DESIGN OF AN ARDUINO-BASED PLATFORM INTERFACED BY BLUETOOTH LOW ENERGY WITH MYO ARMBAND FOR CONTROLLING AN UNDER-ACTUATED TRANSRADIAL PROSTHESIS

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ABSTRACT

In this paper a brief overview on the latest advancements in upper-limb prosthetic technology is presented these mainly derive from the advantages offered by increasingly smart and high performance electronic devices and modules, which now a days are commercially available at low cost then the electronics of Adams hand, a transradial myo electric prosthesis for upper limb.

Amputees, is describes. The devices is equipped with sensor and actuators that simplify at aid the movement; in particular, the mechanisms in which placed can actuated 15 degree of freedom with just one motor (instead of the five or six motors conventionally used in other commercial available prosthesis devices). Two servo motors are actuated the wrist movement.

The myo electric signal use to control the prosthesis are detected through the myo armband, which integrates eight electromyography (EMG)electrodes and an inertial measurement unit (IMU) based on invensense MPU-9150 IC; all these data sent by myo armband through BLE protocol to the realized control electronics which actuates the used motors.

Keywords: Myoelectric signals; prosthesis; electronic equipment Arduino Micro board; firmware; wireless connectivity

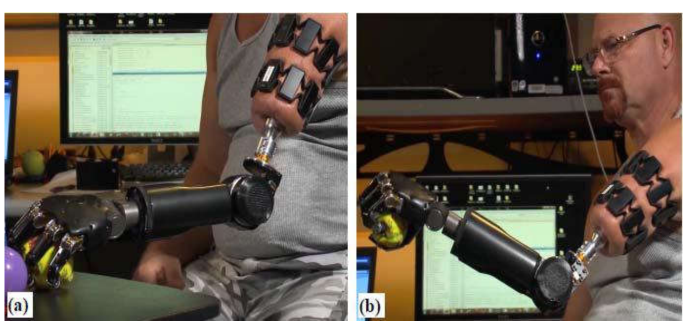
1. INTRODUCTION

A prosthesis is sophisticated medical made up of particular materials and composed of mechanical and electronic modules which interact with the user, allowing reliable and simple movement of the missing limb, based on his specific requirements. A myoelectric prosthesis is controlled by small electrical signals generated by muscle contractions (myoelectric signal) and measured with electrodes placed on (or into) the skin. Unlike other commercially available hand prosthesis, which uses five/six motors, one for each finger, the designed prosthesis implement an under actuated mechanism based rigid and compact gears actuated by single DC motor. This allows obtaining a lighter, more compact, less expensive and easier to use device.

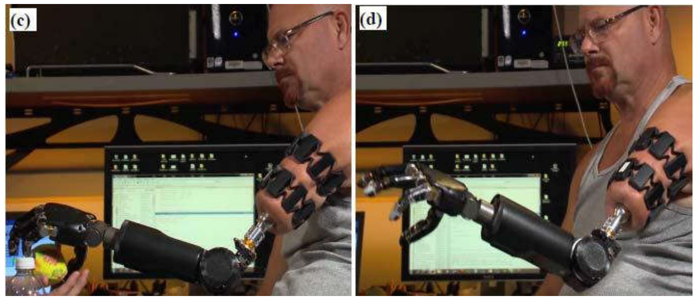
The realized prosthesis is provided with sensors (five LM35 temperatures and five FSR400 pressure sensor, one for each finger) and actuators with simplify and support the hand movements. The myo electric signal are acquired by means of myo armband, A wearable device by thalamic labs Inc. provided with eight Eletromyograhy (EMG) electrodes, a 9-axis inertial measurement unit (IMU) (3-axes gyroscope, 3-axes accelerometer and 3-axes magnetometer) and a transmission module [1]. The realized Arduino-based driving /control electronic unit handle all the prosthesis modules; it acquires data from the five FSR400 force sensitive resistors and from the five LM35 temperatures sensors, it drives the two Futuba S3305 servo-motors used for wrist movement and the Maxon DCX 19S DC motor used to open /closed the hand. Arduino–based control unit receives data wirelessly from myo armband through Bluetooth low energy connectivity, by using a HM11 BLE module, and it exchanges data with the raspberry-Pi3 board manages a 3.5” touch-screen LCD display, which thanks to a dedicated software presence user friendly interfaced used to handle several aspects of the prosthesis management, such as autonomy sensor data displaying, wireless connectivity. In addition, it sends on cloud the data received from the developed board, to a dedicated web server, from which they can be monitored in real-time by the orthopedic staff which follows the users.

