Tactile sensing and feedback in SEMG hand

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Abstract: Active hand prostheses controlled using surface electromyography (SEMG) signals have been used for decades to restore the grasping function. Amputees with myoelectric hands wish to control the prostheses according to their own will and act like human hands as much as possible. Therefore, substantial research efforts have been put forth to advance the control of myoelectric hands. However, the tactile sensing and feedback of the myoelectric hands are still missing, thus limit hand grasp capabilities. In fact, integration of tactile sensing and feedback with hand prostheses plays an important role in improving the manipulation performance and enhancing perceptual embodiment for users. This paper reviews current state-of-the-art of tactile sensing technologies, including tactile sensor types and integration methods. Then, introduces the basic theory of SEMG signals and presents an overview of the sensory feedback employed to prosthetic hand. The paper concludes with a detailed discussion of challenging issues and future developments.

Keywords: tactile sensing; tactile feedback; SEMG signal; review; prosthetic hands.

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1 Introduction

The ‘sense of touch’ can be defined as the information acquired by human tactile perception system through the contact or operation of objects. It is an important sensory function when people contact with the external environment (Kappassov et al., 2015). Tactile information is an important medium for communicating with the environment, whether for human beings or robots (Yousef et al., 2011). The sense of touch itself is very sensitive and it can directly measure the various properties of objects and environments. Humans use the tactile organs of the skin to sense the temperature of the object, grasp objects reasonably and identify objects with the same in visual but different in materials by touch. For the prosthetic hand, tactile information can provide the contact force between the fingers and the objects, the contact position and other important information, which can improve fine grasping ability of the dexterous hand. It is of great importance for prostheses users to explore and operate unknown objects in the external environment.

The main task of tactile sensing is to obtain the object and environment information and to detect or perceive a series of physical characteristics when the prosthetic hand interacts with the object and environment (Tegin and Wikander, 2013). It not only can obtain the contact position of the finger and the object, as well as the contact force distribution function, but also can obtain the information which the vision sensor cannot obtain, as an example the mechanical properties, thermal character and vibration performance of the object.

But for an ideal prosthetic hand (Miao et al., 2015; Ulrika and Ingela, 2015; Peerdeman et al., 2011), it is not enough to have tactile sensing only. Regarding hand capability, an ideal prosthetic hand should have tactile sensation to explore surrounding objects in human-centred environments and deliver tactile feedback in a natural manner. The control of grasping largely depends on tactile feedback and providing feedback to the user would help to operate a prosthetic hand more efficiently. Tactile feedback can deliver the information such as shapes of the object, material property, work position and contact state (friction, sliding) to the human nervous system, so as to realise a closed-loop interaction between human and prosthetic hand (Li et al., 2017). Therefore, a common thought is that prostheses would function better if integrate tactile sensing and feedback with prosthetic hand and make use of tactile information acquired by sensors.

2 Tactile sensing technologies

Tactile sensors can be defined as a tool that can evaluate a given property of an object through physical contact between the hand and the object (Dang and Allen, 2014). Sensors are made of sensitive material or structure and they are mainly used to measure the change of physical properties caused by the interaction between themselves and the external object. Change of capacitance, resistance, optical distribution, electrical charge can be used in the sensing systems. For the prosthetic hand, grasping is one of the basic skill expected to have, most research on tactile sensing focuses on the control of grasp force and pressure to realise stable grasp and fine manipulation (Dang and Allen, 2014). The measured characteristics of touch, however, can be not only force and pressure, but also object parameters such as stiffness, texture and shape (Fishel and Loeb, 2012). Therefore, different transduction techniques are needed to realise a humanoid tactile sensing system.

2.1 Tactile sensor integration techniques

Compared with the dexterous robot hand, the shape, size and weight of the prosthetic hand have more stringent requirements and it also needs to meet the technical requirements such as speed and grasping force (Jiang et al., 2017). Therefore, it is a challenging problem to realise the integration of the structure, actuation, sensing and control of the prosthetic limb under the constraint of size, shape and weight.

