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Study on designing a biped robot With bi-articular muscle type bilateral servo systems

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ABSTRACT

At present, biped robots are designed having motors on each joint. But human have actuators that span two joints, and the antagonistic pair actuator drives two joints at the same time. In these days, the effects of this study that is source of fast motor such as jump or running are investigated on Body moment study and Biology. This study shows the basic principle and the driving mechanism of the new actuator, called bilateral servo system developed in our laboratory, having the bi-articular operation to adjust a biped robot, and characteristics of the actuator that driving joint. As for those characteristics, this paper expresses the bilateral servo system and the robot that use the actuators.

Keyword

bilateral servo, rotary actuator, bi-articular muscle, biped robot

NOMENCLATURE

F_m : Force of master
F_s : Force of slave
A_{ma} : Section area of master (Master cylinder, Bottom side)
A_{mb} : Section area of master (Master cylinder, Rod side)
A_{sa} : Section area of slave (Slave cylinder, Bottom side)
A_{sb} : Section area of slave (Slave cylinder, Rod side)
P_1 : Pressure of bottom side
P_2 : Pressure of rod side

INTRODUCTION

Biped robots have a long history. In Japan, it has began since 1970s. In 1983, Prof. Kato in Waseda University developed a robot that can walk by itself. WL-10 has achieved reliable walking with reliability.
At present, many robots have achieved movement walking with ZMP (Zero Moment Point) control systems. In 1993, they attached upper body on the robot developed without it, and learning control which stability standard is ZMP has learned, at a simultaneous period, the study that makes amends for tree axis moment by the upper body.
And then, from 1996 a biped robot has known as a realistic thing like P2 introduced by HONDA. The posture control of those intelligent biped robots has one motor on each joint, and past system consists of

cooperative control of each joint. We have created a bi-articular actuator that is a bilateral servo system, and systematized posture and force. And as we reproduced antagonistic operating, the robot gets rapid movement and peculiar operation to animals with tedium.

About the peculiar operation of animals, Van Ingen Schenau's group reported that bi-articular muscles are power source and operation that takes energy generate from sgemure of limbs. By same group, at winter Olympic in1998, it is known that many athletes who bi-articular muscles flourished.

N.Hogan reported that bi-articular muscles took part much in setting and tracks of stiffness in work coordinate system. And Kumamoto verified this concept with analysis and robot-arm. In a word, bi-articular actuators are not only human mechanism but also effective means of control problems of robots that have operation with tedium.

When muscles of living things are divided roughly, it becomes mono-articular muscles and bi-articular muscles as shown Figure .1. Especially, bi-articular muscles could drive two joint by itself. As for the actuators, animals could operate rapidly and stably.

By the way, as shown Figure .1, hamstring and rectus femoris in large thigh are bi-articular muscles that span between hip joint and knee joint. And then, gastrocnemial in under thigh is bi-articular muscle that span between knee joint and foot joint.

The characteristics of humans and animal's motion control are summarized as follows.

1) Basically, it is fussy, but can operate smooth, quick and rapid with open loop.

2) Motions such as running or walking are cotrolled in spinal cord level, and it is the sending part of cooperation motion.

