An Innovative Multisensor Controlled Prosthetic Hand

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Abstract—**This article reports the design, realisation and preliminary testing of an innovative multisensor controlled prosthetic hand. The mechanical design is strongly oriented to satisfy the requirements of delivery a penta-digital prosthetic hand with reduced hand size, low weight, independent finger movement and bio-mimetic shape. Moreover, an ad hoc sensing architecture has been designed including traditional EMG system together with in socket force measurement and inertial sensing. This sensing architecture is intended to reduce the socket complexity in terms of adaptation to different patient forearms, without loosing the possibility of performing multiple hand grips. An innovative concept introducing inertial sensing in order to select appropriate robotic hand configurations is also described. A first prototype of the prosthetic hand has been realised and preliminary tests are reported.**

Keywords— **hand prosthesis, force myography, inertial sensing, biomimetic.**

I. INTRODUCTION

The analysis of commercial prosthetic hand available on the market points out the absence of products with reduced hand size, low weight, penta-digital mechanical solution with independent finger movements and bio-mimetic shape. Manufacturers such as Touch Bionics and RSL steeper produce penta-digital hand but only of a big sizes (I-limb [1] and Be-Bionic [2]). Otto Bock [3] produces little hands (even for children) but not with independent movements on the fingers. Another important aspect is the high cost of upper prosthetic devices such as electronic hands or electrical finger nowadays used in partial hand amputation (for example amputation of finger I, II and/or III). To obtain cost reduction is necessary have components for production with scale's economies. Commercially available prosthetic hands are controlled through electromyographic (EMG) signals and patients can set only a few of different hand configurations with the contraction of agonist and/or antagonist limb's muscle. The signal is gathered using electrodes conveniently positioned in the prosthetic socket using residual muscular activities of patient's forearm. This technique has the advantage to allow a "natural" control for the patient but with the limitation of providing only one practical degree of freedom (DOF) of prosthesis actuation, basically opening and closing the robotic hand in a fixed and predefined configuration. Different studies have been done to evaluate more independent channels of control signals from EMG with advanced signal processing techniques [4, 5, 6, 7]. Moreover, several alternative signal sources have been considered in literature: the mechanical force exerted by a tunnel muscle or tendon [8], the acoustic signal generated from muscle activity [9], the morphological changes of residual limb tissues [10]. Moreover, even electroencephalogram (EEG) and neuronal signal have been considered [11, 12]. Many of these scientific works have been limited to laboratory experiments, but are quite far from commercialisation.

The aim of this study is to design and develop a market oriented prosthetic hand (that hereinafter will be called *Tiny-Hand*) having reduced dimension, weight and cost, good biomimetic reproduction of human hand, finger design for use also in a partial amputation and with sufficient grip force. Concerning the control strategy, the Tiny-Hand main requirements were the possibility to perform different kind of hand grips/positions to improve the manipulation experience, without increasing too much the system complexity and the overall costs. To this aim an ad hoc sensing architecture has beed designed, developed and tested. In particular, traditional EMG system has been considered together with in socket force sensing and inertial sensing. In socket pressure sensing has been included to monitor the so called Force Myography (FMG). FMG uses a set of force sensors to measure the pressure on the forearm caused by the muscular activity. FMG signal has been used in few pilot works to extract the hand neuromuscular volition [13, 14]. In the present work in socket force distribution and conventional EMG have been used at the same time to encode subject/patient movement intention. The advantage of the FMG is the reduced sensor cost and complexity with respect to EMG and the possibility to spread the sensor in redundant configuration in order to reduce the personalization effort of the prosthesis. The inertial sensor on the forearm has been included to enable the patient to select different hand grips in relation to the forearm orientation in space. Moreover, the possibility to select

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particular hand configuration in correspondence to peculiar dynamic movements of the forearm has been introduced. The Tiny-Hand prototype has been realised in the frame of the project MANOROB funded by Regione Toscana (Italy) and it has been patented (Italian patent application n. PI2013A000004).

