# Control of Force Display Device by the Force Sensing System using EMG.

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**Abstract**

In recent years, the research area known as Artificial Reality, Virtual Reality and Tele-existence have been paid much attention from various application fields, including entertainment, medical engineering and computer aided instruction. The goal of these areas is to create virtual spaces that give natural feelings to human users, or operators.

To create good virtual spaces, it is indispensable to deal with and integrate various information from various senses that human being has. We, however, concentrate on dealing with one of those senses. It is the sense of force. The sense of force is necessary to realize touch of objects and feelings of its weight.

Most of researches on force display depend on dynamics models of objects to be operated, and control force feedback devices by using the models. On the other hand, for controlling force the feedback devices, we employ information about physiological conditions of operators rather than the dynamics models of the objects. Our method is based on the idea that a control scheme of the force display can be realized by an operator side as complemental way to the conventional methods. We call the system "Personality adaptable type force feedback device system".

**Key words**: Virtual Reality, force feedback, EMG

## 1. Introduction

When a person operates an object, the resultant feeling of the object differs from other persons' feelings, even if they operate a same object. This is because what kind of characteristic of the object is important depends on subjectivity of each person. Ignoring this kind of differences in the processes of making dynamics models of the objects gives operators having incongruity feeling. However this kind of the differences is seldom taken into account.

To deal with this problem, we use not only the dynamics models of the objects, but also use recorded data of operators' physiological conditions collected when they operated those objects in the actual world. In the phase of controlling the force feedback devices, it is a goal of the system to close the operators' physiological conditions to the recorded conditions. This method enables us to cope with the changes of operators' impedance caused by fatigue of muscles and various physical conditions. The control flow is shown in Fig. 1.

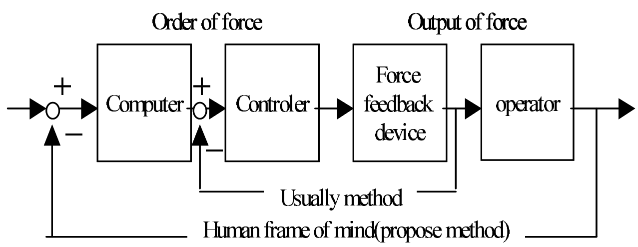


Fig. 1 Control flow

In this paper we use a surface electromyogram(EMG) signal which is one of bio-signals as physiological conditions. The surface EMG signal is active electric potential generated by contraction of muscles. It is measured by electrodes put on an operator's skin. Using the surface EMG signal matches our purpose, because some physiological conditions which concerns with force of the operators are necessary to deal with sense of force.

In order to control the force feedback device, we have to properly decide the magnitude of force the device displays by using the surface EMG signal. Here, we take the following assumption: if two patterns of the surface EMG signal taken from an operator at different points in time are similar to each other, the operator's subjective feelings at those points in time also similar to each other. With this assumption, in order to give operators certai feeling virtually, it becomes a goal of the device to control it so as to close the pattern of operator's the surface EMG signal to those measured in the actual world. Building such devices rise need for attention to the following characteristics of the surface EMG signal:

1) Surface EMG signal relates to force generated by muscles.

2) Surface EMG signal is influenced by fatigue of muscles.

3) Surface EMG signal varies according to operator, and sometimes vary according to time, even if same operator.

And there are following problems:

1) From the viewpoint of signal-noise ratio, the surface EMG signal has undesirable characteristic. In other words, it contains much noise.

2) According to the position of the electrode, measured values largely vary.

To achieve the goal with coping with these characteristics and problems, we employed a feed-forward type neural network for mapping from the surface EMG signal to the magnitude of force to be displayed. Feed-forward type neural network is suit for clustering of data with nonlinearity, and the surface EMG signal have this property. Learning ability of feed-forward type neural network enables us to cope with the problems such as potions of an electrode, fatigue of muscles and individuality. We made prototype of "Personality adaptable type force feedback device system", and investigate operator's feeling about this system.

