EMG control of a pneumatic 5-fingered hand using a Petri net

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Abstract: This paper presents a control method of a 5-fingered artificial hand using EMG signals. Our targeted artificial hand is driven by pneumatic actuators to reduce its weight. Also we do not use electro pneumatic regulators but use ON/OFF solenoid valves to simplify the control system. The pneumatic hand has 15 degrees of freedom, and it seems difficult to discriminate all finger motions only from the EMG signals. Therefore, in this paper, we describe typical hand motions using a Petri net, and efficiently control the finger motions based on this model. Each state of the Petri net indicates a step of the hand posture to complete the intended motion. Simultaneously, this state corresponds to the ON/OFF pattern of the 15 solenoid valves. This enables the operator to control the 5-fingered dexterous hand smoothly, transiting the state in the Petri net according to the EMG motion discrimination. We conducted experiment to verify validity of the proposed method. In the experiment, the typical 5 motions (Spherical grasp, Power grip, Hook grip, Key grip, Precision grip) were successfully performed using the 6-channel EMG signals measured from the operator's forearm.

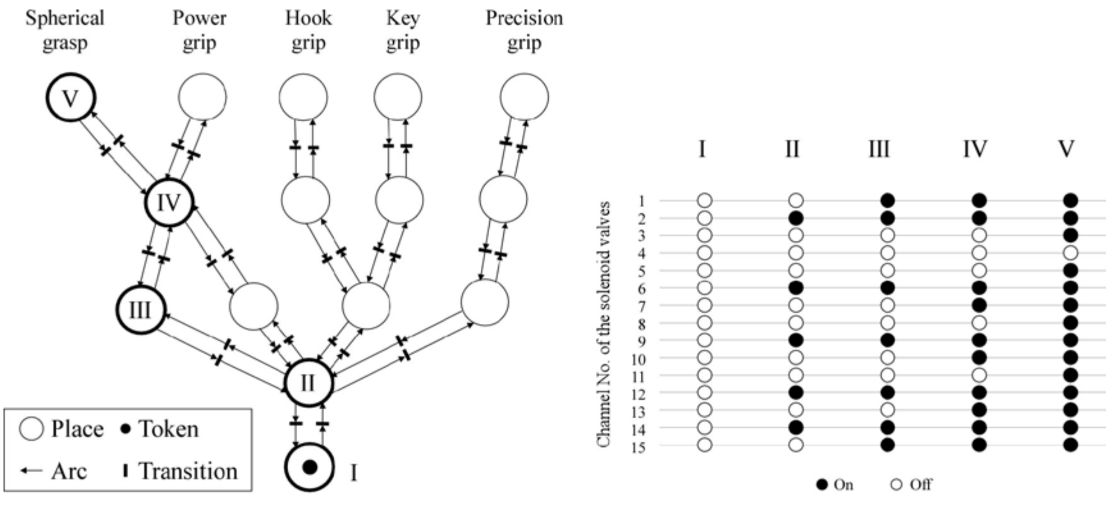
Keywords: EMG, pneumatic hand, Petri net, motion discrimination, neural network

I. INTRODUCTION

Until now, many researchers have designed EMG-controlled artificial hands for amputees. Its motion was previously limited only the opening and closing hand, but novel 5-fingered dexterous hands have been emerged, due to the progress in robotics and mechatronics fields [1]-[3]. For example, Otto Bock Inc. [1] and TOUCH BIONICS Inc. [2] have launched Michelangelo Hand and i-LIMB Hand, respectively. These hands are controlled by EMG signals and realize human-like finger movements.

However, a servo motor is used as the actuator of each finger joint, it is inevitable that its weight raises a physical burden of the operator during a long time of operation, with increasing number of degrees of freedom. Accordingly, a pneumatic actuator was tried to use as the substitute for the servo motor, and several researchers developed the robotic hands driven by the pneumatic actuator [4], [5]. The pneumatic actuator has a great advantage because it has a very light weight so that it can be expected to reduce the hand weight significantly. For example, Tsujiuchi et al. and SQUSE Inc. [6] newly designed the small pneumatic actuator, which can be installed into finger joints, and developed 5-fingered artificial hand [4], [5]. This pneumatic actuator can be driven by a lower air pressure than the previous one. Also, the system becomes compact using a small compressor. But, it is considerably difficult to control the multi-channel finger joints precisely, because non-linear relationship exists between the input air pressure and the output tension.

This paper proposes a novel control method for a 5-fingered prosthetic hand using EMG signals. We adopt pneumatic actuators to control the multiple joints to reduce the hand weight. Also, we use ON/OFF solenoid valves instead of electro pneumatic regulators to simplify the control system. The pneumatic hand has 15 degrees of freedom, so that it appears to be difficult to discriminate the motion of all joints. Therefore, we design the state transition model for the typical hand motions using a Petri net. This model enables the operator to control dexterous finger motions based on the simple discrimination of the discrete hand motions, such as hand opening, hand closing, and so on. Each state of the state transition model corresponds to the hand posture completing to the intended motion, and the ON/OFF pattern of the 15 solenoid valves are changed according to this state. Transiting the state in the Petri net, the operator can skillfully control the 5-fingered dexterous hand smoothly.



