Bioarm, a Prostheses without Surgery

J. Sagouis, A. Chamel, E. Carre, C. Casasreales, G. Rudnik, M. Cerdan

Abstract**—**Robotics provides answers to amputees. The most expensive solutions surgically connect the prosthesis to nerve endings. There are also several types of non-invasive technologies that recover nerve messages passing through the muscles. After analyzing these messages, myoelectric prostheses perform the desired movement. The main goal is to avoid all surgeries, which can be heavy and offer cheaper alternatives. For an amputee, we use valid muscles to recover the electrical signal involved in a muscle movement. EMG sensors placed on the muscle allows us to measure a potential difference, which our program transforms into control for a robotic arm with two degrees of freedom. We have shown the feasibility of non-invasive prostheses with two degrees of freedom. Signal analysis and an increase in degrees of freedom is still being improved.

Keywords**—**Prosthesis, electromyography (EMG), robotic arm, nerve message.

I. Introduction

AT this time, motor disability affects nearly 7,7 million people in France and more than 650 million people around the world. Birth disabilities due to an illness or an accident can affect anyone. That's why it is necessary to find adapted solutions to make the daily lives of people with disabilities easier. Most of the time It is a spinal injury causing the paralysis and without the help of a third person or a medical device such as a wheelchair or walking aid movement is limited. It is also possible that the disability is an amputation, deformity or other injury rendering the person dependent [1]. That is why there are now many solutions on the market to facilitate the lives of these people. There are wheelchairs that are more efficient for an almost full mobility, but also the walking aid system that allows for some movement sending an electrical signal to the muscle of the legs so initiate nerve messages. There are also many more advanced prostheses each with differing degrees of freedom and incredible movement.

Whether mechanical or electrical, they have many qualities and laws. Let us try to understand their functioning.

Today, prostheses are so different depending on the need of the user but also its means. We will focus on the upper limb prostheses. We can distinguish two types of prostheses: active [2] and passive. [11]

The passive prosthesis can replace a missing limb but not to substitute its usefulness. In fact, passive prostheses are not articulate, and they have, for most users, more a therapeutic utilization than a functional utilization. It is for the most part to treat phantom limb syndrome [13] that causes intense pain in people with amputations, recent or not. The phantom limb syndrome refers, for an amputee, the perception of the body part that has disappeared and we say it is the illusion of persistent motor and sensory perceptions that the individual attributed to the amputated limb, even if aware of his amputation. It speaks well of motor and sensory perceptions [3]: people can feel sensations (e.g. feeling a wedding band on a cut finger), but the ghost body part will also be capable of automatic movements or reflex (when hitting the phantom limb, the subject may feel fear response.

Thus, for many patients, the use of passive prostheses can "cure" this syndrome even if it is not effective for everyone.

The other type of prosthesis includes several categories, it is active prostheses. These implants allow patients to recover in part, motor skills and the autonomy he might have before amputation or he simply did not. Among them, we can distinguish two main categories: mechanical prostheses, very cheap but not having many degrees of freedom and electrical prostheses [12], the price varies depending on the degrees of freedom and complexity.

II. So What Are the Issues?

Indeed, electrical implants today have conceivable degrees of freedom but they are mostly very expensive and require major surgery [4]. These operations allow a better understanding of the prosthesis and greater ease of use. After an amputation, the nerves that innervate arms are useless, and the chest muscles are too. TMR (Targeted Muscle reinnervation) [5] is to replace the nerves of the pectoral muscle area where they are served. For this, the nerves of amputated arm are deflected towards this zone. Thus, when the patient decides to move the prosthesis, the motor command issued by the brain and conveyed by the nerves of the delocalized arm, will cause muscle contraction of the reinnervated chest area. This muscular contraction generates a sufficiently large electric field to be collected at a distance on the surface of the skin. The perception of this signal by the electrodes allows the transmission of biological information to the mechanical prosthesis in to render the action relatively intuitive.

This is certainly very effective but is also very costly and requires a long recovery time and rehabilitation.

III. System

A. The Electrodes and the Sensor Plate Muscle V3

The surface EMG electrodes provide a non-invasive technique [6] for the detection and measurement of an EMG signal. From a theoretical point of view, these electrodes form a chemical equilibrium between the sensing surface and the skin of the body by electrolytic conduction, so that current can flow in the electrode. These electrodes are simple and very

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easy to use. Unlike other types of EMG electrodes that are inserted under the skin, the surface EMG electrodes require no strict medical supervision. [7] This is why they are widely used in the control of robotic devices such as prostheses. They are also used by engineers in the latest research on EMG since no medical certification is required. Its use in rehabilitation is encouraged, as it causes no discomfort to the patient. The surface EMG electrodes provide a non-invasive technique for the detection and measurement of an EMG signal [8], [9].