## 2. Design

The block diagram of the proposed model is shown in Fig. 2.We enter into details of the Fig. 2.

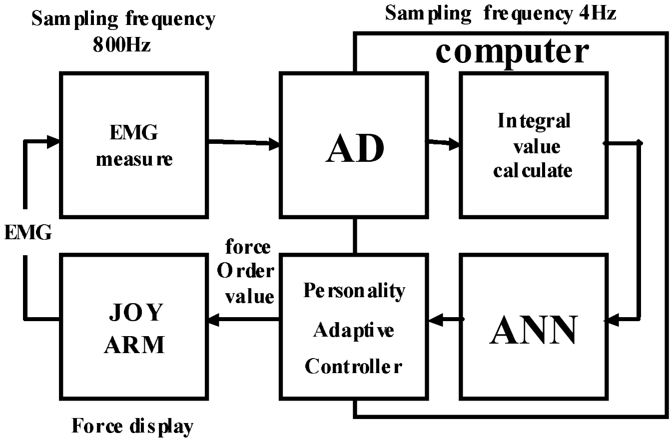


Fig. 2 Block diagram of the propesed model

### Measurement of EMG

We deal with the two channels EMG signals. EMG electrode is shown in Fig. 3. The EMG electrode is a rectangle three centimeters by two centimeters. The position of EMG electrode is shown in Fig. 4. The electrode uses the product of DelSys Inc. The side of radius is channel zero and channel one, and the side of ulna is channel two and channel three. Reference is placed on the wrist near the hand. The sampling frequency is 800 Hz.

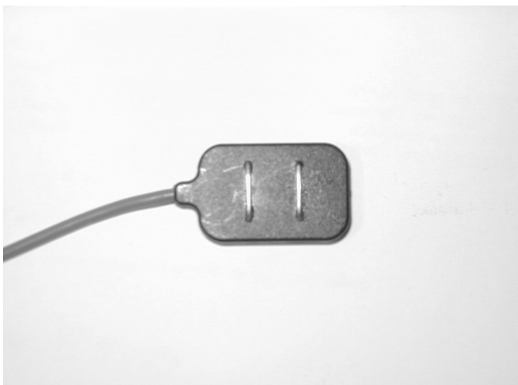

Fig. 3 EMG electrode

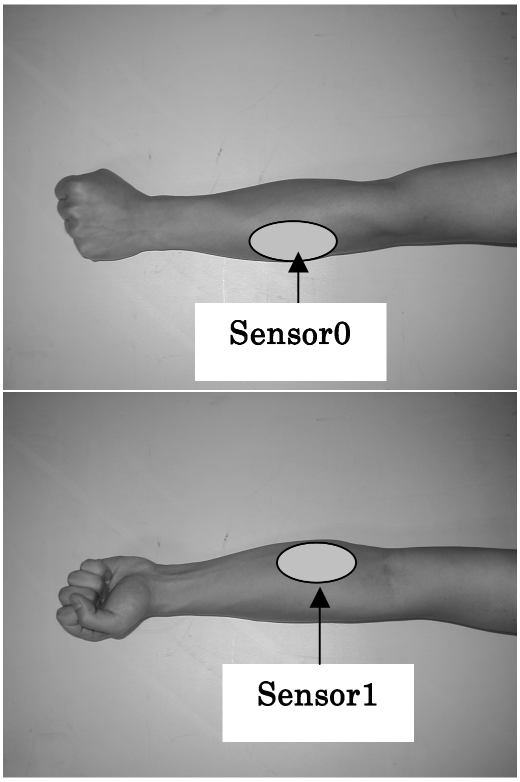


Fig. 4 sensor positions

**Pre process**

EMG measured by the surface electrode is that the temporal and spatiality addition value of the electric pulse which occurred from the tip of the nerve fiber. In other words, muscular impedance around the electrode can be estimated to integrate EMG in the constant time. Only a difference in electric potential from the ground is important here. Therefore, the absolute value of EMG is calculated, and integral value (1) is found after that.

