Proceedings of the 2004 IEEE
International Conference on Robotics and Biomimetics
August 22 - 26, 2004, Shenyang, China

# ICPF Actuator-based Novel Type of Underwater Micro Biped Robot with Multi DOF

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***Abstract* – In the medical field and in Industry application, a new type of A Novel Type of Micro Biped Robot with Multi DOF that can swim smoothly in water or aqueous medium has urgently been demanded. The fish-like microrobot is one of the micro and miniature devices, which is installed with sensing and actuating elements. This paper describes the new structure and motion mechanism of an underwater microrobot using ICPF actuator, and discusses the swimming possibility of the microrobot in water. Characteristic of the underwater microrobot is measured by changing the frequency and the amplitude of input voltage. The experimental results indicate that the swimming speed of proposed underwater micro robot can be controlled by changing the frequency of input voltage; the moving direction (upward or downward) can be controlled by changing the amplitude and the frequency of input voltage.**

***Key Words*:** Microrobot; Micro Biped Robot; Microactuator; Propulsion; ICPF actuator; Propulsion; Optimisation

## I. INTRODUCTION

Intracavity intervention is expected to become increasingly popular in the medical practice, both for diagnosis and for surgery. Recently many microrobots have been developed for various purposes due to the advances of the precise process technology, and further progress in this field is expected. In the medical field and in Industry application, a new type of fish-like microrobot that can swim smoothly in water or aqueous medium has urgently been demanded [1]-[2]. The fish-like microrobot is one of the micro and miniature devices, which is installed with sensing and actuating elements. It can swim smoothly in water or aqueous medium such as use for in-pipe Inspection and microsurgery of blood vessel.

Recently, several types of fish-like microrobot using SMA actuator, GMA actuator, PZT actuator and polymer actuator have been reported so far [3]-[8]. However there are some problems, such as compact structure, low response, leaking electric current, safety in water and so on. It is our purpose to develop a type of fish-like microrobot that can swim smoothly in water or aqueous medium. It has the characteristics of flexibility, driven by a low voltage, good response and safety in body. Biomimetic fish-like propulsion using ICPF actuator as a propulsion tail fin for an underwater microrobot swimming structure in water or aqueous medium is developed. ICPF actuator is made from the film of perfluorosulfonic acid polymer (Nafion 117, du Pont and company) chemically plated on it's both sides with platinum. In many points, ICPF actuator is superior to usual polymer gel actuator such as fast response, driven by low voltage (about 1.5V) in wet condition without electrolysis, safety in body and so on [9]. It is now possible to replicate the undulating motion of marine animals using ICPF actuator in a more direct way. This paper describes the new structure and motion mechanism of an underwater microrobot using **ICPF** actuator, and discusses the swimming possibility of the microrobot in water. Characteristic of the underwater microrobot is measured by changing the frequency (from 0.1Hz to 5Hz) and the amplitude (from 0.5V to 10V) of input voltage. The experimental results indicate that the swimming speed and the buoyancy of the underwater microrobot can be controlled by changing the frequency and the amplitude of voltage.

## II. STRUCTURE OF THE MICROROBOT

### *A. Total Structure of the Microrobot*

**Fig.1** shows the basic structure of the developed underwater microrobot using ICPF actuator. This microrobot consists of the body made of wood material shaped as a fish (A), a pair of tail with a fin driven by ICPF actuator respectively (B), the lead wires for supplying electric energy to ICPF actuators (C) and a pair of fins are installed in parallel structure for generating a large propulsive force. The fins are driven independently. The buoyancy adjuster under of the microrobot body is also driven by the same ICPF actuator. **Fig.2** shows the structure of the developed microrobot, which can adjust the body orientation by changing the center of gravity. The photo of the developed microrobot is shown in **Fig.3**.