2. OVERVEIW ON MYOELECTRIC PROSTHESIS: LATEST TECHNOLOGICAL ADVANCEMENTS

In the following section are reported the latest progresses in the prosthetic field, reached by using myo armband and other technologies for the muscle myo electrical activity detection. Fig.1 shows a patient with a prosthetic arm directly connected to his arm (Osseo-integration) during an experimental test at the johns Hopkins university; the used prosthetic employs two myo armband on the upper arm to detect the electrical activity of the biceps and triceps muscle.



(a) **(b)**



(c) (d)

Fig. 1. *Two Myo armbands used to control the movements of a trans-humeral prosthesis; in this specific experimental test, the patient first grabs and then releases a tennis ball.*

In Fig.2a is shown an upper limb amputee subject wearing a myo armband and a bland is used to better tighten the armband around the arm. The women are able to easily move the robotic prosthesis, attached to a support placed at a certain distance from her (Fig.2b). Furthermore, she is able control hand opening/closing: by activating the arm's muscle, prosthetic hand closes, while by relaxing them the hand opens (Fig.3).

(a) (b)

Fig. 2. *Myo armband worn by an upper-limb amputee subject: the purple band serves to better tighten the armband around the arm.*

(a) (b)

Fig. 3. *By activating the arm muscles the prosthesis hand closes (a), while by relaxing the muscles the prosthetic hand opens (b).*

The *Alfredmann* foundation has created Implantable Myo Electric Sensors (IMES); these are multiple single-channel implanted EMG sensor with allow an amputee to control his/her artificial limb by means of the arm's muscular activity. Fig.4 shows the IME sensors implanted into the arm of the patient. EMG signals, generated by the residual muscle at each implant side, are amplified and digitized by the IMES; an extra-corporeal Telemetry Controller (TC) within the limb prosthesis controls a Time Division Multiplexing (TDM) sequence to provide power and manage RF Transmissions from each implant over a common inductive link. Each IMES is wirelessly powered and telemeters an EMG signals. The TC decodes the received EMG signals from all of the IMES devices, and passes the multi-channels EMG data to a prosthesis controller. By locating the IMES in separately innervated muscles, each IMES can be treated as an independent controlled site with minimal cross-talk or interference [2].

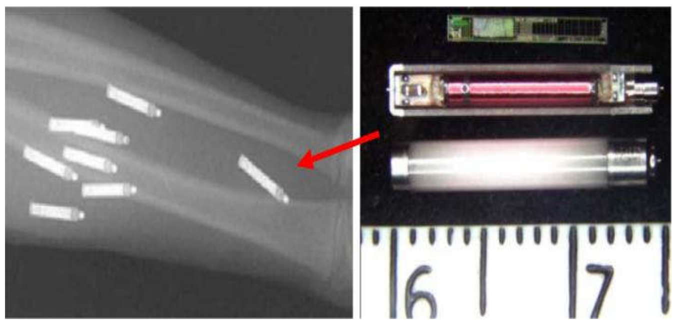
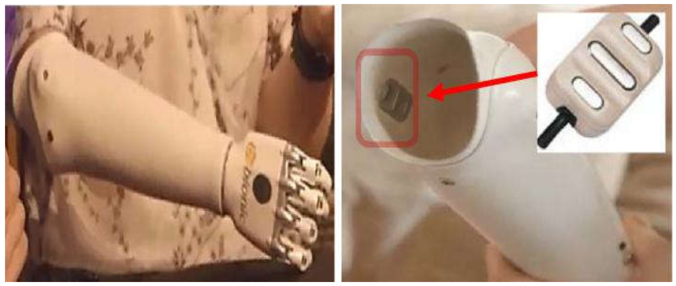


Fig 4. *Several IMES sensors implanted into the arm of an upper-limb amputee. The sensors are 1.5 cm long and are powered wirelessly by a common transmitter coil within the Telemetry Controller*

The user, by thinking to open/close or rotate the prosthetic hand, or to move specific fingers, is able to perform many common movements, as shown in Fig.5

Fig. 5. *The patient with the IMES system implanted is able to perform numerous movements and tasks with his prosthetic hand.*

The Bebionic hand, an advanced prosthesis provided by *Ottobock* company, provides 14 different grips patterns. The prosthesis, shown in Fig.6 is provided with five motors, one for each finger, and microprocessors that continuously monitor the position of each finger. Thanks to auto-grip function, it also automatically senses when a griped item is slipping and adjusts the grip to secure it [3]



(a) **(b)**

Fig. 6. *Bebionic hand prosthesis worn by a patient (a) and Myo-electrodes (MyoBock) provided by Ottobock which are installed into the prosthesis' socket and allows detecting the user muscular activity (b).*

