Development of an Anthropomorphic Prosthetic Hand for Man-Machine Interaction

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Abstract. This paper presents a novel highly integrated prosthetic hand equipped with a man-machine interface for performing good grasping features. The hand has five fingers and each of them can be driven individually by the embedded actuation and control system fitted in the palm. By using the man-machine interface, users can control the prosthetic hand by means of their EMG signals and get grasp force feeling through the sensory feedback system designed based on surface electrical stimulus. At the end of this paper, a grasping trial is presented to verify the ability of interaction between the human body and the prosthetic hand.

Keywords: Prosthetic hand, Man-machine interface, Sensory feedback, Embedded control system.

1 Introduction

The prosthetic hand technology has made great progress under the promotion of robotics and biotechnology. With respect to the semblance [1], control method [2] and dexterity [3], the prosthetic hand is getting close to the real hand. But it should be noticed that the function of normal hand is mainly divided into two aspects: 1. completing the body action under the control of human brain. 2. sensory feedback from body to human brain. It is an obvious process of bidirectional transmission of information realized via passing bioelectrical signal on neural pathway connecting the brain and the hand together. Unfortunately, such mutual awareness can not be fully implemented between the amputee and prosthetic hand, because of the inexistence of the bidirectional messaging channel.

For solving this problem, many researchers have employed some alternative approaches, such as separately establishing the control channel from human-body to prosthetic hand and the sensory feedback channel from prosthetic hand to human body. Recently, the electromyography (EMG) control is mostly applied on the prosthetic hand, resulted from the mature technology of controlling prosthetic hand by identifying EMG patterns [4]. However, the investigation of sensory feedback has not yet formed a mature approach. Reference [5] tried to obtain the sensory feedback in force through using vibration motor under the CyberHand. The tendon-driven prosthetic hand of University of Tokyo [6] initially achieved tactile feedback by

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adopting surface electrical stimulus method [7]. Yet, their control system of the prosthetic hand is based on PC and too large to carry out portably.

In this paper, an intelligent prosthetic hand system named HIT IV hand is proposed to perform man-machine interaction. This prosthetic hand has 5 degree of freedom, 15 rotating joints and can handle all control algorithms in a high integrity control system. The interaction between human body and prosthetic hand is functioned by the discrimination of EMG signals and execution of electrical stimulation on body surface.

This paper is organized as follows: Section 2 will describe the mechatronics design of the HIT IV hand including the mechanism design and embedded control system design. Section 3 will propose the design of man-machine interface. Section 4 will give a grasping experiment to verify the effectiveness of the EMG control and sensory feedback. Finally, conclusions will be revealed in section 5.

2 Mechatronics Design

2.1 Mechanism Design

The HIT IV hand is composed of five active fingers; and each finger is actuated by a DC motor. All the motors, sensors and motion control system are integrated in the hand. The hand is about 90% of a human hand in size, weighs about 420g, whose appearance is shown in Fig.1.

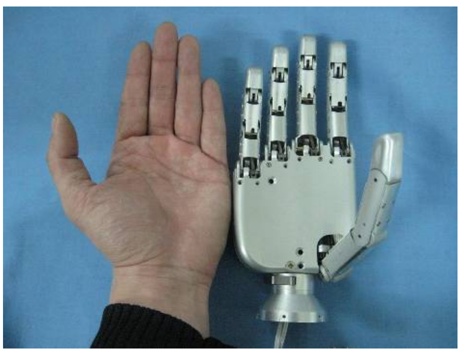

Fig. 1. Comparison between human hand and HIT IV hand

(a) spherical grasp (b) cylindrical grasp (c) precision grasp

Fig. 2. Grasping objects with different shapes

By taking the advantage of coupling linkage mechanism, each finger is capable to rotate around the metacarpophalangeal (MCP), proximalinterphalangeal (PIP), and distalinterphalangeal (DIP) joints for a total of 15 movable joints of the entire hand. Compared with the fixed shape fingers, not only the grasp ability is enhanced, but also the mimics motion of human hand can be achieved. Fig.2(a)(b)(c) shows the grasp ability of the hand.

2.2 Embedded Control System Design

The embedded control system is composed of motion control subsystem and sensory subsystem. Fig.3 shows the details of the system hardware architecture.