### *B. ICPF Actuator*

ICPF actuator is made from the film of perfluorosulfonic acid polymer (Nafion 117, du Pont and company) chemically plated on it's both sides with platinum (one side is 0.003mm in thickness). It is known as an ion exchange membrane. It is a kind of high polymer gel actuator, works only in water and in wet condition. The ICPF is bent into anode side when the about 1.5v voltage is applied onto its surfaces. Displacement of the ICPF is proportional to the electrical voltage in put on its surface as the swelling of polymer gels. The other characteristic of the ICPF actuator is that when the frequency of the applied voltage is low less than 0.3Hz, water around the ICPF surface is electrolysed, so water bleb on both side of the

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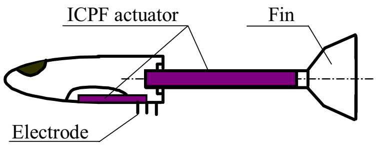
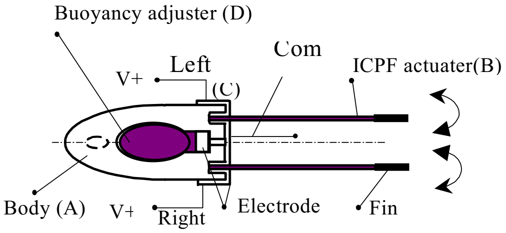
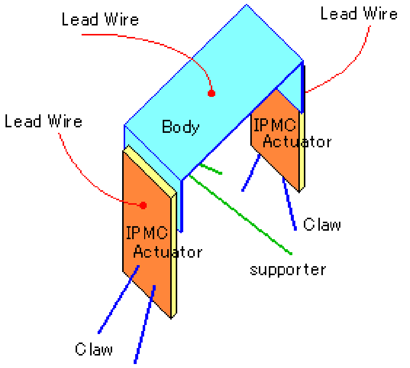
ICPF surface is generated. In result of the change of body volume, and buoyancy of the microrobot can be controlled. ICPF actuator (0.2×3×15mm) is cut in a strip to drive a fin for propulsion, and ICPF actuator (0.2×4×6mm) is used for buoyancy adjuster as shown in **Fig.1**.



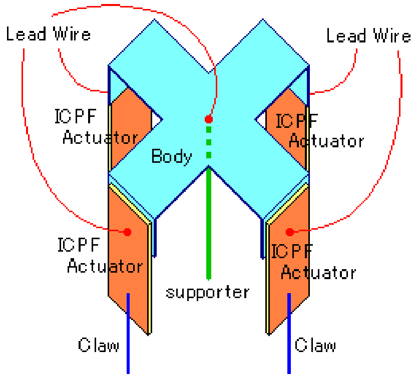
(a) Structure of a Tail



(b) Total Structure



(c) Structure of Micro Biped Robot with 1 DOF



(d) Structure of Micro Biped Robot with Multi DOF

Fig.1 Structure of the Microrobot

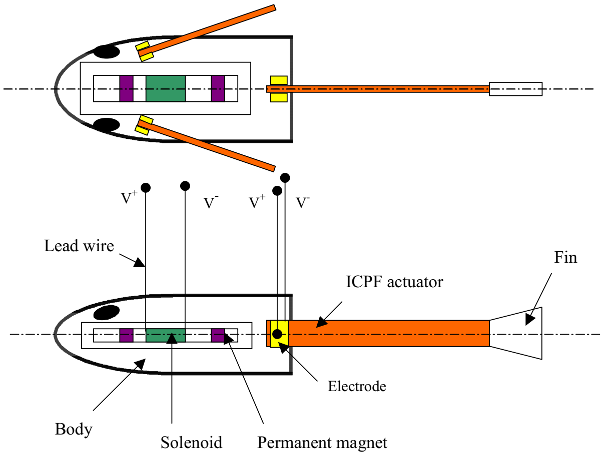
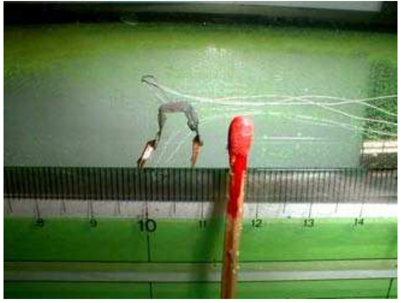
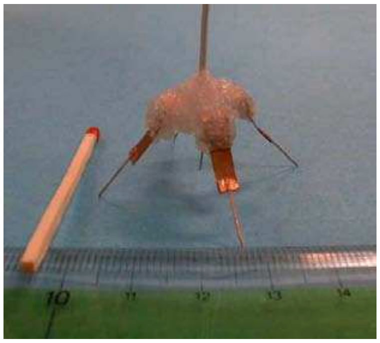