The recent technology progresses in the prosthesis field have allowed obtaining the first upper-limb amputee in the world that is able "feel" the grasped object in real-time with a sensory-enhanced artificial hand. The prosthetic system has been created by Silvestro Micera and colleagues from the Ecole Polytechnique Federale De Lausanne (EPFL) in Switzerland and Sant'Anna School of Advanced Studies (SSSA) in Italy. The prosthetic hand is controlled through the myographic surfaces electrodes integrated into the prosthesis socket. Refined electrical impulses are sent to the central nervous system using other electrodes which are surgically implanted into the upper arm nerves: when the patient grips an object, he is able to feel the strength of his grasp as well as the object shape, roughness, consistency, etc[4]. A prototype of this system, worn by an upper-limb amputee woman, is shown in Fig.7.

Furthermore, recent technological progresses in prosthesis manufacturing allow to perfectly replicating size and weight of the natural hand.

Fig. *7. The prosthetic hand containing sensors and electrodes which allow to "feel" in real-time the shape, roughness and consistency of grasped objects.*

3. CIRCUITAL SHCEME AND DEVICES USED FOR MOTION CONTROL AND TO DRIVE THE TRANSRADIAL PROSTHESIS

The realized prosthesis, named Adam's Hand, is based on an under actuated mechanism which allows to actuate 15 degrees of freedom wit6h just one DC motor [5]. It also equipped with sensors and with actuators which allows wrist movement; myoelectric signals and data related to arm movement with three dimensional space are detected through myo armband (Fig.8a.).

The ST78589 operational amplifier, shown in Figs. 8b and 8c, is sued for the amplification of the signal provided from the eight EMG electrodes and is integrates into each element of the armband. Two rechargeable lithium batteries, shown in Fig. 8d, are used to supply the armband; thes are located into two elements of the armband and can be recharged providing a voltage value of 5V by means of the micro-USB connector.

Fig. 8e shows the electronic control board embedded into the main element of the armband, with its components highlighted using different colors. In particular ,the BLE NRF51822 chip used for the wireless transmission is highlighted in blue, the arm cortex M4 microcontroller in red, the anteena which transmits the data in grey, the vibration motor used for the user feedback in brown and the micro-USB connector in purple; the later is used to recharge the battery and to update the device firmware.

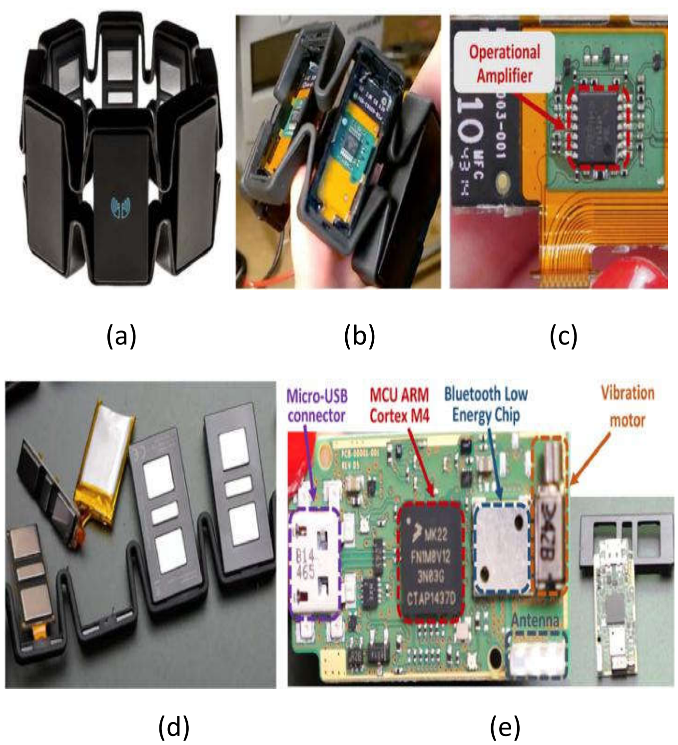


Fig. 8. *View of Myo armband used in the realized prosthesis (a), and of the other components integrated into its cover: the ST78589 operational amplifier (b), (c), the lithium battery embedded into two elements of the armband (d) and the electronic control board embedded into the main element (e).*