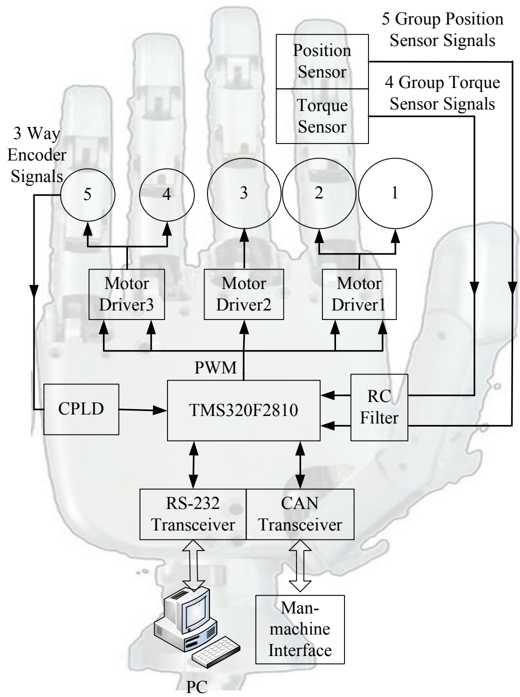

Fig. 3. Architecture of embedded control system

The sensory subsystem is crucial for both sensory feedback function and autonomous hand operation. A number of sensors, such as joint angle sensors, torque sensors and incremental magnetic encoders, are employed in the system. Position control of each finger's base joint can be obtained by means of an absolute joint angle sensor embedded in the mechanisms based on giant magneto resistance (GMR). The main advantages of the GMR sensor are their small sizes and their contactless working principle, which can avoid friction force. To protect the mechanical structure of the finger and measure the actually exerted torque of the finger, one-dimensional torque sensor is integrated into each finger's MCP joint except the little one. These torque sensors are fundamental for impedance control and grasp force sensory feedback. Incremental magnetic encoders mounted on the motor shafts can produce feedback information of the rotation speed of the motor, which can be used in position control loop of the finger's base joint.

The motion control subsystem of prosthetic hand has to meet the requirements of small size, light weight, low power consumption, high computation speed and flexible integration (into the palm). The core of this system is a DSP chip (TMS320F2810) with 64K flash memory, 18K RAM, six independent PWM outputs, 16-channles high-speed A/D converter, two serial communication interfaces(SCI) and one controller area network (CAN) module. The A/D ports are adopted to sample the torque and the position data. The CAN module is used to realize the communication with the man-machine interface. The SCI module is used to communicate between motion control system and the upper device as PC that uses RS-232 protocol for debugging. The PWM port is to drive the H-Bridge drive chip circuitry. Three H-Bridge drive chips which incorporate internal control logic are used to drive the DC motors. A kind of CPLD chip is selected as a coprocessor for dealing with the signals of motor encoders and sending the speed and direction of motors to DSP. The HIT IV hand integrating the embedded control system PCB is shown in Fig.4.

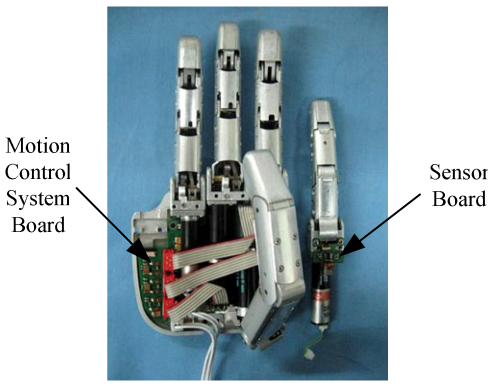

Fig. 4. Control system embedded in the HIT IV hand

3 Man-Machine Interface

The proposed man-machine interface is a type of interactive interface between human body and prosthetic hand for information exchanging. Its hardware is mainly composed of several EMG electrodes, a DSP board and an electrical stimulator as shown in Fig.5.

The DSP board takes charge of the main control scheme and necessary calculations, including: 1) the acquisition and processing of the myoelectric signals; 2) the generation and transmission of the action code; 3) Acquirement of the grasp force and the generation of electrical stimulus waveform data. Towards the complex operation and intensive calculations, a high performance DSP chip (TMS320F2812) is adopted as the main processor of the board, and an additional sRAM (1M) is employed to cache the real-time variables.