Fig.2 Adjusting Structure of the Microrobot Posture

(a) Fish-like Microrobot



(b) Underwater Micro Biped Robot with 1 DOF



(c) Underwater Micro Biped Robot with 1 DOF

Fig.3 View of the Developed Microrobot

## III. MOTION MECHANISM OF MICROROBOT

The developed microrobot has two tails with a fin driven by the ICPF actuator respectively as shown in **Fig.1**. A pair of fins is offset in the distance d, and driven by electric voltage of f1 and f2 frequency independently as shown in **Fig.4**. A motion of a fin is described by combination of two kinds of motion, feathering and heaving. When proper phase difference appears between heaving and feathering, the fin generates an effective force as shown in **Fig.5**. The propulsive force is the sum of drag force vectors to the moving direction in equation (1). It can be realized by changing frequency f1, f2 of the electric voltage applied on the ICPF actuators that the moving motion in the directions (forward, right turn and left turn) as shown in **Table.1**.

The developed microrobot has a solenoid and two permanent magnets. It can change the body posture by adjusting the center of gravity as shown in **Fig.6**.

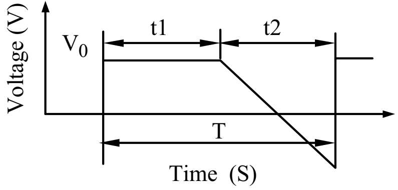


Fig.4 Driving Electric Voltage

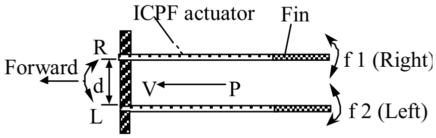


Fig.5 Mechanism of Microrobot Using ICPF Actuator

Table 1 Moving Motion of Microrobot

| | Forward | Right Turn | Left Turn |
|---|---|---|---|
| Right ICPF Actuator frequency f1 | f1 = f2 | f1 > f2 | f1 < f2 |
| Left ICPF Actuator frequency f2 | | | |

$$P = -\frac{1}{2} C_d \rho A \left| V_k \right| V_k \qquad (1)$$

Where $\mathbf{C}_d$ is drag coefficient based on wetted surface area A. $\rho$ is the density of water.

The developed microrobot has a buoyancy adjuster driven by ICPF actuator. The ICPF actuator has the characteristic that when the frequency of the applied voltage is low less than 0.3Hz, water around the ICPF surface is electrolyzed, so water bleb on both side of the ICPF surface is generated. In result of the change of body volume, and floatage of the microrobot can be controlled. The floating mechanism of the developed microrobot is shown in **Fig.7**.

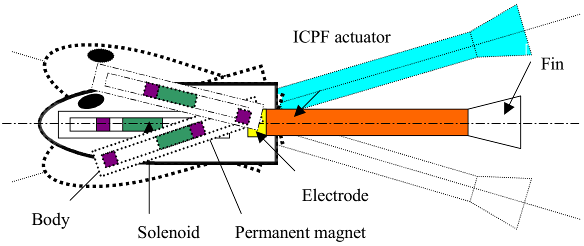


Fig.6 Adjusting Mechanism of the Microrobot Posture

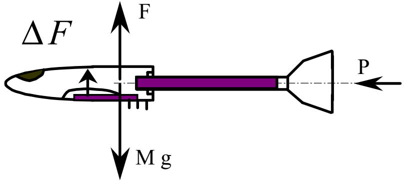


Fig.7 Floating Mechanism of the Microrobot

We know that the floatage of the microrobot is:

$$F = \rho \times V_a \qquad (2)$$

Where $V_a$ is the total volume of the microrobot. At first, the weight Mg is little large than the flotage $F$ and the microrobot is sinking downward in water. When water around the ICPF surface is electrolysed. The generated bleb adsorbs on both side of the ICPF actuator and it increases the total volume of the microrobot by $\Delta v$. It also increases the flotage by $\Delta F$.

$$\Delta F = \rho \times \Delta v \qquad (3)$$

We observed that the volume of the generated bleb could be controlled by changing the frequency and the amplitude of the applied voltage. When

$$\Delta F = Mg - F \qquad (4)$$

It stops sinking and suspend in water. When

$$\Delta F > Mg - F \qquad (5)$$

It begins to float upward. When the frequency of the applied voltage is low less than 0.3Hz. Electrolysis begins to be obvious and the larger the amplitude of voltage applied, the more the volume of the generated bleb will be.