When the prosthetic hand performs the task of grasping or manipulation, the tactile sensors provide the contact force, position and sliding information. The integrated design of tactile sensor array consists of two problems (Jiang et al., 2017; Liu et al., 2012):

a Simplified design and unit layout for tactile sensor array. According to the prosthetic operation function and the demand of perceptual feedback, the configuration of the tactile sensor array is optimised. Tactile sensors should be either flexible shaped to envelop a given surface and rigid as an attachment part.

b Intensive design of information acquisition system for tactile sensor array. If each sensitive unit is connected to the printed circuit boards (PCB) of the sensing array, the amount of wires required to read and transmit the data from the sensing arrays will increase.

An effective way of integrating tactile sensors is to embed them into the robot hand. The embedding procedure of the tactile sensing skin within the robot hand involves the following steps (Schmitz et al., 2011):

- Definition of the surface to be covered by the available computer-aided-drawing (CAD) model or by means of a 3D scanner.
- Manufacturing of the supporting part for the sensor using tactile sensing PCB. This part is to be attached to the robot hand. The use of a 3D printer can facilitate the manufacturing procedure.
- Identification and wiring of the sensing elements.
- Gluing the sensing elements down on the supporting part.
- Covering the sensing elements with flexible material, e.g., silicon rubber. For a specific surface shape, custom moulds should be designed.

2.2 Properties of the tactile sensor used in prosthetic hand

A tactile sensor that meets the requirements of prosthetic hand operation should have the following characteristics: high spatial resolution, high sensitivity, high frequency response, low hysteresis, simple wiring and large surface friction coefficient. High spatial resolution can detect more mechanical information, which can greatly improve the recognition ability of the object shape and the grasping ability of prosthetic hand. However, the increase in resolution can cause three problems: the complex of wire arrangement, the increase of information processing and the reduction of signal to noise ratio. High sensitivity is beneficial to detect low contact force and improve the ability of prosthetic hand to grasp fragile objects, but somehow, it will reduce the detection range of sensor. Frequency response can detect the change of pressure more quickly and improve the real-time performance of prosthetic hand, which is the key performance of slip detection. But yet, the high frequency response requires the high hardness of the cover material of the sensitive element, which will have a negative impact on the grasp stability of prosthetic hand. Because of the above reasons, the prosthetic hand commonly used elastic material as a protective layer of the sensor. When the pressure is loaded and released, the deformation and recovery of the elastic layer will delay, which will lead to hysteresis effect and reduce the spatial resolution and sensitivity of the sensor (Balasubramanian and Santos, 2014).

3 SEMG signal techniques

3.1 SEMG signals

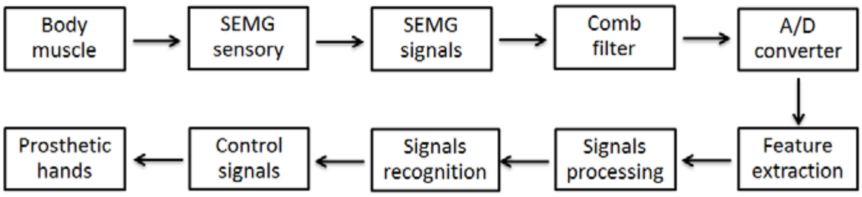
With the development of multi sensor technology, electronic information technology, pattern recognition technology and biomedical engineering, study on surface electromyography (SEMG) controlled prosthetic hand has gained growing attention (Sun et al., 2018). The prosthetic hand based on SEMG signals has become a hot topic in the field of prosthetic control.

The electromyographic (EMG) signal is the summation of the action potentials discharged by the active muscle fibres in the proximity of the recording electrodes (Jiang et al., 2010). As described by Farina and Holobar (2015), the EMG signal can be seen as a neural recording from a peripheral muscle that biologically amplifies neural signals of tens to hundreds motor neuron. A single motor neuron and its corresponding muscle fibres constitute a muscle unit (MU). The SEMG obtains EMG signals by placing electrodes on the skin. It is a kind of bioelectric signal recorded and included by electrodes when neuromuscular system is active. The activity of motor neurons activates the generation of muscle fibre action potentials and a compound action potential recorded at the skin surface is the SEMG recording.

3.2 SEMG feature extraction and analysis

When the SEMG signals are recorded from the muscles, they will be processed and analysed for activating certain prosthetic functions of the prosthesis. SEMG acquisition and processing are shown in Figure 1.