(a) Motion model (b) on/off pattern of the solenoid valves

Fig. 1 Control strategy

This paper is organized as follows. The control strategy of the 5-fingered pneumatic hand is introduced in Section II, the structure of the developed system is explained in Section III, the experiment is reported in Section IV, and Section V concludes the paper.

II. Control strategy

This paper proposed a novel control strategy of the 5-fingered pneumatic hand. The pneumatic hand used in this study has the 15 pneumatic actuators, and each actuator is controlled by the ON/OFF solenoid valve. Therefore, we have to consider how ON/OFF patterns are designed using 15 solenoid valves, and when these patterns are changed. Fig. 1 explains the control strategy of the hand motion based on the proposed method. (a) expresses the state transition model described by the Petri net, and (b) depicts the ON/OFF pattern of the 15-channel solenoid valves. The Petri net is composed of some places, transitions and arcs, that denote the states of the hand postures, the conditions based on the EMG discrimination, and the flows of the hand postures, respectively. At the start of the operation, a token is set on the initial place. The transition means that the duration time of a discriminated motion exceeds the prespecified threshold. For example, the token is moved from I to V, if Spherical grasp is discriminated in the system and its duration time exceeds the prespecified thresholds. Conversely, if No motion is discriminated and its duration time exceeds the threshold, the token is moved from V to I and the hand is opened. According to the places where the token exists, 15 solenoid valves are controlled depicted in (b).

In this paper, we select 5 motions for the discrimination targets: 1. Spherical grasp, 2. Power grip, 3. Hook grip, 4. Key grip, 5. Precision grip. These motions were frequently used in the previous research, and have possibility to discriminate with high accuracy using the EMG signals. It is noted that the proposed control method is not restricted within these 5 motions. We can choose appropriate motions according to operator's operability.

III. Components of the system

Fig. 2 indicates the components of the system. The EMG signals are measured by the EMG amplifier system (DELSYS Inc., BAGNOLI EMG SYSTEM), and are transferred to the personal computer (Hewlett-Packard Inc., HP Pavilion, Intel(R)Core(TM)2 Duo CPU 2.27GHz) via the multi function DAQ (National Instruments Inc., NI USB-6229).

The signal processing, which is conducted in the personal computer, is composed of 3 parts: 1. Feature extraction, 2. Motion discrimination, 3. pattern generation of the solenoid valves. Each process is explained in the following sections.

1. Feature extraction

First, the measured EMG signals are rectified and filtered out through the 4th order Butterworth filter (cut-off frequency: 1.0[Hz]) to extract the amplitude information. The filtered signals are resampled with a sampling frequency of 50.0[Hz], and defined as $E_l(n)$.

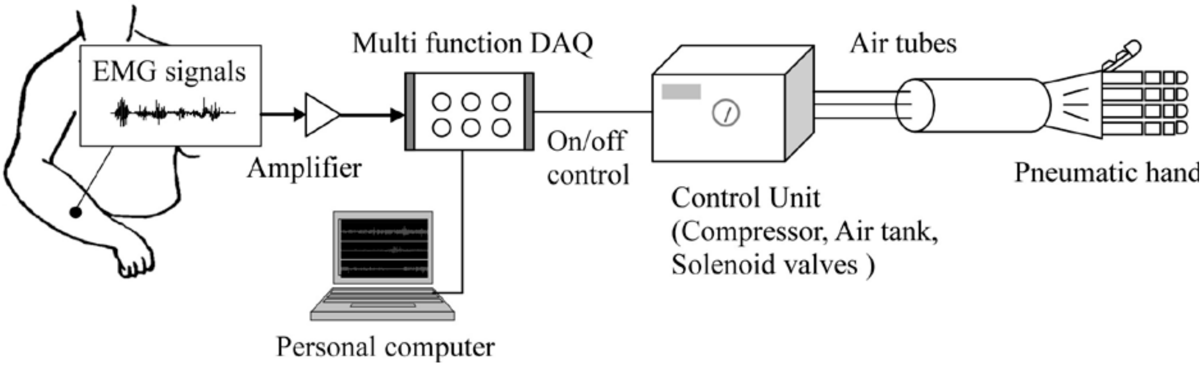


Fig. 2 Components of the system

Then, the pattern vector $x_l(n)$ for the motion discrimination is calculated as

$$x_l(n) = \frac{E_l(n)/E_l^{max}}{\sum_{l'=1}^{L} E_{l'}(n)/E_{l'}^{max}}$$

where E_l^{max} is the maximum value of $E_l(n)$ while the operator executes the maximum voluntary contraction. Also, the muscular contraction level $F(n)$ is calculated to recognize the motion.

$$F(n) = \frac{1}{L}\sum_{l=1}^{L} \frac{E_l(n)}{E_l^{max}}$$

If $F(n)$ exceeds the prespecified threshold α, the system considers motion has occurred.