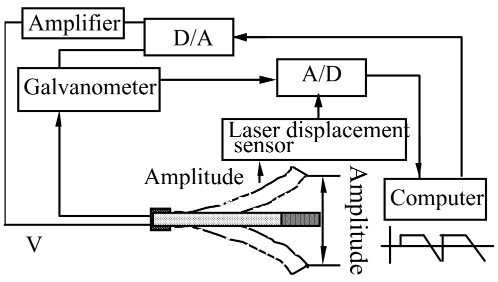


Fig.8 Measurement System

## IV. CHARACTERISTIC MEASUREMENT

### *A. Measurement System*

A computer can control the electric voltage set onto the ICPF actuators. The electrical current is measured by a galvanometer. The bending displacement of a fin at the point of the front end is measured by a laser displacement sensor. The bending amplitude of a fin can be obtained driven by an input voltage as shown in Fig.3. Measurement System is shown in **Fig.8**.

### *B. Characteristic of a Fin of Microrobot*

By using the measurement system as shown in **Fig.8**, the following characteristics are measured. First, we measured the maximum displacement of a fin in the centre point by changing the frequency of input voltage as shown in **Fig.4** in air. Second, the maximum current is also measured by changing the input voltage.

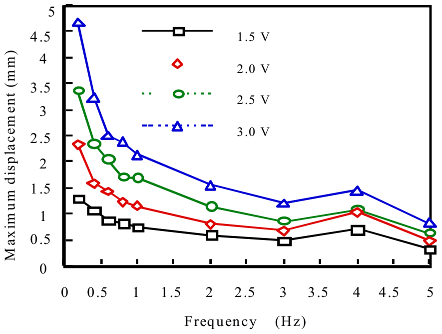


Fig.9 Maximum Displacement (In Air)

The experimental results are shown in **Fig.9** and **Fig.10**. From these experimental results, it is known that the maximum displacement is in inverse proportion to the frequency of the input voltage, and the maximum current is nearly proportional to the input voltage respectively.

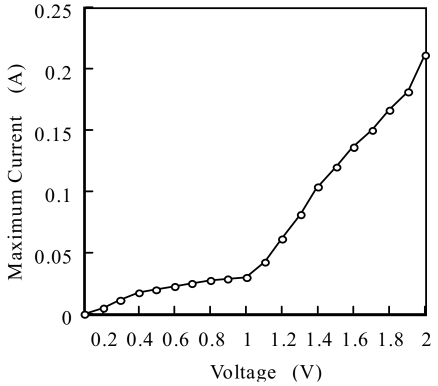


Fig.10 Maximum Electric Current (In Air)

## V. PROTOTYPE FISH-LIKE MICROROBOT

The prototype of developed microrobot using ICPF actuator is shown in **Fig.3**. The specification of the microrobot is 10mm in width and 45mm in length (body 15mm without tail) as shown in **Table 2**. The body of microrobot is mainly made of wood material for lightweight. In order to verify the mechanism of the microrobot, we carry out the swimming experiments in 3 directions with 3 DOF in water by changing the voltage frequency. **Fig.11** shows the swimming motion in the water surface. **Fig.12** shows the swimming motion in the vertical direction reaction in water by changing buoyancy of the microrobot.

Table 2 Specifications of the Prototype Microrobot

| | |
|---|---|
| Size | 10mm*45mm |
| Weight | 0.76g |
| Material | Wood |
| Actuator | ICPF Actuator (0.2*3*15) |
| Power Supply | Electricity (e.g.4V, 0.15A) |

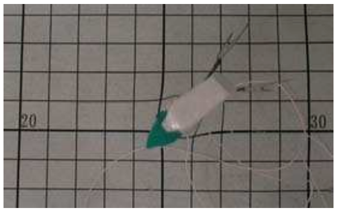
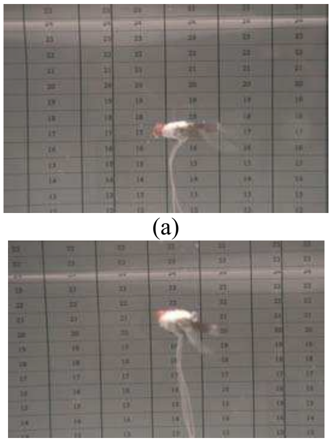