II. MECHANICAL DESIGN

Tiny-Hand (see Fig. 1) is a penta-digital prosthetic device with passive thumb's abduction-adduction. It has 11 DOFs actuated by five motors, hand's dimension (perimeter around the knuckles) is a x-small size for women (about 6 inches). The hand's weight is about 220 grams and the wrist's design has an elliptical geometry to obtain a more natural shape instead of the circular one usually proposed on similar types of prosthesis. Tiny-Hand is a prosthetic device designed for women and adolescents patients, with a great bio-mimetic reproduction and with important advantages relative to cost production. To reach the described requirements a particular attention was applied on the finger design. The DC motor was located directly on the finger to allow the use of the prosthesis also for partial amputation. Moreover, regarding finger kinematic morphology the use of cylindrical joint appeared the best solution to apply. In fact the use of complex kinematic solutions, as for example multi-links system, are difficult to obtain in so a such small devices, providing also great complication during product assembly and maintenance. The number of DOFs for a prosthetic finger could be 1 or 2: in the first solution the flexion/extension of a mono-phalanx can allow limited types of grip and is related to a more simple device with lower cost; on the other hand the use of a system with two phalanges (proximal one and a second that replicate medial and distal ones) allow to reach a better bio-mimetic aspect and a better compliance with different grips. The solution selected use 2 DOFs and the distal phalanx is under actuated through the proximal one. Another important aspect that has been considered during finger design is the stiffness of the system. In case of impacts it is crucial to avoid repercussion on the patient's stump through the support of the same prosthetic device. Moreover, the stiffness of fingers in extension movement has to be quite high to grip different objects in power and precision grips. Finally, a peculiar finger design, consisting in an internal irreversibility of the mechanical transmission, is needed to reduce energy consumption during grips and to allow an high autonomy of the prosthesis. The result of all these considerations is the design of the finger reported in Fig. 2.

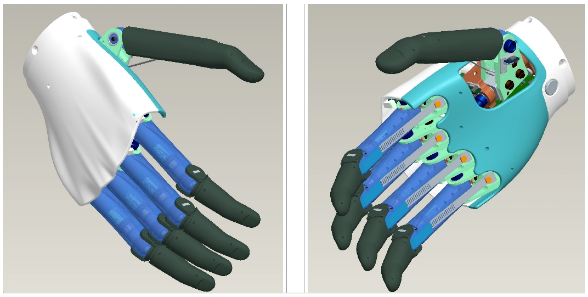

Fig. 1 Tiny-Hand CAD model

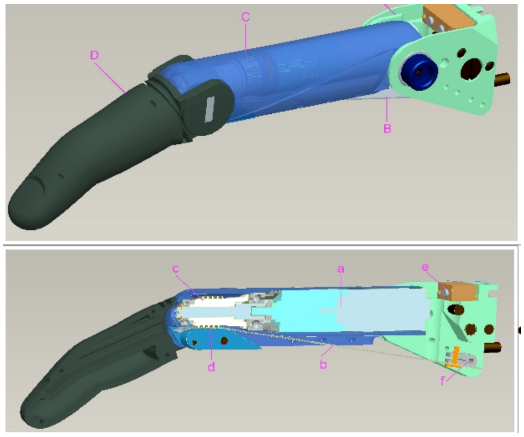

Fig. 2 Tiny-Hand finger components and its sagittal section

III. SENSING SYSTEM AND CONTROL STRATEGY

The Tiny-Hand sensing system is composed of a standard EMG device (produced by Otto Bock), a set of force sensitive resistors for FMG extraction (FSR, Flexiforce A201 produced by Tekscan), an inertial sensor (ADXL330 produced by Analog Devices) and the dedicated acquisition electronics directly connected to the hand controller through a serial link. The acquired signals are elaborated and fused in real time to extract the patient intention in terms of opening/closing the hand and grip selection. The block diagram of the developed control strategy is reported in Fig. 3. The elaboration of FMG signal allows the detection of hand activation, causing the transition from flat neutral position to the selected grip. FMG is acquired trough 8 FSR sensors distributed uniformly around the prosthesis socket placed in the carpal flexor area (Fig. 4 shows the realised preliminary demonstrator). The in-socket force due to the muscular activity of the carpal flexors is continuously tracked by the FSR sensors. The event of hand activation is obtained by an adaptive peak detector algorithm working without predefined thresholds in order to fit with the different physical characteristic of the patients. The FSR lightness, reduced thickness and dimensions allows to

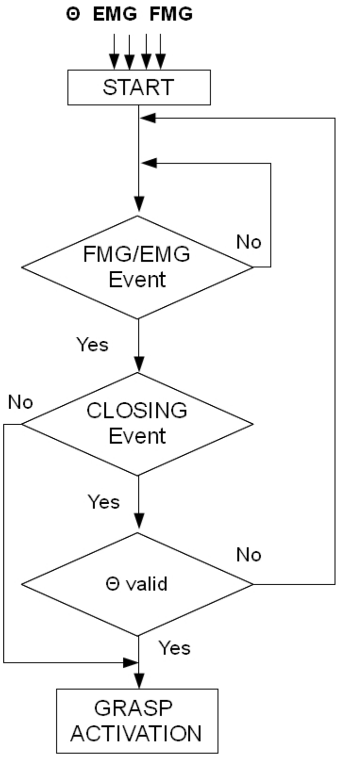

Fig. 3 Block diagram of the developed algorithm. *Theta* is the forearm orientation gather from the inertial sensor

