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Single channel surface EMG control of advanced prosthetic hands: A simple, low cost and efficient approach

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ABSTRACT

Surface EMGs have been the primary sources for control of prosthetic hands due to their comfort and naturalness. The recent advances in the development of the prosthetic hands with many degrees of freedom and many actuators, requires many EMG channels to take the full advantage of the complex prosthetic terminals. Some EMG wearable devices were developed lately, that are able to detect several gestures. However, the main drawbacks of these systems are the cost, the size and the system complexity. In this paper, we suggest a simple, fast and low-cost system which can recognize up to 4 gestures with a single channel surface EMG signal. Gestures include hand closing, hand opening, wrist flexion and double wrist flexion. These gestures can be used to control a prosthetic terminal based on predefined grasp postures. We show that by using a high-dimensional feature space, together with a support vector machine algorithm, it is possible to classify these four gestures. Overall, the system showed satisfactory results in terms of classification accuracy, real time gesture recognition, and tolerance to hand movements through integration of a lock gesture. Calibration took only 30 seconds and session independence was demonstrated by high classification accuracy on different test sessions without repeating the calibration. As a case study we use this system to control a previously developed soft prosthetic hand. This is particularly interesting because we show that a simple hardware that has only a single channel EMG, can afford the control of a multi-DOF prosthetic hands. In addition, such system may be used as a general purpose Human Machine Interface for gaming,for controlling multimedia devices, or to control robots.

1. Introduction

The upper-limp prosthesis field has faced a rapid advancement in the last decade, due to the progress of the enabling technologies such as actuators, sensors, controllers and digital and additive fabrication. In the last couple of years, several complex prosthetic terminals were reported with multiple active degrees of freedom, which reproduce to a good extent the capabilities of the human hand in terms of grasping (Belter & Segil, 2013; Mouri, Endo, & Kawasaki, 2011). For instance the recent commercial hands such as i-limb (TouchBionics), Vincent (Vincent Systems), and Bebionic (Waryck, 2011) implement 5 or 6 actuators, allowing to design quite precise grasps.

On the other hand, it is well known that many amputees prefer a simple and light-weight prosthetic hand. As an example, the single actuator sensor-hand (OttoBock) is being used by amputees for over 40 years, and is still in the market, surely due to its lower cost, but as well because of its simplicity.

Despite the advances on the development of more complex prosthetic terminals, the control of such systems require many control inputs. Current human-machine interfaces based on a few surface EMG electrodes cannot afford enough inputs for controlling the hands with many actuators and many possible grasp postures.

It seems that, the human machine interface for this application did not evolve at the same rate of the advances on the Mechatronics of prosthetic hands. That is, full control of a highly articulated hand still requires a high number of EMG sensors, raising significantly the cost and complexity of the system. It is a common configuration to utilize four EMG channels, as adopted in Naik, Kumar et al. (2010) and Ajiboye Weir (2005), in order to be able to detect wrist and 4-fingers flexions and extensions (Fig. 1); other authors, like Yang, Zhao, Gu, Jiang, and Liu (2009) and Al-Timemy, Bugmann, Escudero, and Outram (2013), use 6 bipolar electrodes for recognizing up to 19 and 15 hand postures respectively for controlling highly dexterous hands. Eight channel (Cipriani et al., 2011) and ten channel (Bitzer & Van Der Smagt, 2006) surface EMG systems with bipolar electrodes

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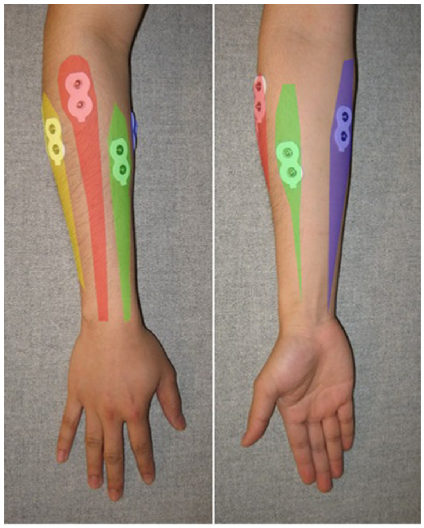

Fig. 1. A 4 bipolar electrodes placement on the forearm, as carried out in Khokhar, Xiao, and Menon (2010): The four electrodes are used to monitor the activity of the muscles Flexor Carpi Ulnaris (FCU), Palmaris Longus (PL), Extensor Digitorum (ED) and Extensor Carpi Radialis (ECR).

positioned on the forearm were also reported. However, integration of excessive number of inputs makes the system bulky, complex, costly, and probably more prone to the Electromechanical system failures.