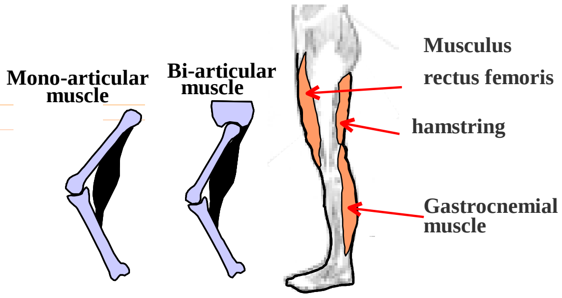

Figure .1 Mechanism of bi-articular muscle

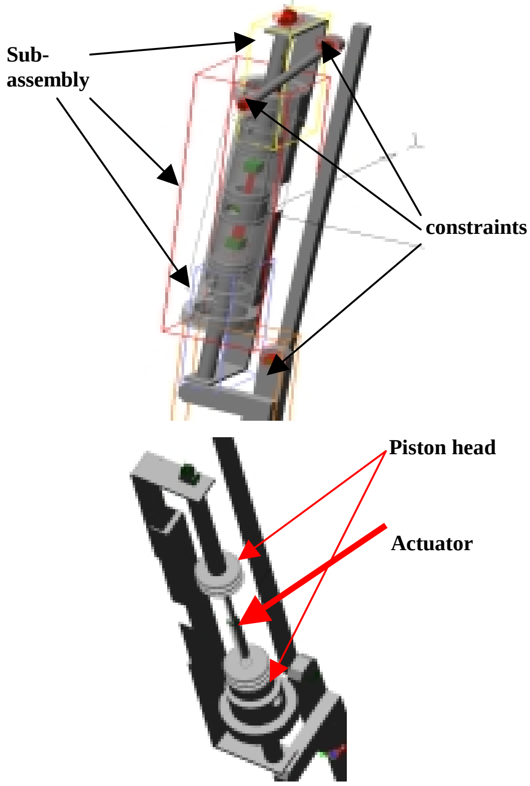

Figure .2 Link of CATIA assembly model and Visual Nastran

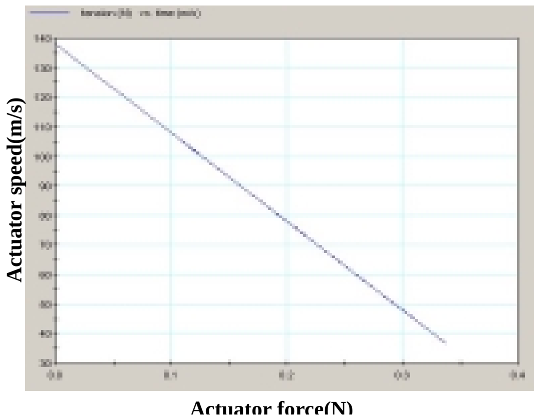

Figure 3.1 Specification of actuator

THE MECHANISM OF POWERED LOWER LIMBS OPERATION SIMULATION WITH VISUAL NASTRAN

The bi-articular actuator drawn with CATIA was linked with a Visual Nastran for operation simulation (Figure 2). Here, as a source of driving, movement type actuator soon is installed between two piston heads. The relation between force and velocity is made linear for simplification and we operated simulation. Figure 3.1 shows the specification of the actuator. The result is shown in Figure 3.2, 3.3.

THE CONTROL SYSTEM OF BI-ARTICULAR MUSCLE TYPE ACTUATOR

The control system is shown in Figure 4. The device needs to read signals from a pressure sensor and a potentiometer for

each feedback. The control unit with analog to digital conversion machine can read amplified signals.

The PWM control system can drive motors and open-shut solenoid valves, and the device can drive both one and two joints.

BI-ARTICULAR ACTUATOR COMPOSED ON BILATERAL SERVO SYSTEM

Figure 5 shows the bilateral servo system that can reproduce operation of a bi-articular muscle. This mechanism consists of master cylinder with a single rod and a slave cylinder with double rods united by tube in parallel. The master cylinder consists of a rotation - straight-line conversion mechanism and a motor. This master cylinder has three pressure sensors and three potential meters. And then, the slave has an operation of bi-articular muscle, and it can drive two joints with switch of electromagnetic valve.

The thrust of master cylinder's rod, and we define the slave cylinedr's thrust as F_m, F_s,

$$\begin{cases} F_m = A_{ma} \cdot P_1 - A_{mb} \cdot P_2 & (1) \\ F_s = A_{sa} \cdot P_1 - A_{sb} \cdot P_2 & (2) \end{cases}$$

$$F_s = \frac{A_{sa}}{A_{ma}} \cdot F_m \qquad (3)$$

Basically, the slave cylinder is driven by motor that set on the master cylinder. The thrust is generated by ratio of sections because of incompressible fluid in cylinders. So the torque and speed of the slave cylinder is described by deference of section. Table1 shows that relationship.

Table1 The relationship of ratio of sections and values

Ratio of section	Transmission force	Stroke
Am1<Am2	F1<F2	X>Y
Am1=Am2	F1=F2	X=Y
Am1>Am2	F1>F2	X<Y

OPERATION CHARACTERISTICS WITH OPEN LOOP CONTROL

Figure .7 shows the device developed in our lab. And Figure 8 is the operation chart. The slave cylinder is set on hamstrings for re production of operation of bi-articular muscle. Therefore, this device can drive two joints at same time.

Diameters of master and slave are 50, 30 respectively.

