Proposal of Bioinstrumentation Using Flex Sensor for Amputated Upper Limb

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Abstract— **We previously proposed a new bioinstrumentation using the shape deformation of the amputated upper limbs without using the myoelectricity generated on the skin of the upper limbs. However many electronic parts were required owing to a bridge circuit and multi-amplifier circuits so as to amplify a tiny voltage of strain gages. Moreover, the surplus heat might occur by the overcurrent owing to low resistance value of strain gages. Therefore, in this study, we apply a flex sensor to this system instead of strain gages to solve the above problems.**

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 ratio of people supplied the myoelectric prostheses is extremely low and many upper limb amputees remain to use conventional prostheses due 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 people 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 their 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.

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 required. It is recognized that the electric prostheses do not require many functions and is sufficient if there is even one degree of freedom motions (opening/closing) of the hand according to the survey we conducted.

Accordingly, we previously proposed 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[3], [4], [5]. We focused on a different situation from most of the previous studies in which most electric prosthesis use EMG signals for configurations and movements. In the above method, the repeatability is superior to the myoelectricity because the shape deformation is directly measured by strain gages. Consequently, a patient would be able to master the skill of operation immediately.

However many electric parts were required owing to a bridge circuit and multi-amplifier circuits so as to amplify a tiny voltage of strain gages. As a result, there is chance of increase in total weights and costs when we make a practicable proposed prosthesis in future. Moreover, the surplus heat might occur by the overcurrent owing to low resistance value of strain gages. Therefore, we apply a flex sensor to this system instead of strain gages to solve the avobe problems in this study. The flex sensor is capable of making a simple composition by using voltage divider. Accordingly, it is possible to reduce total number of electronic parts substantially. Furthermore, the flex sensor can prevent heat from occurring owing to the overcurrent because the flex sensor usually have a huge resistance.

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II. PROPOSAL OF BIOINSTRUMENTATION USING FLEX SENSOR FOR AMPUTATED UPPER LIMB

If some muscles remain in an amputated upper limb, since an upper limb amputee is able to transmit neurotransmission signals to muscles from 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 as shown in Fig. 1. The high repeatability on the shape deformation of skin surface involving the rotational motions can be realized because the increase and decrease of muscles does not arise quickly.

Fig. 1. State of stump (Left:Pronation, Center:Neutral, Right:Supination)

We focus on the feature of a flex sensor for industrial use by means of the bioinstrumentation in this study. The flex sensor, the mechanical sensor which outputs a big resistivity change as a deformation generated by the bending, has been known to have various features; for example, are 0.43[mm] in height, $-35°$ to $+80°$ in temperature range, 25[kΩ] in flat resistance, -45[kΩ] to $+125$[kΩ] in bend resistance range.

The flex sensor is applied to the shape deformation sensor of the skin surface. A relatively big resistivity change which responds to the bending of flex sensor reflected the shape deformation of skin surface is able to be easily transformed into a big voltage change so that a microcomputer can recognize by more simplified amplifier circuit in comparison with the circuit using strain gages. When an amplified voltage change is used as a differencial input of motor, an operational intention can be transmited to an 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, we explain about the mounting position of proposed shape deformation sensor. The sensor is mounted on a part near the stump of amputated upper limb, directly putting on a special bioinstrumentation device (Patent applied for.) using polymer hydrogel sheet in such a way that a patient can mount it on oneself by only the other arm (healthy side) as shown in Fig. 2. The bioinstrumentation device using the flex sensor and polymer hydrogel sheet is shown in Fig. 3.

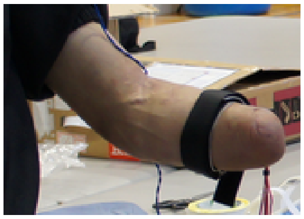

Fig. 2. Installation placement of shape deformation sensors

Fig. 3. Proposed bioinstrumentation device using flex sensor and polymer hydrogel sheet

Next, a detail figure of sensor (Cross-section view) about the sensor action on the forearm is shown in Fig. 4. 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 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 dsPIC30F (16-bit digital signal controllers made by Microship Technology Inc.). 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 dsPIC30F is shown in Fig. 5. 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, there is a possibility it causes 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.

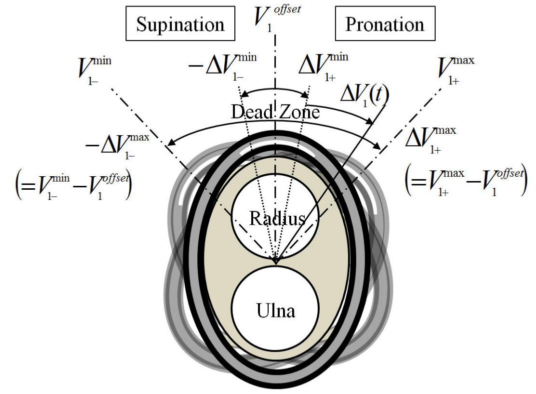

Fig. 4. A detail figure of sensor (Cross-section view)

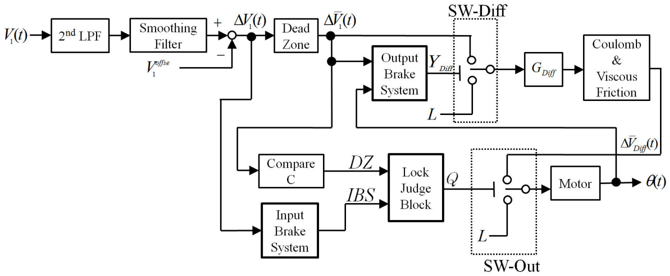

Fig. 5. Block diagram of control system

C. Measure for safety at input side

By setting up Dead Zone ($-\Delta V_1^{min}$[V] $\sim \Delta V_1^{min}$[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. And the logical value table of Compare DZ for $\Delta\bar{V}_1(t)$ is shown in Table I.