Figure 1 The frame diagram of SEMG acquisition and processing



The purpose of signal analysis and processing is to discuss the possible cause of SEMG signals change and reflect activity and function of muscles effectively by the change of SEMG signals. The task of signal recognition is to translate the input SEMG signals into corresponding motion control commands. The feature extraction of SEMG signal is considered as one of the most important steps in pattern recognition. The classification of feature quantity will directly determine the classification effect of the algorithm (He et al., 2017). To improve the performance of the classifier, researchers have been using different types of SEMG features as an input to the classifier. To achieve optimal classification performance, the properties of SEMG feature space (e.g., maximum class separability, robustness and the computational complexity) should be taken into consideration (Fang et al., 2015).

4 Tactile feedback

Tactile feedback is a method to provide sensory information to the body, through a sensory channel different from that normally used (e.g., substitute touch with hearing) or through the same channel but in a different modality (e.g., substitute pressure with vibration) (Kaczmarek et al., 1991). The success of the approach depends on the user's ability to interpret the type and location of the stimulus and associate it with the prosthesis. The most common method is to translate tactile information from the prosthesis to the amputee using vibration, electrotactile or auditory substitution.

4.1 Vibrotactile feedback

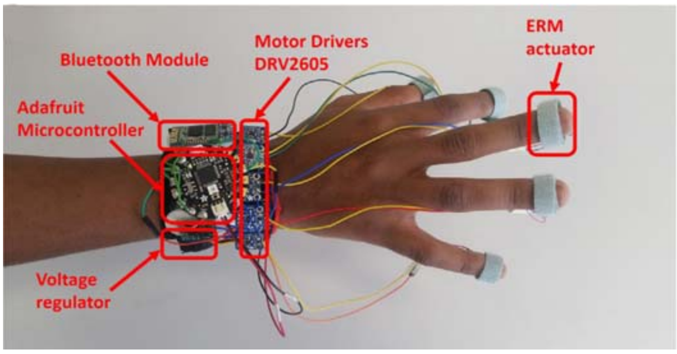
Vibrotactile feedback involves communicating sensory information from the prosthesis to the user through the application of mechanical vibration to the user's skin at forearm (Cipriani et al., 2012). The main features of the stimulus are vibration frequency, amplitude and duration of vibration, typically at frequencies in the range of 10–500 Hz (Kaczmarek et al., 1991) and they can be modulated to convey different kinds of information like grasping forces and pressures present in the prosthesis.

The vibrotactile feedback in prosthetic has been widely researched due to its higher compatibility with EMG control and acceptability compared to electrotactile stimulation (Kaczmarek et al., 1991). And then, it has been widely researched due to its higher compatibility with EMG control and acceptability compared to electrotactile stimulation (Kaczmarek et al., 1991). Explore on vibrotactile sensory substitution has been mostly applied to communicate tactile information during grasping tasks. Vibrotactile feedback systems have been used in research with the Otto Bock, motion control and iLimb myoelectric prostheses (Saunders and Vijayakumar, 2011; Chatterjee et al., 2008; Sears et al., 2008). Recent studies (Cipriani et al., 2012; Tejeiro et al., 2012) have reported that vibratory feedback was shown to improve user performance through a better control of grip force and success rates in performing grasping tasks. Currently, a wearable vibrotactile haptic device has been developed for stiffness perception during an interaction with virtual objects, as shown in Figure 2(a). A vibrotactile stimulation system applied with a myoelectric prosthetic hand is illustrated in Figure 2(b). With the development of technologies, they are potential to be applied in sensory rehabilitation.

4.2 Electrotactile feedback

Electrotactile feedback is induced by a current that flows through the skin. Recently it was exploited in the Yokoi Hand to deliver grip force feedback on a single skin-site and by Geng et al. (2011) to investigate the effects of different patterns on the perception threshold. Electrotactile feedback system is comprised of force sensors that are placed on the fingers and palm of a prosthetic hand, interface circuits for processing the sensor data and electrodes that are placed on nearby skin (Cloutier and Yang, 2013). It communicates sensory information to the prosthetic user via electrodes placed on the user's skin. Electrotactile feedback can be used to elicit pressure and lip feedback. Sensory communication is most often achieved through modulation of the electrical current parameters: amplitude, frequency and pulse rate to single or multiple electrode sites (Antfolk et al., 2013). Through the experimental method, the relationship between electrical stimulation parameters and the grasping force in prosthesis should be determined to make user feel comfortable and safe and have a clear sense of excitement.

