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Proposal of Bioinstrumentation Using Shape Deformation of Amputated Upper Limb

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***Abstract*— Some upper limb amputees have been annually supplied with myoelectric prostheses by social rehabilitation promotion services. However, the persons supplied with the prostheses have been limited because a supply system has not been established yet. Accordingly, we propose a new bioinstrumentation using the shape deformation of the amputated upper limbs without using the myoelectricity generated on the skin of the upper limbs. The repeatability is superior to the myoelectricity because the shape deformation is directly measured by strain gages and also the cost is much superior to the myoelectricity.**

I. Introduction

A myoelectric prosthesis for an upper limb amputee is technically superior to a cosmetic glove and a body-powered prosthesis in some ways. Therefore, some upper limb amputees have been annually supplied with a myoelectric prostheses by social rehabilitation promotion services within the jurisdiction of Ministry of Health, Labor and Welfare[1]. However, the rates of people who have been supplied is extremely low and many upper limb amputees remain to use conventional prostheses owing to the grant system lag of prosthetic device expenses. Consequently, the grant system lag prevents the independence of daily living and the vocational rehabilitation.

According to the sixth artificial limbs prosthesis expert meeting reports[2] under the auspices of Labor Standards Bureau, Ministry of Health, Labor and Welfare, the number of allowance of myoelectric prostheses is 4 cases in the Services and Supports for Persons with Disabilities Act, and 17 cases in the Industrial Accident Compensation Insurance Act. The persons who are supplied with the prostheses are limited slightly due to the limitation of application that an injury suffered or a disease in the course of his employment in the Industrial Accident Compensation Insurance Act. Owing to the strict review standards on the allowance for a study, 25 out of 95 applicants for the grant system have not been supplied over the past 4 years (April 2008 to March 2012). Moreover, because the period of the grant system on the allowance for a study is not longer than 5 years (April 2008 to March 2013), it is assumed that the allowance rates will decrease in future than at present.

The background of the low supply rate is considered as follows: 1) It is difficult for the amputees to purchase the prostheses without the grant system because the exclusive German commercial products are expensive. 2) It is difficult to generate the myoelectricity stably. 3) It depends on the differences among individuals. Therefore, the electric prosthesis without relying on electromyogram signals are needed.

For instance, a hand gestures measurement and a classification system for the electric prosthesis have been proposed[3], [4]. The system is composed of 54 pieces of force sensitive resistors, a measurement and digitalization unit and a pattern recognition software module. Although the system can classify hand gestures by using a learning software, the accuracy of recognition is not perfect in case of some gestures. Moreover the system needs to learn by repetition for the classification any number of times.

On the other hand, it is recognized that the electric prostheses do not required many functions and is sufficient if there is even one degree of freedom motions (opening/closing) of the hand in the preliminary our survey.

Accordingly, we propose a new bioinstrumentation using the shape deformation of amputated upper limbs for electric postheses without using the myoelectricity generated on the skin of the upper limb in this study. We focus on a different situation from most of the previous studies in which most electric prosthesis use EMG signals for configurations and movements.

In our method, the repeatability is superior to the myoelectricity because the shape deformation is directly measured by strain gages and also the cost is extremely superior to the myoelectricity. Furthermore, a patient can master the skill of operation immediately.

II. Proposal of Bioinstrumentation Using Shape Deformation of Amputated Upper Limb

If some muscles remain in an amputated upper limb, since an upper limb amputee is able to transmit neurotransmission

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signals to muscles from his/her brain, rotational motions (a pronation and a supination) of bones (a radius and an ulna) of a forearm can be generated. In particular, the bones near the stump of amputated upper limb are dynamically rotated and the skin surface is greatly transformed. And because the increase and decrease of muscles does not arise quickly, the high repeatability on the shape deformation of skin surface involving the rotational motions can be realized.