4. HARDWARE REPRESENTATION

Fig.9 shows a functional scheme of the different electronic modules connected to the realized driving and control electronic board, which is shown in Fig.10 This last, based on the Arduino Micro prototyping board, acquires data from five force-sensitive resistors and five LM35 temperatures sensors, one for each finger, and it drives two Futaba S3305 servomotors used to actuate the wrist and a Maxon DCX19 S motor used to actuate the fingers; the board also receives data from Myo armband through an HM11 BLE unit. Furthermore, the detected data, after the processing phase, are stored and then transmitted to the Raspberry Pi 3 board, embedded into the prosthesis' socket, which sends these data to a dedicated server on cloud via Wi-Fi connection. In addition, an LCD touch screen display, connected to the Raspberry PI board, is used to visualize and manage all the information related to the prosthesis

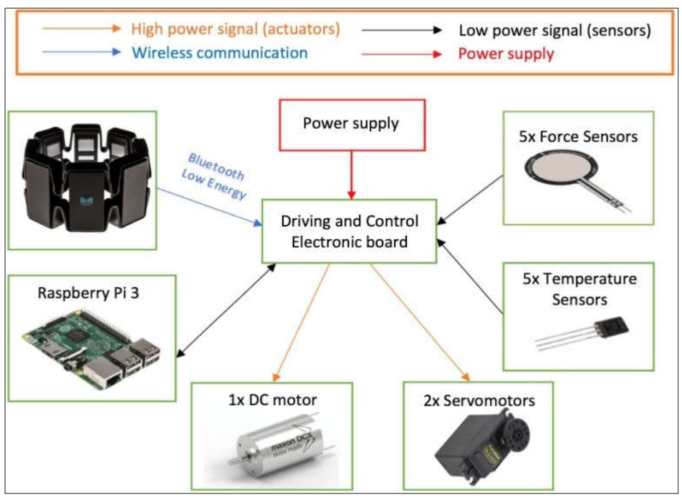


Fig. 9. Electronic modules employed in the Adam's Hand realized prosthesis: Myo armband, the Raspberry Pi3 board, one DC motor, two servo-motors, five temperature and five force sensors, all interfaced with the designed driving and control electronic board.

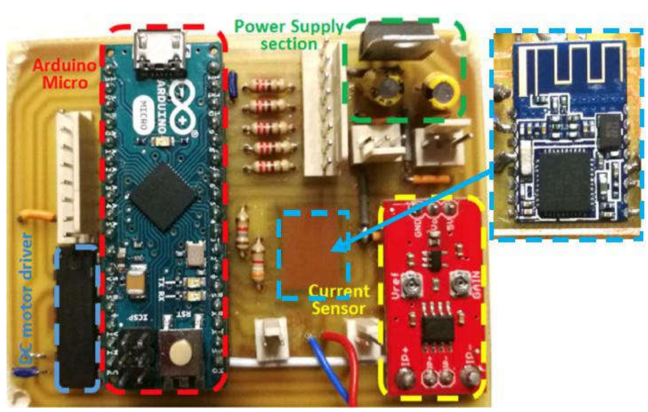


Fig. 10. *Adam's Hand driving and control unit: the different electronic modules (Arduino Micro board, DC motor driver, Power Supply Section and Current Sensor) are highlited using different colors.*

An ACS712 current sensor is used to acquire the current absorbed by the DC motor in order to evaluate the torque generated by the motor itself. Hence, taking into account also the data provided by the pressure sensors, it is possible to control the grip of objects in a more effective way, i.e. by tying the absorbed current and hence the torque generated by the DC motor with the signals originated by the pressure sensors. Fig. 11 shows a schematic view of the connection s between the Arduino micro board and the sensors and actuators used to drive the hand.

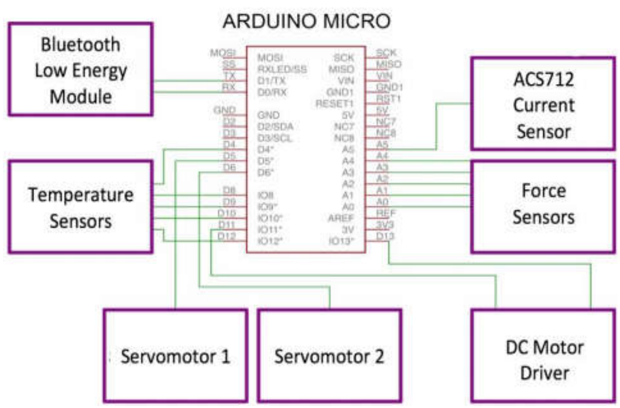


Fig. 11. Schematic view of the connections between Arduino Micro board and the modules, sensors and actuators used in the realized prosthesis.

