 3-DOF powered joints and 3-DOF passive joints. These powered joints are under torque control amplifying the human leg force exerted by each foot in task space. The Power Pedal amplifies the human leg force 7 times normally, and can amplify it up to 40 times. The VPLS contributes the stability of the power amplifying control.

Even though the Power Pedal is just a power-amplifying tool for human, not autonomous, bipedal walking with human skill and robot power has been realized by our Power Pedal.



(a) Overview

(b) Physical connection to human

Fig. 2. Power Pedal

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