We focus on the feature of a strain gage for industrial use by way of the bioinstrumentation. The strain gage, the mechanical sensor which outputs a tiny resistivity change as a deformation generated by the bending, has been known that it is very light at about 10 [μm] in thickness and is superior in elasticity and moisture resistance. The strain gage is applied to the shape deformation sensor of the skin surface. A tiny resistivity change which respond to the bending of strain gage involving the shape deformation of skin surface is able to be easily transformed into a big voltage change that a microcomputer can recognize by a simple amplifier circuit. If a amplified voltage change is used as a differencial input of motor, an operational intention can be transmited to a electric prosthesis directly and intuitively. Our method have the high repeatability in comparison with the myoelectricity and have the high usefulness in bioinstrumentation.

III. Summary of Shape Deformation Sensor

First, taking an upper limb amputee for example, we explain about the mounting position of proposed shape deformation sensor (Fig. 1). The sensor is mounted on a part near the stump of amputated upper limb, directly putting on a ring-shaped metal tape, and involving in a special band (Patent applied for.) deviced in such a way that a patient can mount it on oneself by only one arm (healthy side).

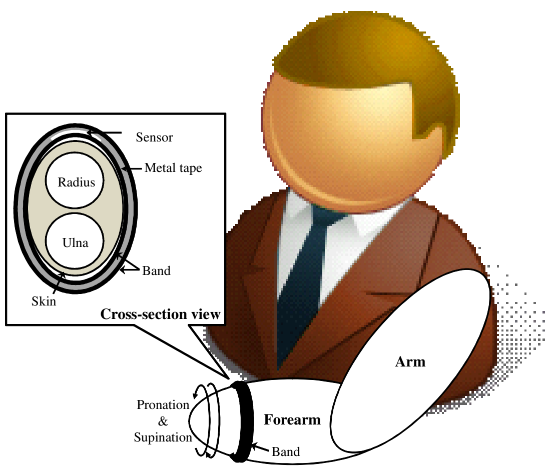

Fig. 1. Installation placement of shape deformation sensors

Next, a detail figure of sensor (Cross-section view) about the sensor action on the forearm is shown in Fig. 2. When a pronation motion or a supination motion occur, the voltage change $\Delta V_1(t)$[V] relative to the shape deformation of the skin surface is generated and is used for a differential function (velocity reference signal) in gripping and releasing motion of the electric prosthesis. The voltage

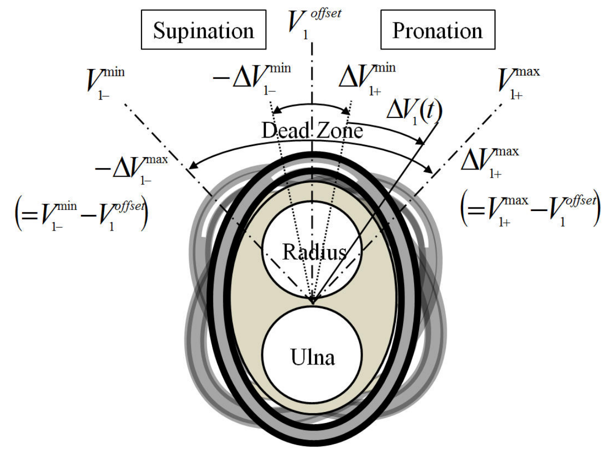

Fig. 2. A detail figure of sensor (Cross-section view)

change $\Delta V_1(t)$[V] is replaced with 0 [V] by compulsion in Dead Zone ($-\Delta V_1^{min}$[V] $\sim \Delta V_1^{min}$[V]) for the purpose of prevention of malfunction. Furthermore, when the voltage change $\Delta V_1(t)$[V] exceeds upper and lower limit (Maximum value ΔV_{1+}^{max}[V], Minimum value$-\Delta V_{1-}^{max}$[V]), although the motor is braked by compulsion for the purpose of ensuring of safety, it can be easily canceled the brake by operator's pronation motion or supination motion. Thus, an operational intention can be transmited to a electric prosthesis directly and intuitively.