2. Motion discrimination

In the proposed method, we use a neural network to discriminate the operator's intended motion. The neural network can learn feature patterns and adapt the system to the differences due to the individuality, the electrode locations, and so on. Before the motion discrimination, the neural network has to be trained using learning samples. The initial value of the weight coefficient is a random number from 0 to 1. The mean square error is used as the energy function, and the learning is carried out to minimize this function. The back propagation method is adopted for the learning algorithm.

3. Pattern generation of the solenoid valves

Finally, the ON/OFF patterns of the solenoid valves are generated. In this process, we use the state transition model which describes typical grasp motions using a Petri net. The control signal for the ON/OFF solenoid valves is generated, transitioning the state in the Petri net according to the EMG motion discrimination. These signals are returned to the control unit through the Multi function DAQ. The compact compressor (SQUSE Inc., MP-2-C) is installed in the control unit, and it drives the pneumatic actuators in the finger joints.

IV. Experiment

We conducted experiment to verify the validity of the proposed method. Subject controlled the 5-fingered pneumatic hand using his EMG signals. Before the experiments, we explained the purpose of the experiments and obtained informed consents from the subject. Subject was briefly trained for about 30 minutes before the measurements. The EMG signals were measured from 6 electrodes, and the number of the discrimination target were 5 motions: 1. Spherical grasp, 2. Power grip, 3. Hook grip, 4. Key grip, 5. Precision grip, which frequently arise in daily activities. The 6 electrodes were placed on the right forearm surrounding regular intervals. The operator does not have to set the electrodes on the associated muscles strictly, due to the learning ability of the neural network. The neural network can learn the pre-extracted EMG patterns to adapt the system to individualities, electrode locations, and so on. The parameters in the signal processing were set as follows: the number of the learning data was 50 samples for each motion. The threshold of the duration time of the transitions was 0.5[sec].

Fig. 3 shows examples of the motion control using the developed system. Subject performed the 5 motions. The figure indicates the 6-channel of EMG signals, the muscular contraction information, the changes of the place in the Petri net, and the discrimination results. During the operation, no discrimination error was observed and the token in the Petri net appropriately transited based on the discrimination result. We

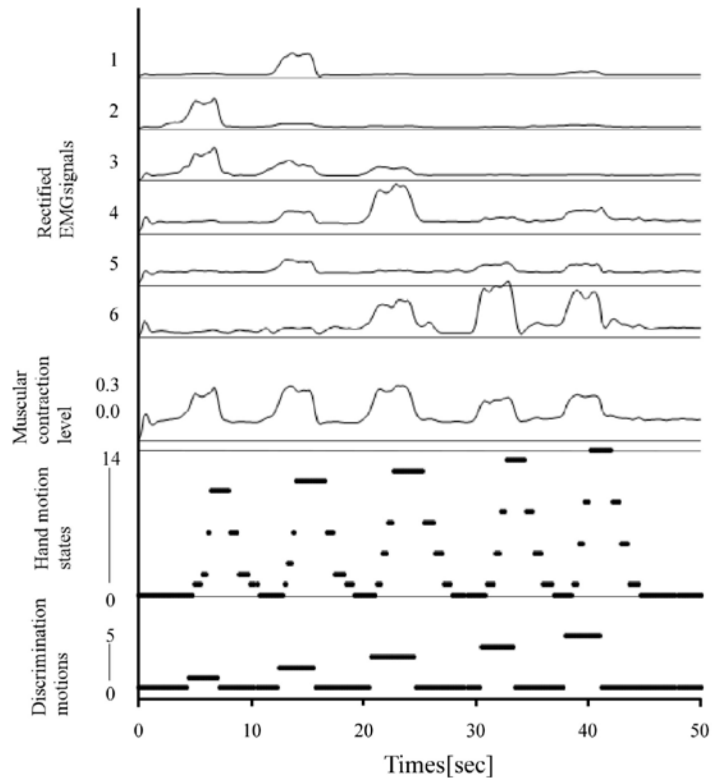


Fig. 3 Control example

confirmed that all 5 motions were successfully carried out in regular order.

V. CONCLUSION

This paper proposed the novel EMG control method for 5-fingered pneumatic hand. We introduced the typical hand motion model described by a Petri net into the control system, because it was difficult to control 15 degree-of-freedom hand precisely using only the EMG signals. Each place in the Petri net corresponds to the ON/OFF pattern of the solenoid valves, and the token is moved based on the result of the motion discrimination. The pneumatic actuators installed in the finger joints are controlled according to places where the token exist. Consequently, the operator can control 5 finger motions smoothly and naturally discriminating only the discrete motions, e. g. hand grasping, hand opening, and so. on. To verify the validity of the proposed method, the experiment was conducted. In the experiment, we examined the control performance of 5 typical grasping motions: 1. Spherical grasp, 2. Power grip, 3. Hook grip, 4. Key grip, 5. Precision grip. The experimental result confirmed the validity of the proposed method.

In future study, we would like to re-design discrimination algorithm to improve the discrimination performance. Also, we will optimize the mechanism of the pneumatic hand for amputee's daily activities. A part of this work was supported by Adaptable and Seamless Technology Transfer Program through Target-Driven R & D of Japan Science and Technology Agency.

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