5. Block Diagram:

Adam's Hand custom firmware has been developed using Arduino IDE (Integrated Development Environment). The programming language is C++, but thanks to many already implemented libraries, it is possible to program the microcontroller at high-level. The developed firmware contains nine functions: three functions manage Pose data, IMU data and EMG data derived from Myo Armband, two other functions mange pressure sensors data, three functions manage the two servomotors and the DC motor and, finally, a fourth function resets all the motors to their base position, corresponding to hand reset position. The block diagram shown in Fig. 12, reports the main functions of the firmware installed in the Atmega32U4 Arduino micro microcontroller.

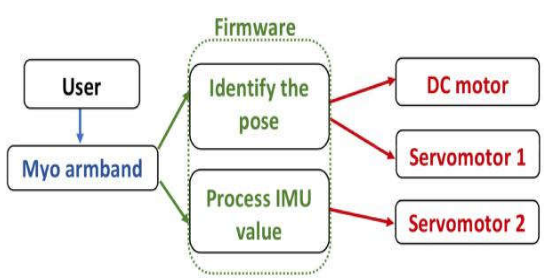


Fig. 12. *Block diagram of the main functions performed by the firmware*

Performed experimental tests show that the realized electronic system (and developed firmware) allows to correctly detect the different data provided by temperature and pressure sensors, located into the 3Dprinted prototype of the fingertips, and by the Myo EMG electrodes and IMU and to drive the chosen DC and servo motors. The whole device is supplied through the 7.2 V-900mAh Otto bock lithium-ion Energy pack 757B20, which allows for a continuous operation of about 4.5 h; this time interval is too limited to ensure a suitable user experience; hence the next version prototype will use a higher capacity battery in order to obtain an autonomy of at least 8h.

In order to verify the the correct functioning of the realized hardware and software, data provided from temperature and pressure sensors and from the inertial Measurement unit and the EMG electrodes embedded into Myo armband have been visualized in real time on the PC terminal. In addition to reading the raw data from the serial monitor, an executable script was developed, using Walfarm Mathematica software, for visualizing the muscular activity of the user wearing the armband (Fig.13) and the data provided from the inertial unit. These data are stocked on a cloud database through the Raspberry Pi 3 board, to be monitored by the orthopedic staff.

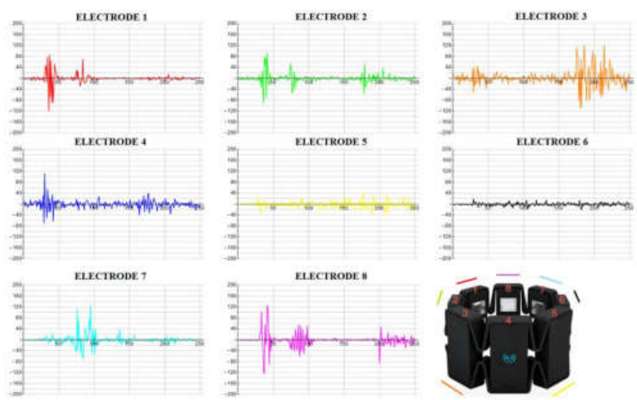


Fig. 13. *Graphic interface, developed by using Wolfram Mathematical software, for the visualization of the EMG signals provided from the eight EMG electrodes integrated into the Myo armband.*

In Fig.14 shows the designed prosthesis; the realized electronic control board and the Raspberry Pi 3 board are located into the prosthesis' socket, behind the touch-screen display, while the Myo armband is visible on the right.

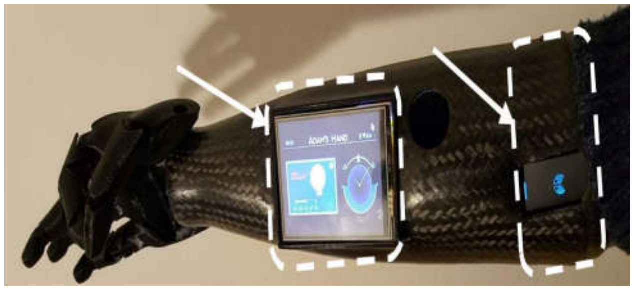


Fig. 14. *View of the realized prosthesis; the touch screen display and the Myo armband housed into the prosthesis' socket are highlighted*

6. CONCLUSION

This research work initially presents an overview of the most recent development in the prosthesis field; then Adam's Hand, a transradial myoelectric prosthesis realized for upper limb amputees, is presented. It is equipped with sensors and actuators that simplify and aid the hand movements: in particular, it is based on a mechanism that actuates 15 degrees of freedom with just one motor. In addition, two servomotors are used to actuate wrist flexion/extension and pronosupination. Myo armband is used to detect myoelectric signals and forearm movements. The realized Arduino-based driving/control electronic unit handles all the prosthesis modules; experimental results show that all the data are properly acquired from the used sensors and that the actuators are correctly controlled.

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