Fig.11 Floating Motion in water surface



(a)

(b)

Fig.12 Floating Motion of the Microrobot

## VI. EXPERIMENTAL RESULTS

We made the swimming experiments of the prototype microrobot using a measurement system shown in **Fig.13**. The propulsive forces for various frequencies were measured using a laser displacement sensor, an electric balance and a copper beam. The copper beam is soft enough to be bent by the propulsive force. The electric balance is used for the force evaluation. We also measured the propulsion speed for various frequencies using a high-speed camera. The average value of over 20 data is used as the final test data. By changing the frequency from 0.2Hz to 5Hz at 2.5 voltage input, the experimental results of average propulsive force, and average speed are shown in **Fig.14**. Experimental results show hat the moving speed 1.3mm/s~5.21mm/s can be obtained by changing the voltage frequency. **Fig.15** shows the floating speed for the microrobot. From the experiment results, it can be known that changing the voltage frequency can control the floating speed. **Fig.16** and **Fig.17**show the walking speed for the underwater micro biped robot. From the experiment results, it can be known that changing the voltage frequency can control the walking speed for the mirorobot.

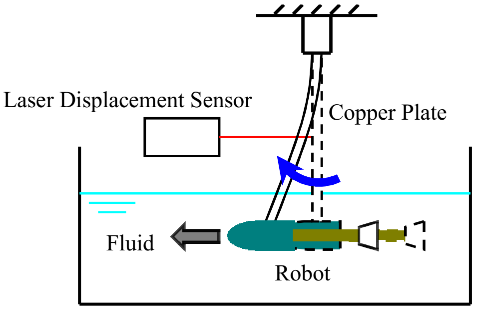


Fig.13 Measurement System of Propulsion

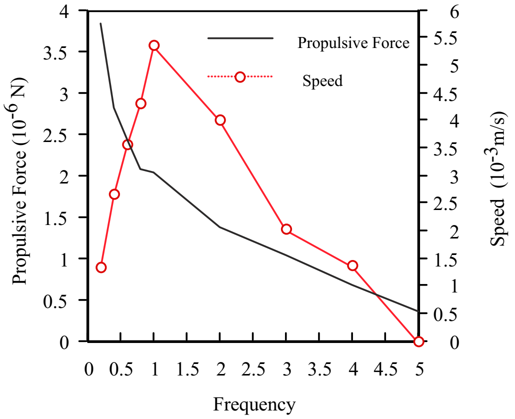


Fig.14 Experimental Results (2.5V)

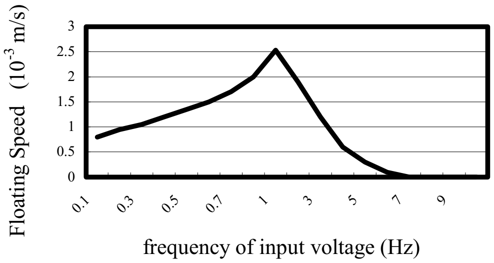
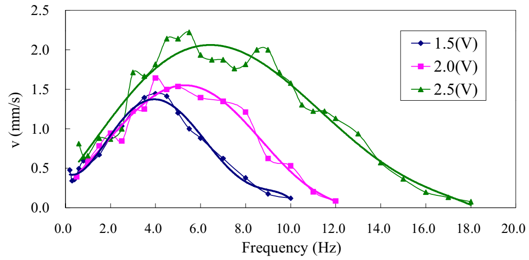
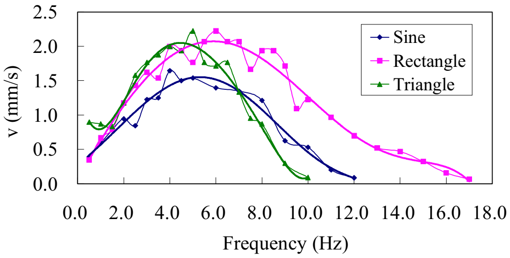