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.

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)

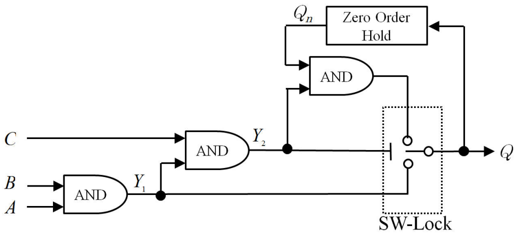

Fig. 6. Block diagram of LockJudgeBlock

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.

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

The flex sensor, made by SPECTRA SYMBOL, are used for the measurement of biosignal. We use the flex sensor SEN-10264, 2.2 [inch] in length, in this study. For a comparison, the amplifier circuit using strain gages and a flex sensor are shown in Fig. 7 and Fig. 8, respectively.

According to Fig. 7, many electric parts are required owing to a bridge circuit and multi-amplifier circuits so as to amplify a tiny voltage of strain gages. The weight is 18g. On the other hand, according to Fig. 8, the flex sensor can make a simple composition using voltage divider. In other words, it is possible to reduce total number of electronic parts substantially. Therefore, we applied the flex sensor to this system instead of strain gages. As a result, it is possible to decrease total weights and costs when we make a practicable

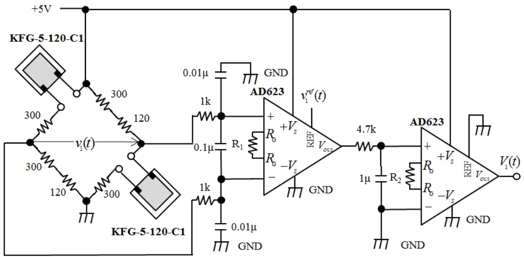

Fig. 7. An amplifier circuit using strain gages

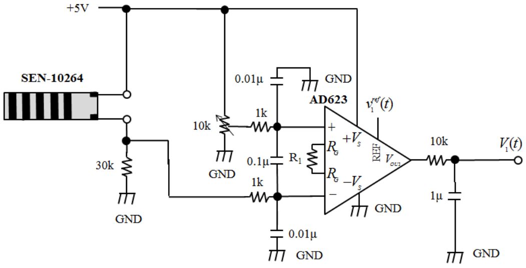

Fig. 8. An amplifier circuit using a flex sensor

proposed prosthesis in future. Additionally, the flex sensor can prevent the surplus heat from occurring owing to the overcurrent because the flex sensor usually have a huge resistance.

V. DEVELOPMENT OF PROPOSED ELECTRIC PROTHESIS

A. Prosthetic socket

Joint development has been underway with the artificial apparatus manufacturer, KYOWA CO.,LTD. Fig. 9 shows a producing prototype-type prosthetic socket that has the ability to realize our basic idea. The socket is manufactured so as to fit completely near an elbow that hardly rotates structurally. Consequently, the socket can be fitted to the amputated upper limb stably. Furthermore, a prostetic hand can be settled stably because the tip of socket is not affected by the rotation of the limb in the socket due to the tight fitting of the elbow and the socket. The weight is 165g.

Fig. 9. Prosthetic socket under construction

B. Prosthetic hand

Joint development has been underway with the aviation part manufacturer, Iwata Machinery Works Ltd. Fig. 10 shows a producing handroid-type prosthetic hand that has the ability to realize a prosthetic hand of stylish and light weight. The weight is 170g. This hand has some features as follows: Func.1: 5 fingers simultaneous movable, Func.2: 1 motor simultaneous drive, Func.3: flexion and full-grip capability, Func.4: extension and returning to the original prosthesis position.

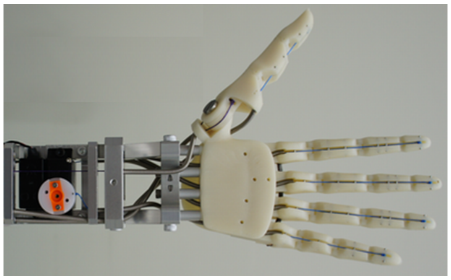

Fig. 10. A handroid-type prosthetic hand under construction

C. Cosmetic glove

Joint development has been underway with the artificial apparatus manufacturer, SATO GIKEN CO.,Ltd. has the ability to realize a cosmetic glove that feels like a real material. The weight is 290g. Fig. 11 shows a producing prototype cosmetic glove for the prosthetic hand.

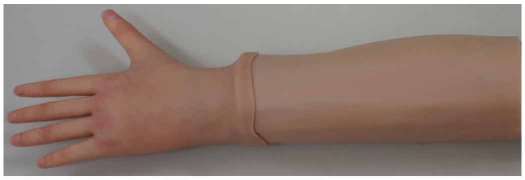

Fig. 11. Cosmetic glove for prosthetic hand

VI. CONCLUSION

We proposed a new bioinstrumentation using flex sensor for amputated upper limb without using a myoelectricity generated on the skin of the upper limb in this study. From the viewpoint of reduction of the total weights and costs and the risk of the overcurrent in practicality, we applied a flex sensor to this system instead of strain gages. Consequently, it was possible to reduce total number of electronic parts substantially and to improve the safety for patients. The detailed results of tests for healthy subjects and the validity of proposed bioinstrumentation are presented on the day.

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