Measurements of potentiometers and change values of pressure at two joints driving simultaneously are shown in Figure 8. A is a center part change value of pressure of the slave, B is the position of master, C is the bottom change value of pressure of the bottom of

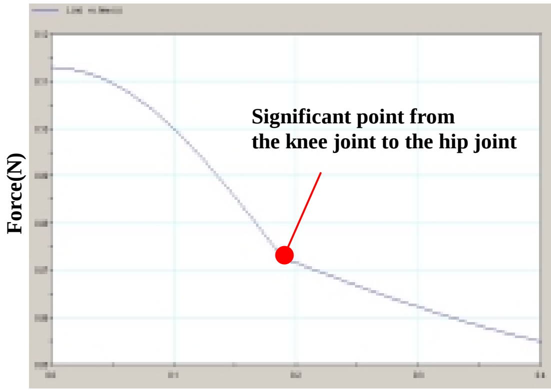

Figure 3.2 Length curve of actuator

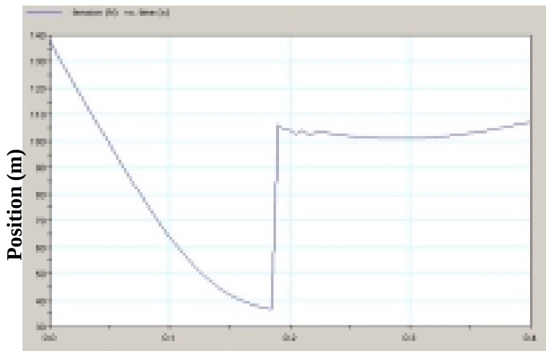

Figure 3.3 Actuator torque curve

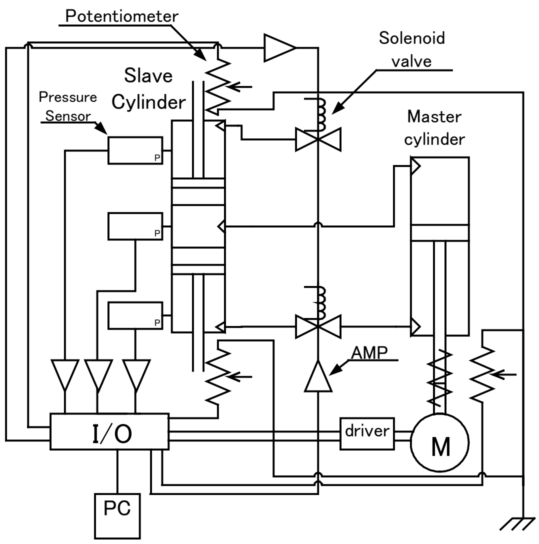

Figure .4 Bi-articular muscle actuator control method(1CH)

the slave, D is the position of bottom of slave, E is the position of the upper position of the slave, F is the change value of the pressure of the upper position of slave.

The effects shows that we get linear and stability operation with open loop control. And then, it is possible to control presser and potential with that characteristic.

If there is no feedback signal, we can drive motor on master and get stability operation.

Figure .6 shows driving of the actuator.

OPERATION EXPERIMENT BY POSITIONAL FEEDBACK CONTROL

We need to verify if the actuator can operate repeatedly with feedback signal or not for adjusting to biped robot. The operation way is to be converted displacement of slave cylinder, and then, when the value reach purpose values that set in PC, the valve switch. Figure 9 shows the effect. Figure .6 says that it is possible to be adjusted the actuator to robot's walking.

CONTROL SYSTEM OF ROTARY TYPE ACTUATOR

In general, motors are used on industrial-use robot's joints in rotary operation. In this study, we have designed a rotary type bilateral servo system. Figure .10 shows the rotary type bilateral servo system developed in our laboratory.