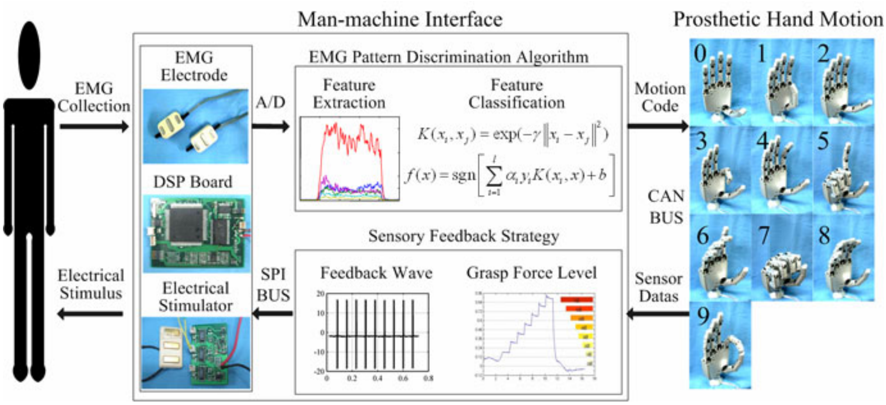

Fig. 5. Control structure of man-machine interface

Fig.5 also shows the working flow of the man-machine interface. After being amplified, filtered and rectified by the active electrodes (OttoBock 13E200=50), six channels of EMG signals are sampled at the A/D conversion ports of the DSP with a 12-bit precision. Prediction are performed on each sample using pattern recognition methods, therefore the predefined hand action modes can be recognized. Labels of the action modes are encoded and transferred to the motor controller of the prosthetic hand through CAN bus connection. According to the differences of the action modes, the prosthetic hand will perform corresponding actions automatically and acquire the force information through proprioceptive torque sensors. Based on the measurement of the grasp force, the man-machine interface translates and sends this information to the stimulator via SPI bus, meanwhile, the stimulator generates electrical stimulus wave on the surface of the human body according to the force volume.

3.1 EMG Processing

Main feature of the Otto Bock electrodes 13E200=50 is that they produce the EMG signal linear to the muscle contraction intension. Many researches [8] have revealed that this type of active electrodes can be successfully applied on the hand motion classification and hand force regression for obtaining the EMG signals. Six Otto Bock electrodes are placed on the forearm of the human body to extract the myoelectrical signals [9].The whole processing of the EMG signals includes:

1) Feature extraction; as stated before, because of the fine property of the output signals, sampling points at a frequency of 100Hz are directly used as the input feature vectors (6- dimension) to the classifier.

2) Pattern classification; a machine learning method, support vector machine (SVM) is adopted for the recognition of the action patterns based on the EMG samples. Linear kernel is used for the binary classsification of any mode pairs (one-against-one) [10]. So, there will be a total of C_{10}^{2} classifiers, and the final decision of the mode label will be made depending on their ballots.

3) Mode encoding and transmission; the 10 modes are sequentially labelled as 0-relexion, 1-thumb flextion, 2-thumb extention, 3-index flextion, 4-index extention, 5-rest three finger flextion, 6-rest three finger extention, 7-all flextion, 8-all extention, 9-nip (thumb and index flextion). The label are directly transferred to the hand controller via CAN connection, and the controller will command the correlative motor/motors to drive the prosthetic hand's fingers to perform the current action modes according to the label, as shown in Fig.5.

3.2 Sensory Feedback Based on Electrical Stimulus

For getting the knowledge of the prosthetic hand's exerting force while grasping objects, thus making the amputees be able to control the force as their intentions, a sensory feedback system is proposed. The feedback system utilizes the prosthtic hand's MCP torque sensor for getting the hand's exerting force. The force data is acquired and graded by the hand's motion control system, then transmitted to the man-machine interface via CAN bus connection. The man-machine interface generates some constructive parameters for establishing the stimulation waveform based on a typical stimulation strategy, then transmits the data to the stimulator via SPI bus connection. The stimulator produces the concrete stimulus waveforms which will be applied on the human body. Fig.6 shows these operations in detail.

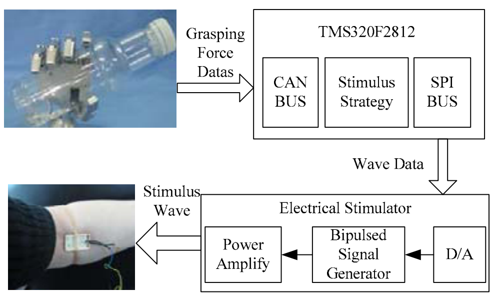

Fig. 6. The structure of the force feedback system

The feedback system utilized a self-built micro electrical stimulator, which is also shown in Fig.5. The multi-channel stimulation electrode can realize 8 stimulating grades and consumes little power. The stimulus waveforms are modulated square waves, as shown in Fig.7, where the continus diphase square wave is utilized as the carrier wave [11], t1 is the stimulating time, t2 is the intermittent time, T is a period of the stimulating pulses. At present, 8 grades of stimulation intensity can be performed according to the scope of the grasping force (0F-1F, F denotes the maximum force), as shown in Fig.8. The pulse frequency of the stimulator can reach to 100Hz from 0Hz gradually, which makes the feeling of the electrical stimulus more and more intensive.