Figure 2 (a) Wearable haptic device with five vibrotactile actuators (b) vibrotactile feedback system applied with a myoelectric prosthetic hand) (see online version for colours)

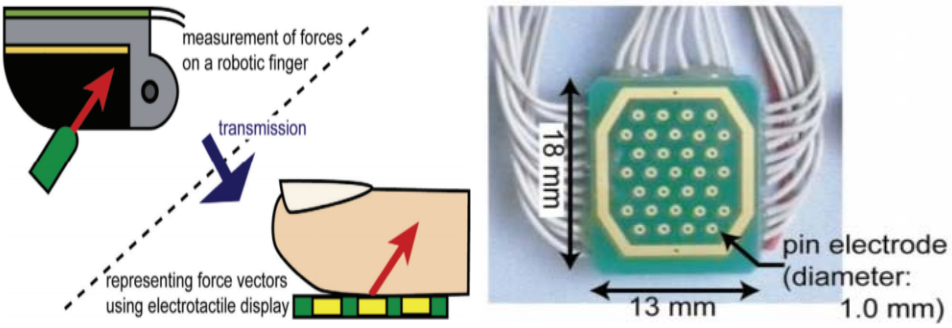


(a)

(b)

Source: [a]Maereg et al. (2017) and [b]Cipriani et al. (2008)

Figure 3 (a) Representing the distribution of force vectors on a fingertip using the electrotactile display (b) electrodes of electrotactile display (see online version for colours)



(a) (b)

Source: Sato and Tachi (2010)

Sato and Tachi (2010) proposed a design of electrotactile stimulation for distribution of force vectors that can be represented by an electrotactile display; the principle is shown in Figure 3(a). The structure of an electrotactile display is shown in Figure 3(b).

4.3 Auditory feedback

Auditory feedback has been demonstrated as a technique to convey contact of a robotic hand to an object as well as the position of the hand's digits and intended grasping pattern (Gonzalez et al., 2011, 2012a). Methods of auditory feedback provide information on the state of a robotic or prosthetic hand through varying frequencies of tones or sounds.

Gonzalez et al. (2012b) designed an experience to explore the effect of using an auditory display as a sensory feedback system for reaching and grasping movements for prosthetic applications. The results showed that the usage of an auditory display to monitor and control a robot hand improved the temporal and grasping performance greatly, while reducing mental effort and improving their confidence.

Gibson and Artemiadis (2015) presented a method of sensing tactile information in dexterous manipulation by multi-frequency auditory signals. By grasping several objects of varying stiffness and weight with EMG prosthetic hand, the tactical information was provided in time through the proposed auditory feedback. Results showed that users were able to adapt and learn the feedback technology after short use and could eventually use auditory information alone to control the grasping forces of a prosthetic hand.

5 Conclusions

Although some tactile sensing and feedback techniques have been developed to solve the problem of integration of tactile sensing and feedback with hand prostheses, but with limited success in commercial application. There are still much challenges and opportunities in the field of tactile sensation restoration.

For the most current tactile sensors, the tactile sensor arrays cannot fully meet the requirements of the prosthesis. But the multi sensor information fusion can not only enhance the detection accuracy of the fingertip contact force of prosthetic hand, but also improve the rolling contact accuracy of unknown objects. Therefore, multi sensor information fusion technology is expected to improve the manipulation performance of prosthetic hand.

In relation to SEMG signals, the processes of SEMG signal acquisition and feature extraction are more susceptible to external noise. Among the aforementioned tactile feedback, electrotactile feedback is believed to be the most promising technique its small dimension, low noise and friendly interface with electronics. However, electrical feedback signals and SEMG signals inevitably interfere with each other, especially the electrical feedback signals have a greater influence on the SEMG signals, which can lead to the degradation of the EMG signal quality. So how to restrain the interference between electrotactile feedback and SEMG signal is a key problem to be solved.

With regard to tactile stimulation feedback, challenges are natural sensation generation and multi-sensation restoration. The current feedback modalities can only provide one or two sensing information, such as force or pressure. But other tactile features, such as texture, shape and stiffness also need to be provided by feedback system. So, multiple tactile sensations are expected, furthermore, to be fed back simultaneously just like the way that human skin works. Therefore, it is expected that an effective sensory feedback which can generate natural tactile perception will facilitate clinical use in prosthetic hands or other application in virtual reality.

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