realise a redundant distribution of force sensors in the area of interest. In this way the precise positioning of in-socket FSR is not needed, thus reducing the socket complexity in terms of adaptation to different bodily structures of the patients (in contrast with EMG sensor positioning that has to be patient specific). The EMG sensor is used to discriminate the intention of deactivating the hand grip (i.e. transition from the performed grip to the neural flat hand position). The sensor is placed on the carpal extensors and the acquired signal is elaborated by means of standard EMG treatment algorithms. This sensing architecture, using FMG on the flexor and EMG on the extensor, has been experimentally identified by using, in the system design phase, a more complex prototype based on two EMG sensors (placed on both flexor and extensor muscles) and the FSR configuration previously described. These experiments have pointed out a close correlation between the FSR relived in the flexor area and the correspondent EMG sensor and a low correlation of the FMG and EMG taken on the extensor. Fig. 5 shows the signals acquired in the identification phase on a patient performing continuos cycles of alternate activations of the carpal flexors and extensors.

Fig. 4 Sensor arrangement in the prosthesis socket

Another innovation of the proposed control strategy is the direct correlation between the arm spatial orientation, detected by the inertial sensor, and the grip selection. Practically, if the patient activate the hand through the carpal flexor movement detected by the FSR sensors, the performed robotic hand grip changes according to the forearm orientation. In the first trials, five different functional grasps were associated to different forearm orientations. Moreover, an addiction hand configuration can be activated if the inertial device recognised a peculiar dynamic movement pattern of the forearm (in this first example a forearm shake was selected). In the first Tyny-hand prototype this modality was linked to a pointing with the forefinger (possibly useful for PC keyboard usage). This configuration can be deactivated by the recognition of the same activation movement pattern. Before the final integration, the sensing system was linked to a tridimensional hand model replicating the robotic hand functionalities (shown in the monitor present in Fig. 6).

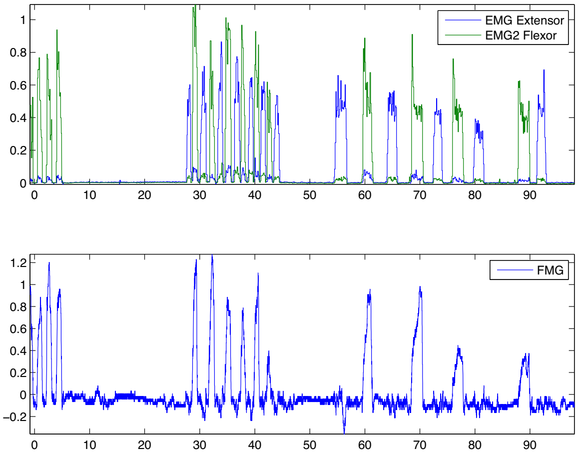

Fig. 5 EMG and FMG signals acquired during the design phase

IV. PRELIMINARY RESULTS

The first prototype of the Tiny-Hand has been realised consisting of both the mechatronic hand and the described sensing system integrated togheter (Fig. 6). The prototype has been preliminary tested on ten non patient subjects, with the prosthetic hand fixed on a bench as shown in Fig. 5. The subjects were asked to arbitrary choose a certain number of hand grips and to perform the necessary movements to select them. Before the test a brief training phase was performed where the subjects were free to learn the prosthesis usage. The Tyny-Hand performances were evaluated in terms of number of recognised grip intentions. The test, although preliminary, has demonstrated encouraging results in terms of potentiality and robustness to different subject physical structures (above 90% of the hand grips were effectively recognised).

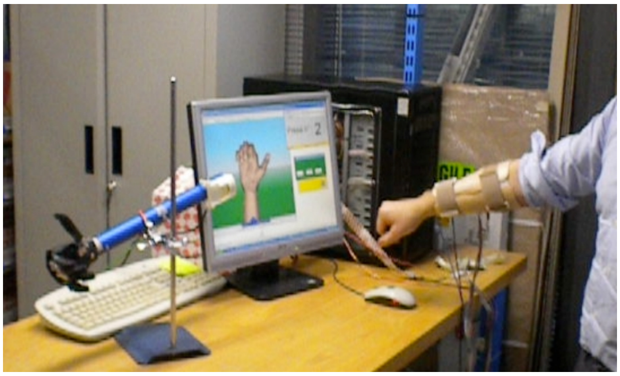

Fig. 6 Tiny-hand prototype during the preliminary testing phase

V. CONCLUSION

The paper shows the prototype realisation and the preliminary testing of an innovative prosthetic device. This pentadigital mechatronic hand is characterised by reduced dimension, weight and cost and good bio-mimetic reproduction. It can be adapted to small hands, such as the ones of children and women, and even to partial amputation. From the control strategy point of view, an innovative multi-sensing system has been developed. The main characteristic of the realised sensing system is the reduced complexity and the possibility to perform multiple hand grips. The realised prototype has been tested on normal subjects with encouraging results. Future activities will be an extensive validation phase and an accurate analysis of the signal processing strategy.

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