$$I=\sum_t |e(t)| \bullet \Delta t \quad (1)$$

I : Integral value
e(t) : EMG signal at time t
Δ t : 1/(sampling frequency)

Next, it needs to be considered that the dispersion of the integral value is reduced. It is done concretely in the following method. The method prepares for the integral value of eight sections where time continues, and it excludes two the biggest integral values and two of the smallest ones. Then, it averages four left integral values. This value is handled as one normalized integral value.

**Artificial Neural Network (ANN)**

We employed a feed-forward type neural network for a mapping from the surface EMG signal to the magnitude of force to be displayed. In this network, It is made to record that operators' surface EMG signal collected when they operated those objects in an actual world. And, when a certain feeling is given virtually to the operator, ANN degree of resemblance of recorded EMG and present EMG is outputted. The network uses (2).

$$u_i^m = \sum_{j=1}^{n_{m-1}} w_{ij}^m \bullet x_j^{m-1} \quad (2)$$
$$x_i^m = f\left(u_i^m\right)$$
$$f(u) = 1/\left(1+\exp(-u)\right)$$
$$\left(m = 2,3, i = 1,\cdot\cdot\cdot, n_m\right)$$

$n_m$ : The number of the cells of the m layer

$x_i^m$ The cellular output of the i turn

$w_{ij}^m$ The cellular weight of the j turn of one previous layer

$f(u)$ The function of sigmoid

$$\frac{\partial E}{\partial x_i^3} = x_i^3 - d_i$$
$$\frac{\partial E}{\partial x_i^2} = \sum_{k=1}^{n_3} \frac{\partial E}{\partial x_k^3} f\left(u_k^3\right) w_{ki}^3$$
$$\Delta w_{ij}^m = -\mu \frac{\partial E}{\partial x_i^m} f\left(u_i^m\right) x_j^{m-1}$$

$d_i$ The training data of i turn

$\mu$ Learning rate

It was made three layers structure of ANN, and the following is the number of neuron of each layer. The input layer is two neurons which is the number of the sensors. The middle layer is ten neurons. The output layer is three neurons which is the number of the loads

**Personality Adaptable controller**

In the phase of controlling force feedback devices, the goal of a system is to close the operators' surface EMG signal to the recorded surface EMG signal. And in order to control the force feedback device, we have to properly decide the magnitude of force which the device displays by using the surface EMG signal. Personality Adaptable controller calculates that force. As for the details, it is stated in section 3.3.

**JOYARM**

JOYARM manufactured by Mitsui Engineering & Shipbuiding Co.Ltd display force. Force of six shaft can be displayed JOYARM by DC motor, and it can monitor a three-dimensional position. JOYARM display the load0 (0kg), load1 (83.68kgmm) and load2 (167.29kgmm) as a torque load toward the rotation movement of the arm.


Fig. 5 JOYARM

## 3. Experiments

### 3.1 Experiment 1

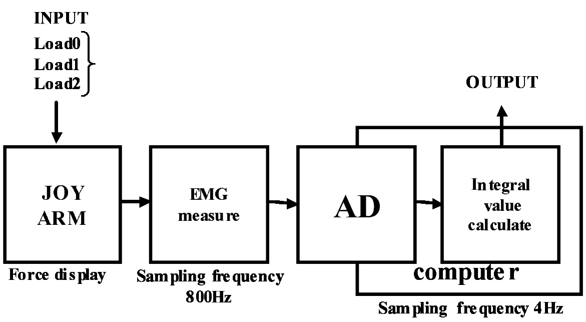


Fig. 6 Control flow of Experiment of measure EMG

The procedure to measure the surface EMG signal is explained in this section. And it is examined what kind of characteristics there are in surface EMG signal. Then, concrete experiment process is shown.

