A *MyoKinetic* HMI for the Control of Hand Prostheses: a Feasibility Study

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***Abstract*— In an attempt to overcome the several limitations of currently available/investigated human-machine interfaces (HMI) for the control of robotic hand prostheses, we propose a new HMI exploiting the magnetic field produced by magnets implanted in the muscles. As a magnet is implanted in a muscle it will travel with it, and its localization could provide a direct measure of the contraction/elongation of that muscle, which is voluntarily controlled by the individual. Here we present a proof of concept of a single magnet localizer, which computes on-line the position of a magnet in a certain workspace. In particular, the system comprises a pair of magnetic field sensors mounted on custom printed circuit boards, and an algorithm that resolves the inverse magnetic problem using the magnetic dipole model. The accuracy and the repeatability of our system were evaluated using six miniature magnets. Ongoing results suggest that the envisioned system is viable.**

I. INTRODUCTION

THE restoration, following amputation, of dexterous control equivalent to that of the human hand is one of the major goals in applied neuroscience. Pivotal to this is the development of an intuitive and effortless human–machine interface (HMI) that maps the sources of volition to the degrees of freedom (DoFs) of the artificial hand. Although significant research efforts have been made with invasive approaches, like peripheral nerve interfaces, epimysial electrodes through osseointegrated implants, or implantable myoelectric sensors (IMES) [1], [2] the unique clinically viable technique today is the use of surface EMG to control the movements of an electromechanical prosthesis [3]. In fact, the envelope of the EMG signal is broadly proportional to the level of contraction of the muscle being recorded. However, as currently implemented - due to the lack of independent control sources - it does not provide simultaneous control over multiple DoFs [4]. In turn, this type of control can be very slow and unintuitive. On top of that, EMG electrodes are intrinsically unable to stimulate the individual's body to provide sensory feedback [5]. The lack of musculoskeletal and proprioceptive sensory feedback in myo-prostheses is probably one of the main reasons for their rejection, as a residual limb with intact sensibility is often more functional than a non-sensitive prosthesis [5].

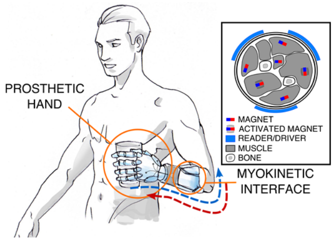

Fig. 1 MyoKinetic interface envisioned in the MYKI ERC Project.

Here we present the pilot work done in the framework of a new research effort funded by the European Research Council (ERC), which aims at developing a dexterous hand prosthesis with tactile feedback that is naturally controlled and perceived by the amputee. This project, dubbed MYKI (standing for MYoKInetic interface) by abandoning the conventional paradigm of transducing electrical signals, aims at developing a bi-directional HMI exploiting the **magnetic field**. Core of this system is a multitude of Magnetic Markers (MM, e.g. magnets) implanted in independent muscles and external magnetic localizers/actuators (MLA) able to (i) continuously localize the position of the MMs and, at specific times, (ii) induce subtle movements in specific MMs. In fact, as a MM is implanted it will travel with the muscle it is located in, and its localization will provide a direct measure of the contraction/elongation of that muscle, which is voluntarily controlled by the central nervous system. In this way it could be possible to decode the efferent signals sent by the brain by observing a by-product of the muscle fibers recruitment. On the other hand, a movement induced in the implanted MM by the external MLA, could provide a perceivable stimulus, conveyed to the brain by means of the peripheral sensory receptors present in the muscle (e.g. muscle spindles or Golgi tendon organ) or in the neighbouring skin (tactile mechanoreceptors). In this way we aim at providing tactile and/or proprioceptive sensory information to the brain, thus restoring the physiological sensorimotor control loop. Remarkably, with passive magnetic tags and wearable localizers/actuators, it could be possible to implement a wireless, bidirectional HMI with dramatically enhanced capabilities with respect to the state of the art interfaces.