The rotary type actuator exchanges the slave cylinder of bi-articular muscle type actuator for the rotary actuator. Rotary actuator of old model couldn't keep arbitrarily control position. With this mechanism, it is possible to control position as for the antagonistic operation. And then, this actuator doesn't need power amplifier as for the difference of pressure on inside, so it is easier mechanism and lighter weight

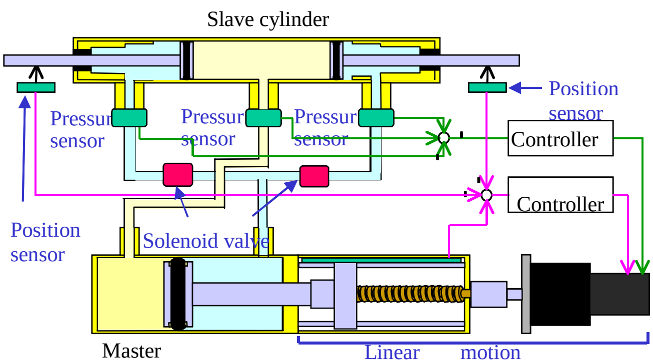

Figure 5 Bi-articular actuator composed on bilateral servo system

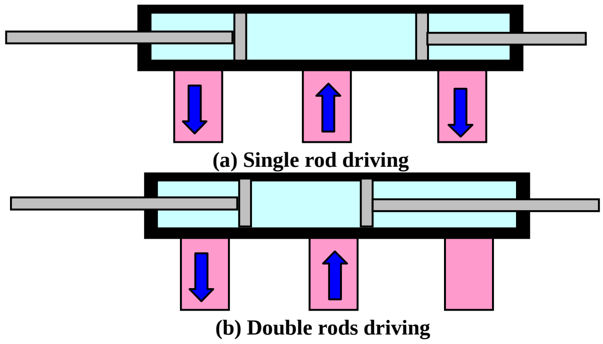

Figure .6 Driving way of the actuator

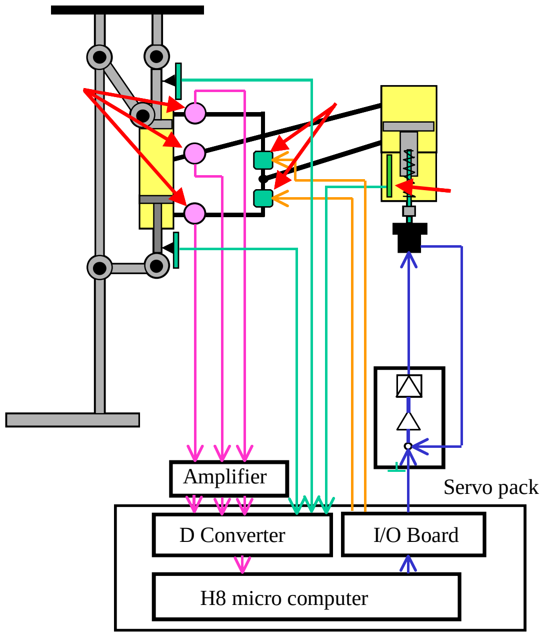

Figure .7 Device of experimentation

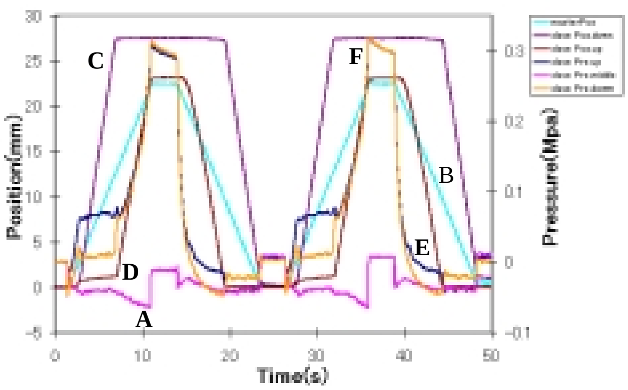

Figure 8 Measurement of potentiometers and change values of pressure

EXPERIMENT OF THE ROTARY TYPE BILATERAL SERVO SYSTEM

Position-feedback experiment

We have had a load test of bilateral servo system. The device of the experiments is shown in Figure 11.

The experiment results are shown in Figure 12, 13(horizontal, vertical).

The result shows that the line with 12kgf has a little overshoot and height of retentively.

Pressure-feedback experiment

The device of the experiments is shown in Figure 11. The experiment results are shown in Figure 14, 15(horizontal, vertical).
The result shows that change of the line is extremely few with minute pressure changes.
And then, table2 compares weight with torque of this rotary actuator and General motor's

Biped robot and the Element technologies

On this study, we drew a draft of a robot that had an operation of bi-articular muscle at fast. Because of using this actuator, the robot can move not only one joint but also two joints at the same time. And the robot has freedom of degree enough, two DOF on hip joint, one DOF on knee joint, two DOF on ankle joint to walk straight. And the foot is designed that has two toes with load cells and heel to reproduce a foot bottom bow cap and to stand on those three points. This mechanism is to adjust to ruggedness geographical features for controlling posture. And then, toes can operate originally to produce floor reaction force.