The detail condition was shown in section 2. The posture of measurement is shown in Fig. 7. We show the sequence of the loads which JOYARM displays. First, displayed load0. Secondly, displayed load1. Thirdly, displayed load2. Interval of the experiments is long enough, because we want to refresh operator. We do not determine special interval time. Each operators determined interval time. The time of measurement is 1.5-second par one experiment. We get six integral values from one experiment. Because there are three loads, we get 18 integral values. The experiment went toward one operator. The operator is a man 24 years.

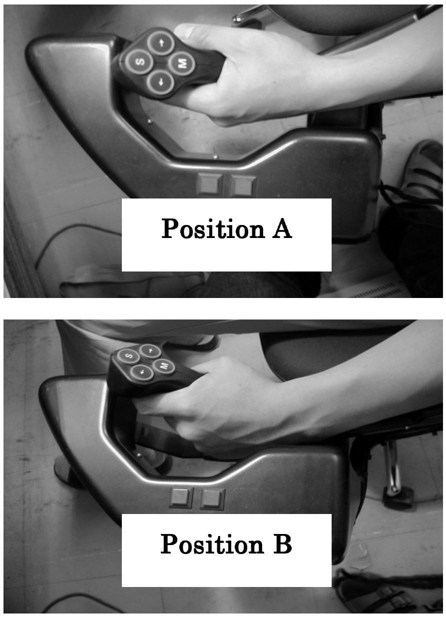


Fig. 7 Measured Positions

### 3.2 Result of experiment 1

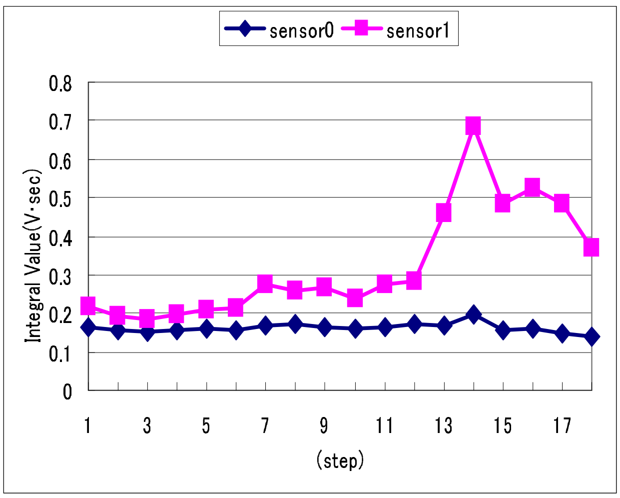


Fig. 8 result of experiment 1

The experiment result is shown in Fig. 8. The horizontal axis of ordinates is step, and the vertical axis is the integral value (V・sec).The diamond mark represents the integral value of sensor0 and foursquare mark represents the integral value of sensor1. JOYARM displays the load0 from first to sixth steps, displays the load1 form seventh to twelfth, and displays the load2 thirteenth to eighteenth. The graph indicates, the integral values of seventh-twelfth larger than the integral values of first-sixth, and the integral values of thirteenth-eighteenth larger than the integral values of seventh-twelfth. This result is corresponding references [1]-[4]. References have described that when a load becomes big, the integral value becomes big, too. And, when a load becomes big, dispersion is big, too.

### 3.3 Experiment 2

The purpose of this experiment is the movement confirmation of the system which showed it in Fig. 2. The outline of this system is as follows.

1) We measure operators' surface EMG signal collected when they operated those objects in the actual world, and it is recorded in ANN. In this experiment. Three kinds of loads that were displayed by JOYARM of the experiment 1 are recorded in ANN.

2) As for a goal for control of JOYARM is to measure recorded the surface EMG signal. As a result, the operator was given certain feeling of 1) virtually. In this experiment, it is tried to display the feeling of load1 of the experiment 1 to the operator.