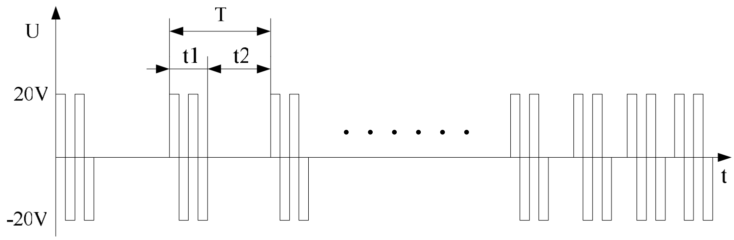

Fig. 7. Electrical stimulation waveforms

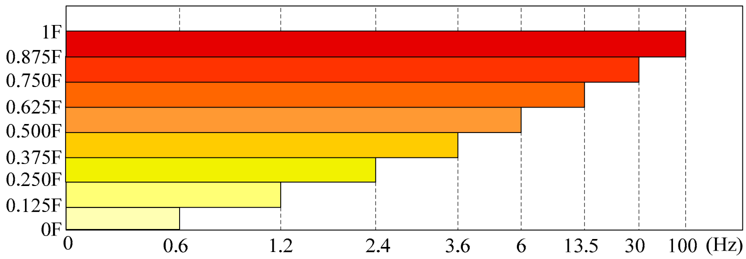

Fig. 8. Relationship between the grasping force and the grades of the stimulation

4 Experiment of Man-Machine Interface

In order to verify the features of man-machine interface, a grasp trial controlled by the EMG has been performed here. The hardware setup is exhibited in fig.9, which includes a prosthetic hand, a man-machine interface DSP board, an electrical stimulator, a stimulus electrode, 6 EMG electrodes, and a DC power source.

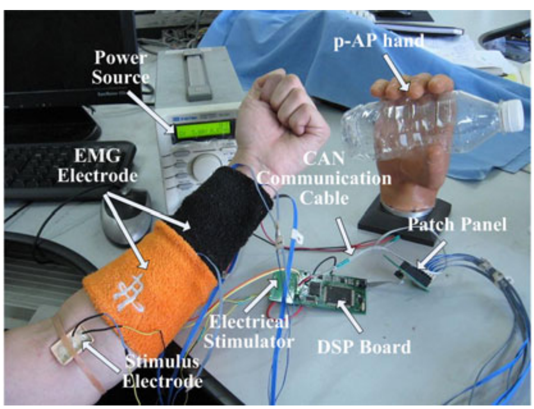

Fig. 9. Experimental setup

The experiment was performed on a healthy subject. The prosthetic hand was controlled by the subject's forearm EMG signals to hold a plastic bottle more and more tightly. Meanwhile, the information of the hand grasp force was transmitted to the subject through the graded electrical stimulation. The stimulation intensity indicates the different levels of the grasp force introduced in section 3.2. Fig.10 shows the torque curve of index finger. Several squeezing and release action can be found in Fig.10.Then, Fig.11 shows the corresponding stimulus wave, which becomes more and more serried and changes sparse at last. Through this way, the subject can get an approximate sensory feedback about the grasp force.

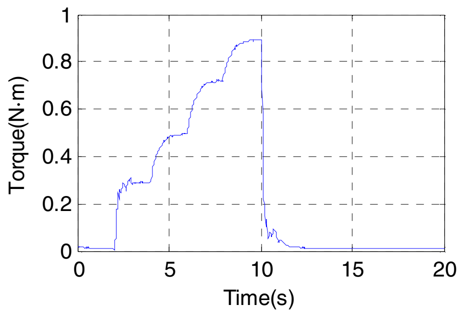

Fig. 10. Torque curve of index finger

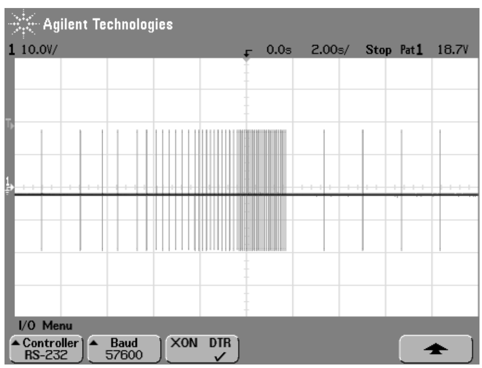

Fig. 11. Stimulus wave flowing through the body surface

5 Conclusions

This paper developed a new highly integrated five-finger prosthetic hand with ability of interaction between human body and the prosthetic hand. Each finger of the hand was designed based on the coupling linkage principle and actuated by a DC motor individually. The embedded control system was composed of a sensory subsystem and a motion control subsystem which were integrated in the structure of prosthetic hand. A novel man-machine interface was designed for the hand based on EMG and surface electrical stimulus, which can discriminate 10 types of hand gestures and feedback 8 levels of the grasping force intensity. Experiments were conducted using the developed system for a healthy subject. The experimental results showed that the subject can control the prosthetic hand through his EMG signals and get an approximate feeling about the grasp force at the same time.

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