IV. Design of Bioinstrumentation System Using Shape Deformation of Amputated Upper Limb

A. Summary of system

Proposed bioinstrumentation system can be separated from three function (Input part, Control part, Output part). Input part consists of two shape deformation sensors. Control part consists of an amplifier circuit (Block to amplify output voltage of sensor) and a DSP (Digital Signal Prosessor : Control system to process control signals in real-time). Output part consists of a motor driver and a motor (DC motor and Encoder). In order to realize the gripping and releasing motion of the electric prosthesis mentioned above, the block diagram of control system composed in the DSP is shown in Fig. 3. The system has a control program of returing to a safe state in case there is a failure or malfuction.

B. Measure for noise

Since the high frequency noise exist in $V_1(t)$ amplified to thousands times, it is possible to cause the malfuction when $V_1(t)$ is used as a control signal. Acoordingly, we apply 2nd order low pass filter to $V_1(t)$ in order to suppress the high frequency noise and utilize a smoothing filter (a simple moving average) so as to smooth the after filtering. Transfer functions of each filter are as follows:

$$\texttt{2nd LPF} : \frac{(2\pi \times f)^2}{(s + 2\pi \times f)^2}. \quad (1)$$

$$\texttt{Smoothing Filter} : \frac{\Sigma_{k=0}^{n-1} V_i(t - k\Delta t)}{n}, i = 1, 2, \quad (2)$$

where f is a cutoff frequency, Δt is a sampling time, n is a number of sample.

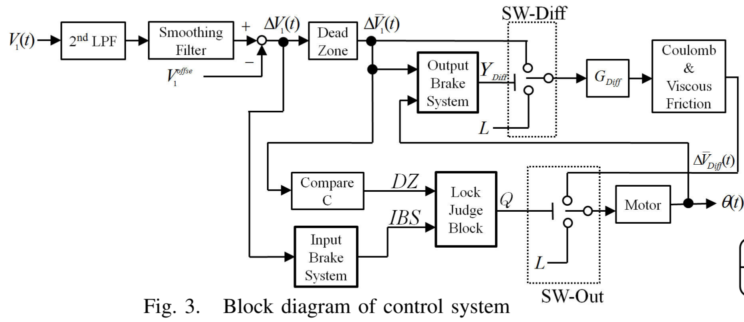

Fig. 3. Block diagram of control system

TABLE III

LOGICAL VALUE TABLE OF LOCK JUDGE BLOCK

State	IBS	DZ	IBS · DZ	Q(=IBS)
Impossible	L	L	L	L
Stop	L	H	L	L
Dead Zone	H	L	L	H
Action	H	H	H	H

(IBS : Input Brake System, DZ : Dead Zone, Impossible : (IBS,DZ)=(L,L) is exclusive)

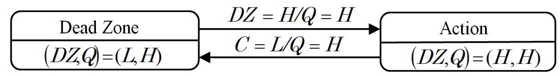

Fig. 5. State transition figure in the case of B=High)

C. Measure for safety at input side

By setting up Dead Zone ($-\Delta V_1^{min}$[V] $\sim$ ΔV_1^{min}[V]) to the voltage change $\Delta V_1(t)$[V] of the sensor for the purpose of prevention of malfunction, the sensivity can be dull. The range of Dead Zone is individually determined by adjusting the extreme values in advance. Here the relationship of the voltage change $\Delta V_1(t)$[V] and $\Delta\bar{V}_1(t)$ passed through Dead Zone is shown in Fig. 4. And the logical value table of Compare DZ for $\Delta\bar{V}_1(t)$ is shown in Table I.

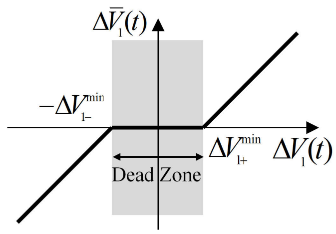

Fig. 4. Relationship of input/output in Dead Zone

TABLE I

LOGICAL VALUE TABLE OF COMPARE DZ

$\Delta\bar{V}_1(t)$	DZ
$\Delta\bar{V}_1(t) = 0$	L
$\Delta\bar{V}_1(t) \neq 0$	H

(L : Low, H : High)

By setting up upper and lower limit (Maximum value ΔV_{1+}^{max}[V], Minimum value $-\Delta V_{1-}^{max}$[V]) to the voltage change $\Delta V_1(t)$[V] of the sensor for the purpose of ensuring of safety, an excessive input (i.e. beyond the limits of rotation of motor) can be prevented. Here the logical value table of Input Brake System for $\Delta\bar{V}_1(t)$ is shown in Table II.