3) The output values which got it in 2) is inputted to Personality Adaptable controller, and the controller decide the magnitude of the force which JOYARM displays

Next, the details of Personality Adaptable controller are shown. First, the purpose of the controller is stated. In order to give operators a certain feeling virtually, it becomes a goal of JOYARM to control it so as to close the pattern of operator's the surface EMG signal to those measured in the actual world. Here, ANN degree of the resemblance of recorded EMG and present EMG is outputted. Therefore, it is decided that the purpose of the controller increases the degree of a resemblance. In other words, in this experiment, in order to give the operators load1 feeling virtually, it becomes a goal of JOYARM to control it so as to close the output layer of the three neurons of the ANN are outputted to (load0,load1,load2)=(0,1,0).to those measured. So, it is represented the following algorithm. It is shown about the case that load1 feeling is given virtually to the operator. The flow chart is shown in Fig. 9. Input of the flow char is output of the ANN and the current order value of JOYARM, and the output is the next order value of JOYARM. The coefficient was decided as follows. $\alpha$ =0.8, $\beta$ =1.

Next, detailed experiment condition is stated. The posture shown in Fig. 7, and measuring time is three seconds. And, The operator is the same person as the experiment 1. Then, a sensor isn't re-covered. The initial value of JOYARM was made load1. This experiment went twice on the same condition.

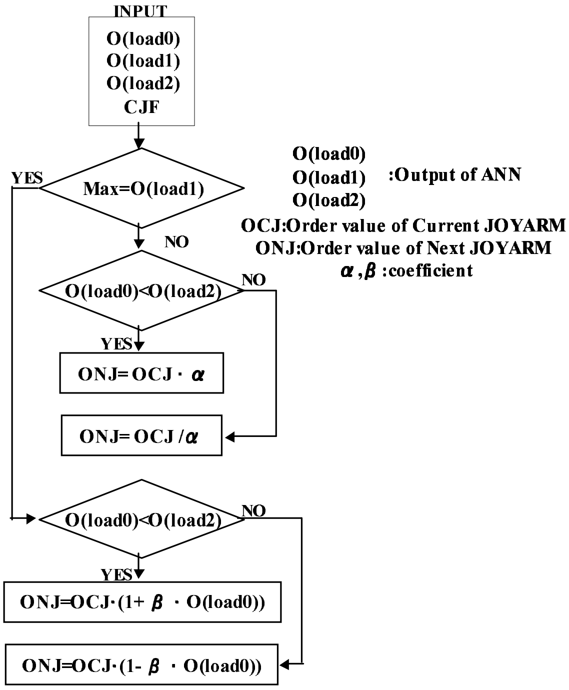


Fig. 9 flow chat

### 3.4 The result of the experiment 2

The experiment result is shown in six Figures. The resultA is the first experiment result. The resultA is shown in the right. The resultB is the second experiment result. The resultB is shown in the left. The horizontal axis is time with six Figures as well. Fig. 10 and Fig. 13 are the graphs which show two integral values (V・sec) of sensor0-sensor1. Fig. 11 and Fig. 14 are the graphs which show the output value of the ANN. Fig. 12 and Fig. 15 are the graphs which show the values (kg・mm) displayed by JOYARM.

1) resultA

First, see to the integral value of the sensor1 in Fig 10. the minimum integral value is about 0.3(V・sec). The maximum integral value is about 0.45(V・sec). These are equivalent to the output value of the load1 in Fig. 8. As this result, The output of load1-neuron is always close to 1 in Fig. 11.

Second, it turns to Fig 11. It pays attention to about 2.5 seconds and 7.2 seconds. Here, load0-neuron output a big value, and load1-neuro output a small value. It is a cause by operator's physiology condition change. The integral value becomes small, and the output of neuron changes. The output of JOYARM is bigger than the one before in Fig. 12. This is because Personality Adaptable controller worked suitably.