In this abstract we present a proof of concept of a single magnet localizer, which computes on-line the position of a magnet in a certain workspace. In particular the system

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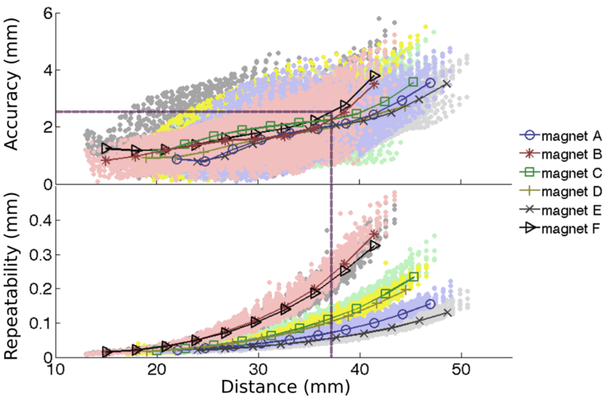

Fig. 2 Accuracy and repeatability for the tested magnets as a function of the distance between the sensor and the magnet. Bold markers represent the median values.

comprises a pair of magnetic field sensors mounted on custom printed circuit boards, and an algorithm that resolves the inverse magnetic problem [6], using the well-known magnetic dipole model. The accuracy and the repeatability of the system were evaluated using six candidate MMs.

II. MATERIAL AND METHODS

A. *On-line Single Magnet Localizer*

We developed an on-line magnet localizer (ML) based on the off-the-shelf three-axis magnetic field sensor HMC5983 (Honeywell Inc.). The sensor is able to measure magnetic fields ($B_{X,Y,Z}$) in the range of ±800 µT, which is suitable for sensing the field produced by magnets having dimensions compatible for muscle implantation (e.g. the size of an IMES [2]). The sensor was used in conjunction with a 8-bit microcontroller used for pre-processing the magnetic field data and for sending it (10 Hz) to an external PC through a serial bus (RS-485). The PC implemented a custom software written in Visual C# .NET which computed the spatial coordinates of the magnet, using the model of [6], with rejection of the geomagnetic field [7], at a 100 ms update rate. The rejection of the geomagnetic field (25-45 µT) is crucial because the latter falls within the working range of the sensor and as such affects the localization of the magnet when the reference frame of the sensor moves with respect to hearth (this will surely occur in a prosthetic device).

B. *Evaluation of the Single Magnet Localizer*

The residual geomagnetic field after the rejection procedure was assessed by randomly rotating the ML with respect to hearth, when no magnets faced the sensor.

The accuracy and repeatability of the magnet localizer were assessed by means of a three-axis micrometric positioning system used to move the candidate magnet (Table I) within a measurement volume (40x40x20 mm^3). Starting from a distance in the normal direction of d_{min} between the magnet and the ML, 4851 equidistant positions were tested within the volume (spatial resolution of 2 mm). The d_{min} was empirically chosen for each magnet in order to avoid saturation of the sensor.

TABLE I
FEATURES OF THE ASSESSED MAGNETS

	Shape	Dimensions (mm)	Weight (g)	Magnetic Moment (Am^2)
A	Cylinder	Ø 3 x 6	0.322	0.0368
B	Disc	Ø 4 x 1	0.095	0.0110
C	Disc	Ø 4 x 2	0.191	0.0237
D	Cube	3	0.205	0.0241
E	Sphere	Ø 5	0.497	0.0511
F	Sphere	Ø 3	0.107	0.0123

The accuracy was computed as the mean (n=100) Euclidean distance between the computed position and the actual position. The repeatability in each point was computed as the modulus of the three components of the standard deviation (n=100) of the computed position.

III. RESULTS AND CONCLUSION

The procedure adopted by our system for rejecting the geomagnetic field allowed to attenuate it by 95%. The median accuracies for each magnet were all comparable and below 2.5 mm within a sphere having 38 mm radius from the sensor, within the workspace. Beyond this distance the accuracy rapidly degraded, especially for magnets with lower magnetic moment (i.e. magnets F and B, Fig. 2). This result, if transferred to the prosthetic application, would signify that our system could localize a magnet within a volume of 23 cm^3, which is compatible with the deformation of a forearm muscle under contraction. More interesting is the result from the repeatability test. The latter was found to be proportional to the distance between the magnet and the sensor, nonetheless always lower than 500 µm within the measured volume, for all the tested magnets (Fig. 2). This implies that arbitrary, but repeatable movements of an implanted magnet in a forearm muscle could be reliably decoded and used to control a dexterous hand prosthesis.

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