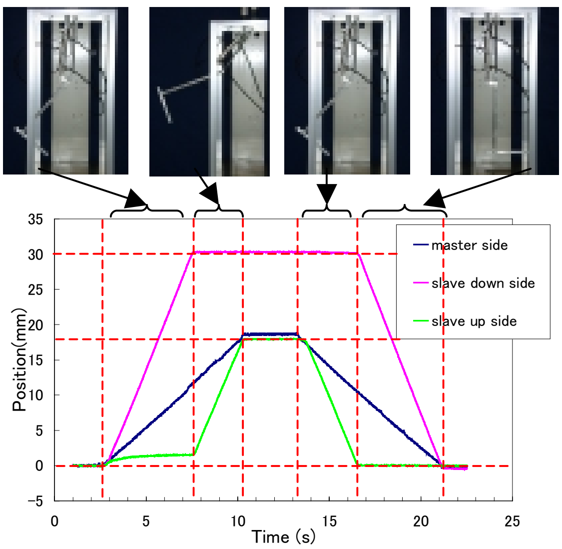

Figure 9 Measurements of potentiometer and change values pressure

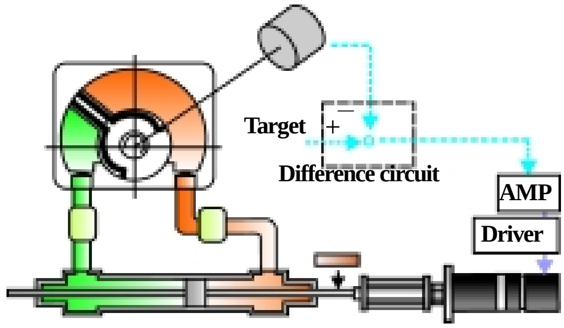

Figure 10 Rotary type bilateral servo system

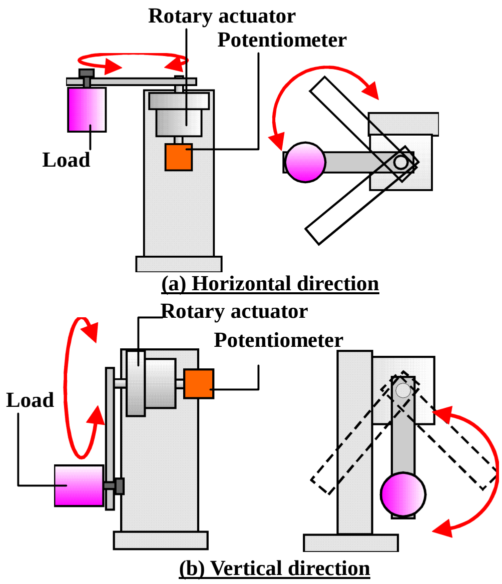

Figure .11 The device of experiments

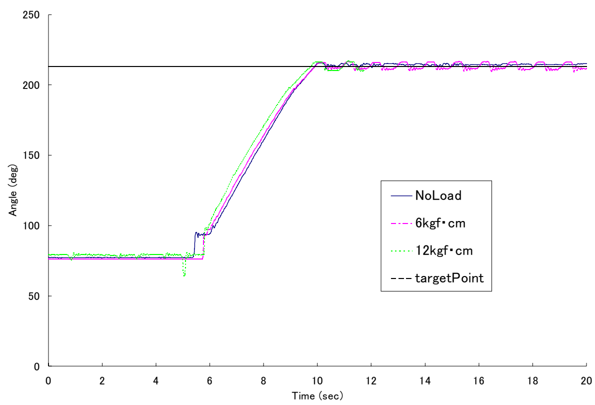

Figure 12. Experiment result of position feedback (Horizontal)

CONCLUSION

Generally, a biped robot has one actuator at each joint. We suggested the robot which one actuator moves joints of the both ends of a femur like human muscles. And the robot has rotary bilateral servo actuators at the hip joint and the ankle. The rotary actuator of the hip joint is used for the lateral elevation.

In this paper, the basic motions of those actuators were confirmed by simulation and experiment. Those results are as follows.