2) resultB

First, it looks at to the integral value of the sensor1 in Fig. 13. The minimum integral value is about 0.3(V・sec). The maximum integral value is about 0.5(V・sec). These are equivalent to the output value of load1 in Fig. 8, too. As a result, the output of load1-neuron is always close to 1 in Fig. 14, too.

Second, it refer to Fig 14. It gives a closer look about 3.8 seconds and about 8 seconds. Here, load2-neuron output a big value, and load1-neuro output a small value. This result didn't happen in resultA. The output of JOYARM is bigger than the one before in Fig. 15. Personality Adaptable controller works suitably here, too.

3) resultA and resultB

The resultA is compared with the resultB. In the resultA, the integral value at the start of the experiment is small. Then, it increases. In the resultB, the integral value at the start of the experiment is big. Then, it decreases. The tendencies are different, because operator's physiology condition changed. This system ran normally in such a case as well.

## 4. Conclusions

In this paper, The following were confirmed.

1) Surface EMG signal relates to generated force.

2) Surface EMG signal sometimes vary according to time.

3) Personality Adaptable controller was made, and a performance was confirmed.

4) Personality adaptable type force feedback device system was made, and a performance was confirmed.

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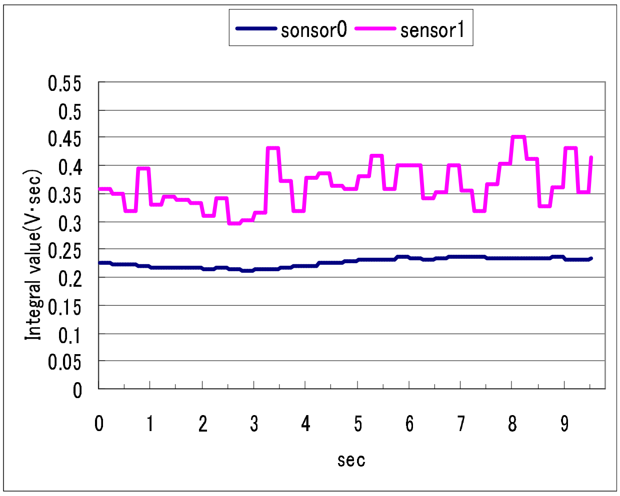


Fig. 10 The integral of EMG experiment 2(resultA)

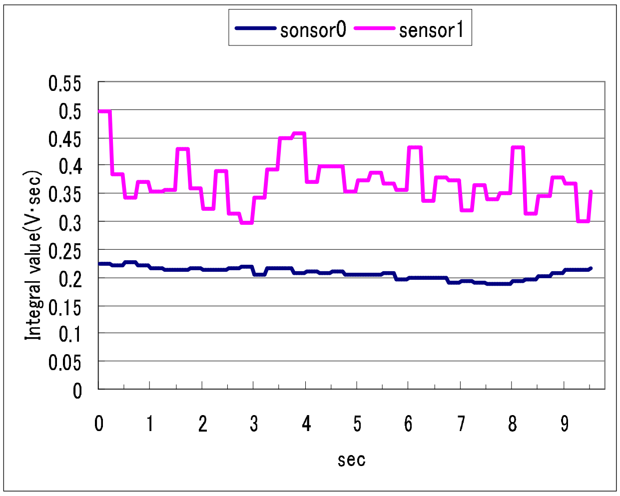


Fig. 13 The integral of EMG experiment 2(resultB)