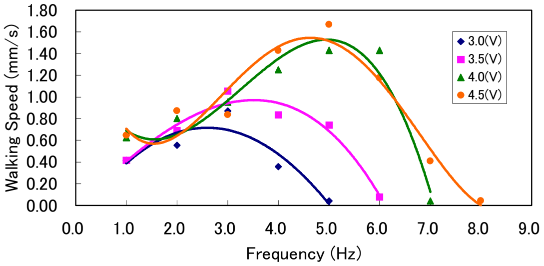
Fig.15 Experimental Results of Floating Speed



(a) Walking Speed with Voltage



(b) Walking Speed with Driving Wave



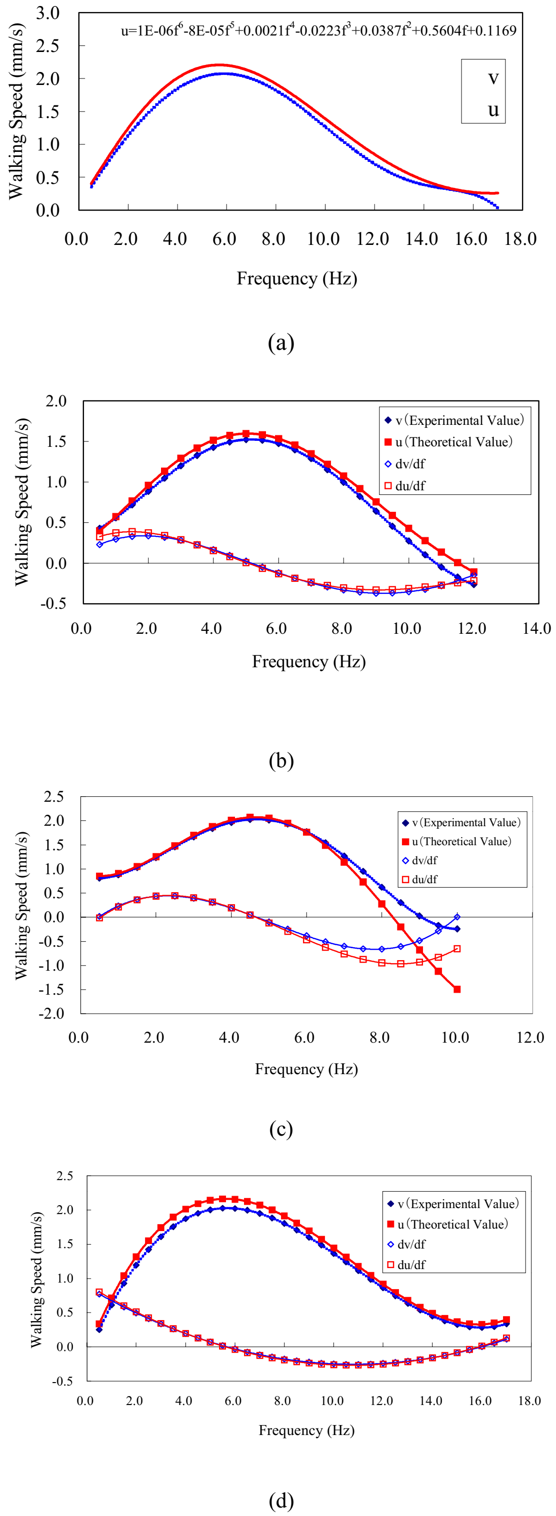
(c) Walking Speed for Microrobot with 2DOF

Fig.16 Experimental Results of the Walking Speed

## VI I. CONCLUSIONS

In this paper, we propose a new prototype model of an Underwater Micro Biped Robot with Multi DOF utilizing **ICPF** actuator as the servo actuator to realize swimming motion with multi DOF. The mass center of the microrobot can be controlled by one electromagnetic actuator. So the floating motion in vertical direction has been realized easily. There are two pair of fins, a mass center adjuster and a floatage adjuster. Characteristic of the underwater microrobot is measured by changing the frequency and amplitude of input voltage. The experimental results indicate that the swimming speed of proposed underwater micro robot can be controlled by changing the frequency of input voltage, the moving direction (upward or downward) can be controlled by changing the amplitude and the frequency of input voltage.

Based on the experiment result, it verified that the running speed of a micro bipedal robot was controllable by adjusting input voltage and frequency. The application to a living thing type admiration robot etc. can be considered.



(a)

(b)

(c)

(d)

Fig.17 Calculation Results of Walking Speed

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