The smooth motion and the kick motion needed for walking of the robot were conduced by simulation and experiment of actuators imitating human bi-articular muscles, called as bi-articular muscle actuator.

(1) We confirmed that the rotary actuator for oscillating movement has slight pressure fluctuation by simulation and experiment of its basic motion.

(2) And we compared our rotary actuator to commercial rotary actuators and d higher positioning accuracy than commercial actuators.

(3) All actuators are bilateral servo system, and the power-assisting function by the control of position and force became possible.

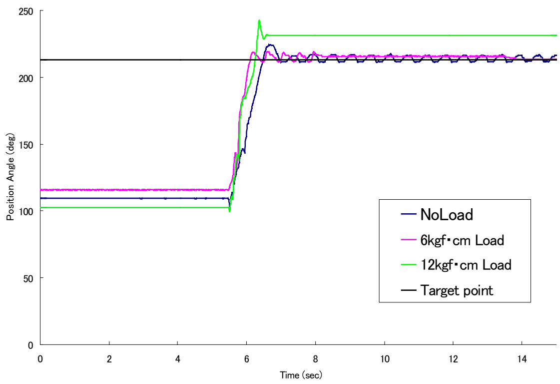

Figure .13 Experiment result of position feedback (Vertical)

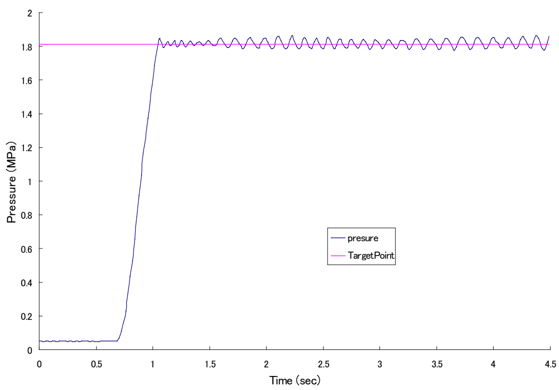

Figure .14 Experiment result of pressure feedback (horizontal)

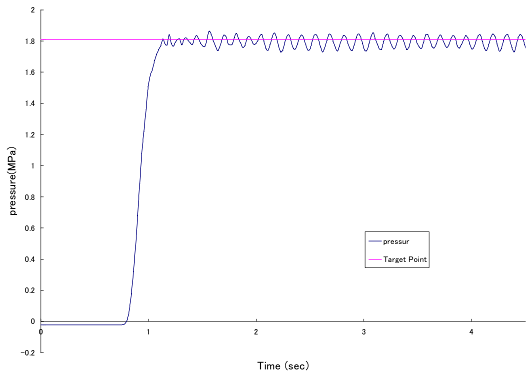

Figure .15 Experiment result of pressure feedback (vertical)

Table2 characteristics table of swing type bilateral servo

Mechanical part	Single Behn type rotary actuator	AC Motor (200W)
The maximum of movable area	270°	—
Official torque	66.35 N・cm (6.77kgf・cm)	59.0 N・cm (6.01 kgf・cm)
Weight	72g	3200 g

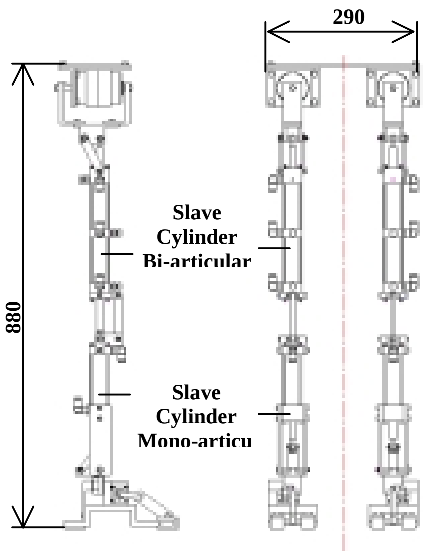

Figure 16 Appearance of the robot

References

[1]T.Osima, T.Fujikawa, M.Kumamoto: Functional Evaluation of Effective Leg Muscular Strength Based on a Muscle Coordinate System Composed of Bi-articular and Mono-articular Muscle-Estimation of Functional Effective Muscular Strength from Output Force Distribution-, The Japan Society for Precsion Engineering,.Vol.67, No.11, pp1824-1828, 2001