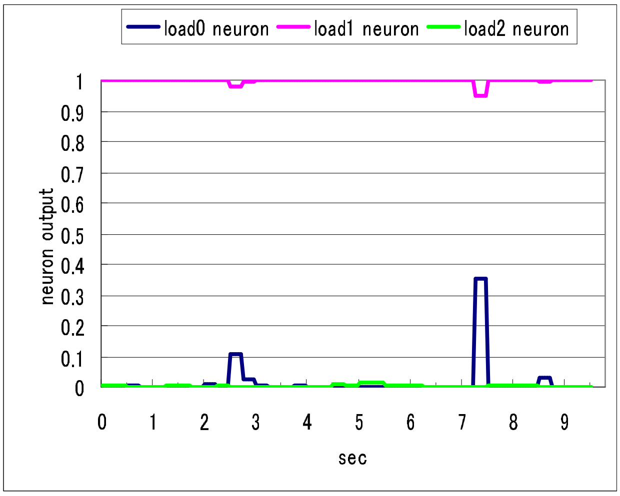


Fig. 11 The output of ANN(resultA)

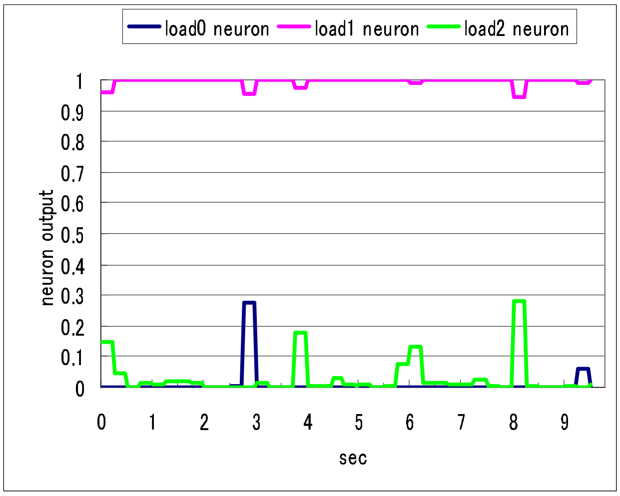


Fig. 14 The output of ANN(resultB)

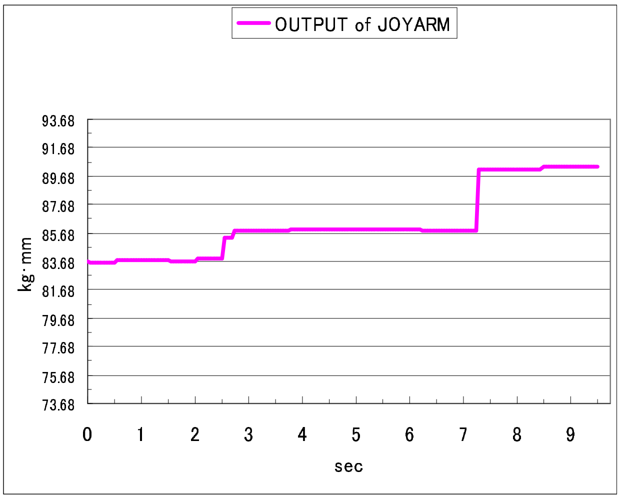


Fig. 12 The output of JOYARM(resultA)

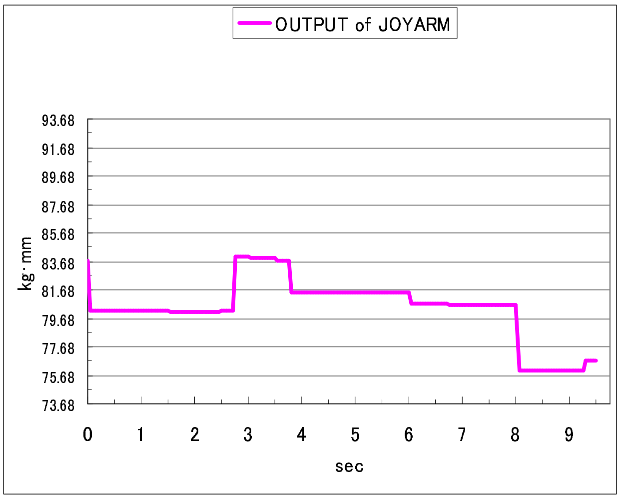


Fig. 15 The output of JOYARM(resultB)