TABLE II

LOGICAL VALUE TABLE OF INPUT BRAKE SYSTEM

ΔV_1	B
$\Delta V_1 \geq \Delta V_{1+}^{max}$	L
$-\Delta V_{1-}^{max} < \Delta V_1 < \Delta V_{1+}^{max}$	H
$\Delta V_1 \leq -\Delta V_{1-}^{max}$	L

Lock Judge Block, which has output signals (IBS and DZ) of two blocks (Input Brake System and Compare DZ) above as input signals, is a synthetic logical operation block referring to the differencial function. Here a logical operation (four states in total) of Lock Judge Block is shown in Table III. State "Impossible" shows that (IBS, DZ)=(L, L) is not valid because the relations between IBS and DZ are obviously exclusive as shown in Table I and Table II. Furthermore, The rest states come and go mutually according to Fig. 5. However, Fig. 5 shows the state trasition in the case of IBS=Hign in Table III. It is unnecessary to show the state trasition figure because the output Q becomes certainly Low regardless of the level of executable DZ when IBS=Low as shown state "Stop" in Table III. The block diagram of Lock Judge Block that realizes the the state trasition figure above is shown in Fig. 6.

D. Measure for safety at output side and impproving of responce

By setting up upper and lower limit (Maximum value θ_+^{max}[rad], Minimum value $-\theta_{1-}^{max}$[rad]) to the rotational angle $\theta(t)$[rad] of the motor for the purpose of ensuring of safety, an excessive output (i.e. beyond the limits of rotation of motor) can be prevented. Here the logical value table of Output Brake System for $\theta(t)$ is shown in Table IV. It is necessary for the motor drive to overcome a coulomb's friction at the start of rotation of the motor and a viscous friction during the rotation. Accordingly, we perform a nonlinear processing (Offset voltage ΔV_{Diff}^{min}, Coefficient of viscous friction K_V, and Amplifier ratio G_{Diff}) to the differential input passed through Dead Zone and give a linear velocity reference signal $\Delta\bar{V}_{Diff}(t)$ for the motor driver. Here the relations of $G_{Diff}\Delta\bar{V}_1(t)$ and $\Delta\bar{V}_{Diff}(t)$ is shown in Fig. 7.

TABLE IV

LOGICAL VALUE TABLE OF OUTPUT BRAKE SYSTEM

$\theta(t)$	Y_{Diff}
$\theta(t) \geq \theta_+^{max}$	L
$-\theta_-^{max} < \theta(t) < \theta_+^{max}$	H
$\theta(t) \leq -\theta_-^{max}$	L

E. Measurement of biosignal and amplification method

An amplifier circuit of biosignal using the sensor is shown in Fig. 8. Two general-purpose foil strain gages KFG, made by KYOWA ELECTRONIC INSTRUMENTS CO., LTD., are used for the measurement of biosignal. Moreover, a tiny voltage change $v_1(t)$ is measured for twice as sensitivity of the shape deformation using 2-Gage System. Futhremore, $V_1(t)$ is given by amplifing a tiny voltage change $v_1(t)$ to more than 5000 times so that a microcomputer can recognize the voltage by using two AD623, Instrumentation Amplifier made by ANALOG DEVICES,INC., Incidentally, amplifier ratio G_1 of the first AD623 and amplifier ratio G_2 of the second AD623 are decided by the calculation formula as shown in Eq. (3), and the product of them becomes an amplifire ration from $v_1(t)$ to $V_1(t)$.