In the i-limb prosthetic hand, in order to enable the user to select between different grasping postures, a mobile phone application is designed, in which the user can select between the various grasp postures (TouchBionics). While this approach provides a good way to take advantage of all actuated degrees of freedom of the hand, it is probably not very convenient for the user to use one hand to select the grasping postures of the bionic hand from a mobile application.

In some prosthetic terminals which are controlled through pre-defined grasp postures, either a multi-channel EMG input or other additional input sources must be employed (e.g. foot control, or mobile phone applications were demonstrated (TouchBionics; Vincent Systems; OttoBock)).

For commanding a grasping action, Independent from the source of the input (EMG, Mobile application, etc.), it is more intuitive to use grasp postures (such as open and close), than controlling the fingers individually. Also it is shown by neuroscienticsts that for the grasp action, the human brain does not control each of the finger joints and each of the muscles individually, but employs some predefined grasping synergies (Castellini & Van der Smagt, 2013; Santello, Baud-Bovy, & Jörntell, 2013). On the prosthetic terminals, such grasp postures can be pre-defined based on the design of the prosthetic hand and the number of such grasp patterns depends on many factors such as the number of actuators, and the actuation strategy. Yet, it is always desired to make the system as simple as possible for the user, and to have the minimum number of grasp patterns.

It is worth to mention a recent study (Bullock, Zheng, Rosa, Guertler, & Dollar, 2013), in which an extensive analysis was performed on the daily activities of four subjects: two housekeepers and two machinists. They showed that for 80% of the study duration the housekeepers used just five grasps postures and the machinists used ten (out of a total of 33 grasp postures presented in Feix, Romero, Ek, Schmiedmayer, & Kragic, 2013). Therefore, it is probably feasible to define a limited number of grasp postures (e.g. less than 5), able to achieve most of the required daily tasks.

In this article, the term motor synergy refers to the pre-defined trajectories for all actuators of a prosthetic terminal. Our goal is that the user is able to select between these motor synergies. It should be then noted that while in most of prosthetic hands, a motor synergy corresponds to a single grasp posture, this is not the case for under-actuated and compliant hands. In compliant hands, a motor synergy does not always correspond to a single grasp posture, but a range of grasp postures, depending on the shape of the object. This is in fact positively exploited to develop prosthetic hands which can adapt to a wide range of geometries, with a simple electro-mechanical and control structure. Therefore, the number of the required motor synergies is smaller than the grasp postures achieved by the prosthetic hand, which is beneficial for system simplification, as it will be demonstrated in the final section of this paper (case study).

The general goal of our research is to use the surface EMG signals in order to control a multi-DOF hand that is programmed to achieve a limited number of pre-defined motor synergies. The objectives of this research work can be summarized as:

1. To develop a simple and efficient method which enables the user not only to grasp/release the object, but also to select between different pre-defined grasp postures, solely with surface EMG electrodes as the input source
2. To investigate the possibility of using a single channel EMG signal for achieving the task above

If succesful, this method and system can provide a simple, low cost and efficient interface between humans and advanced upper-limb prosthetic terminals, which has not been reported before. For the first problem, we consider a hand controlled by several motor synergies and design the required inputs from the user as the following 3

1. **Close**: to close the hand and perform a grasp.
2. **Open**: to open the hand and release the object.
3. **Change**: to navigate through the available motor synergies and select one.

With these 3 inputs, one is able to control a prosthetic hand, as long as the number the of closing patterns is within a reasonable range. As explained earlier, the advantage of integrating compliance into prosthetic hands is that the number of actuation synergies is reduced compared to the traditional rigid hands, which makes the simple single channel EMG system suitable for these hands. For controlling this new kind of prostheses, the EMG system will be internally developed, because of the unavailability of EMG pattern recognition devices which could fit the strict requirements of low-cost and easy training. Indeed recently, a gesture recognition armband, the Myo armband was commercialized (Thalmic Labs). This armband is able to detect five gestures, which can be used as a general purpose Human Machine Interface (HMI), but it can be also used to control a prosthetic hand based on the idea above. However, myo armband embeds 8 EMG channels, and thus it is relatively bulky to be used for prosthetic applications. There are other solutions for the EMG gestures classifications, like the BioSLeeve (Michael et al., 2013) and BioVolt (Infusion Systems), are complex and costly. The BioSleeve implements 16 electrodes, which result definitely overstated for the current application, while the BioVolt is simpler and comprehends 3 bipolar electrodes plus a pre-processing unit.

The purpose of the current research is hence to recognize the pre-mentioned 3 gestures by using the minimum number of signals taken from the amputee's forearm, in order to maintain the system low-cost and simple; therefore, we would like to investigate the most extreme case of recognizing all these gestures with a single EMG channel. While, the "Open" and "Close" gestures, or