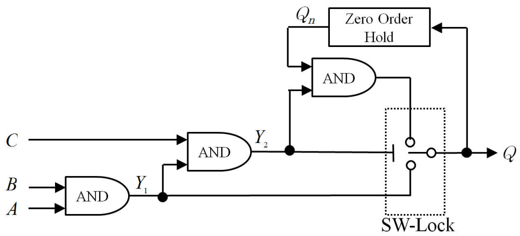

Fig. 6. Block diagram of LockJudgeBlock

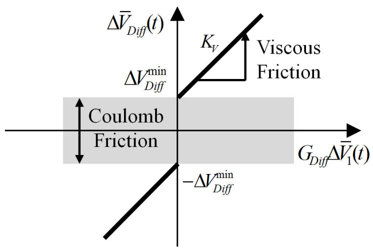

Fig. 7. Relationship of input/output in coulomb & viscous friction

$$G_1 = \left(1 + \frac{100k}{10k}\right) = 11, \quad G_2 = \left(1 + \frac{100k}{200}\right) = 501 \quad (3)$$

V. Clinical tests by bioinstrumentation system using shape deformation of amputated upper limb

A. Experimental equipments

Fig. 9 shows the appearance of experimental equipments in this study. This equipment is composed of a hand-made amplifier circuit, a DC servomotor (made by HARMONIC DRIVE SYSTEMS INC., RH-14D-3002), and a DC servomotor driver of the analog velocity reference input type (made by Servo Techno Inc., PMA2). An encoder (made by HARMONIC DRIVE SYSTEMS INC., Encoder resolution 1000 [p/r]) is used for the measurement of the displacement. DSP (made by dSPACE GmbH, DS1104, sampling period 1.0 [msec]) is used as hardware controllers.

B. Clinical tests

A subject of an experiment is one adult male who underwent amputation (a long stump) of the left forearm. The contents of clinical tests is to confirm the basic motion (state "Dead Zone" and state "Action") in the case of IBS=High=const. in Table III. An appearance of a band mounted amputated left forearm and clinical testing on a subject are as shown in Fig. 10 and Fig. 11. It is confirmed that he enables to transmit his operational intention (the strength and direction of rotational speed) to the motor directly and intuitively according to the results of clinical tests.

VI. Conclusion

We proposed a new bioinstrumentation using the shape deformation of amputated upper limb for electric posthesis without using a myoelectricity generated on the skin of the upper limb in this study and performed clinical tests for an upper limb amputatee, and confirmed the validity of proposed method. The detailed results of clinical tests are presented on the day.

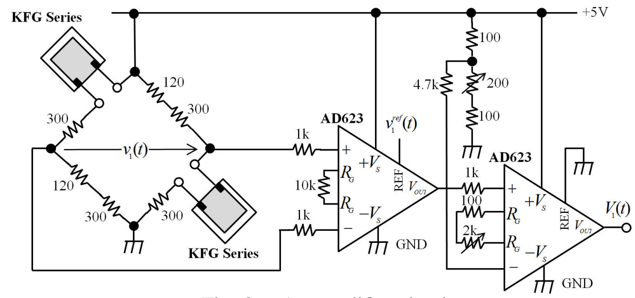

Fig. 8. An amplifier circuit

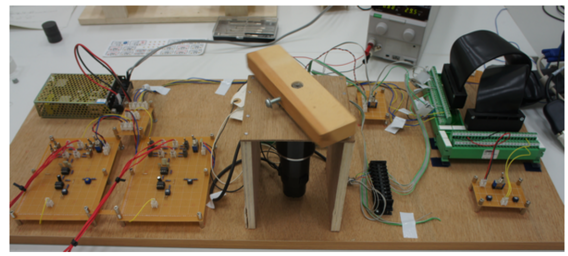

Fig. 9. Experimental equipments

Fig. 10. A band within a sensor

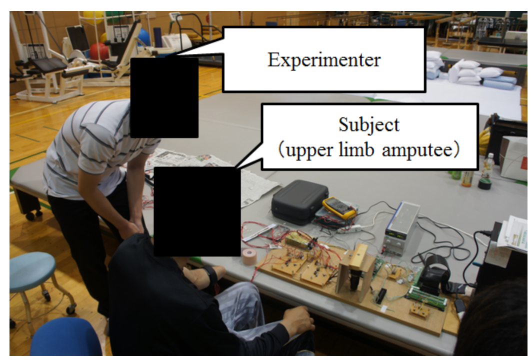

Fig. 11. Clinical testing on a subject

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