We used the model sensors Muscle Sensor V3, which are connected to a card for processing the received signal directly. They allowed us to visualize the nerve messages sent to the muscles. They comprise three independent sensors, one positioned on the base of the muscle, the other on the middle of the muscle and the latter serving as a reference is set to a bone (the elbow in our study). Once each sensor set, reading the nerve message is done by the calculation of the potential difference between two electrodes on the muscle. The result is compared to the action taken on the elbow, which serves as a reference. The sensor plate muscle can then process the received signal by the electrodes; it is directly connected to the latter.

B. The Microcontroller Arduino Uno

This microcontroller and the software that allows for programming are freely available. It can be programmed to analyse and produce electrical signals, to perform very different tasks, such as control electronics or even fly a robot. In our case, we use it to control a robotic arm. This platform is based on an input / single output interface. It is connected to a programming interface called Processing. Processing allows us to create our interface between the patient and the prosthesis. The programming software is a Java Arduino module, free and cross-platform application for code editor and compiler.

C. Alimentation

The system can be powered from a computer via USB. However, for the sake of mobility, it can also be powered using two 9V batteries. This makes the system portable and is used to meet the mobility needs of the patient.

D. Robotize Arm

The robotic arm that we used is consisting of five actuators which all permits to simulate an arm. For our project, we just used the two of us, one to simulate the elbow movement and the other one to lock the hand. To control the elbow's movement, we used the impulse voltage sent by the muscle contraction to the Muscle Sensor V3 when the patient bends his elbow. All voltage values correspond to a normal movement and are included between 0V and 4V. We study all values and calculate an average, which is converted to an angle for controlling the prosthesis. This entire step is very quick and allows for a real time sensation.

When a voltage exceeds 4V for more than 2 seconds, the other servomotor is activated to control the hand and the prosthesis closes its hand.

To sum up, we are able to control two servomotors with only one muscle.

But if we have more muscle sensors, we can combine them to control more servomotors with a few muscles.

For example: if we have two groups of muscle sensors, one on the arm and on the thigh, with only a few movements, we could control maybe 4 or 5 servomotors…

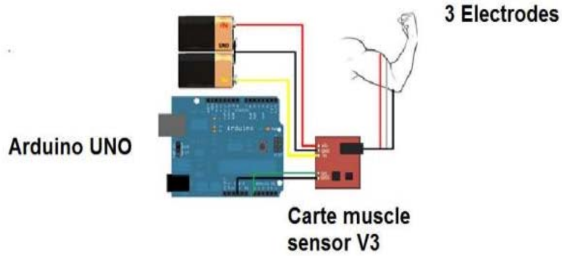

Fig. 1 The various system components of Bioarm

IV. RESULT

Once the message arrives in the nervous muscle, it completely unfolds. EMG electrodes thus recover the signals arriving in the muscle and the muscle map Sensor V3 is responsible for processing these signals to make them usable for the Arduino microprocessor. EMG electrode placement is important because otherwise the measurement would not be optimal.

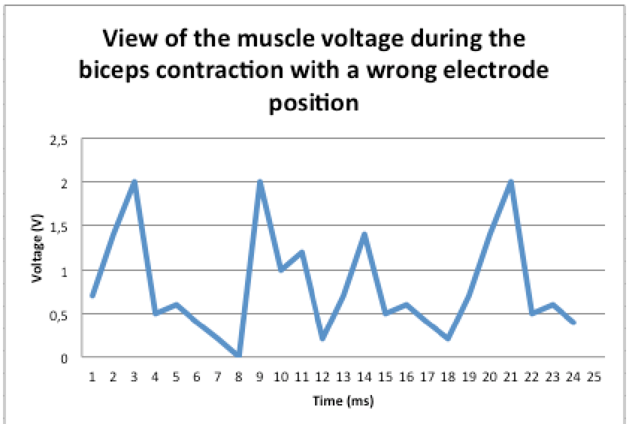

Fig. 2 Graph showing the different voltage pulse on the biceps thanks to a wrong position sensor

As you can see with this diagram, if the position of the electrodes is wrong, all the values are incorrect and the only thing we can see is muscle's artefacts.

For our study, we have to use voltage to send it to the prosthesis.

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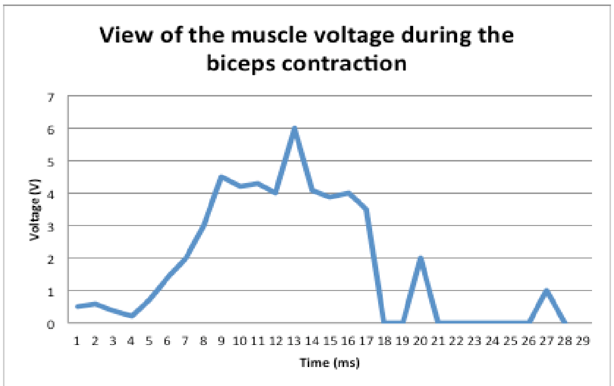

Fig. 3 Evolution while a biceps contraction thanks to a correct position sensor

This diagram shows the electric impulse due to patient movement. This is the kind of data we use to control our prosthesis. As you can see, the evolution at the middle of the graph symbolizes the entire movement of the patient. But there are other kinds of movements we can use.

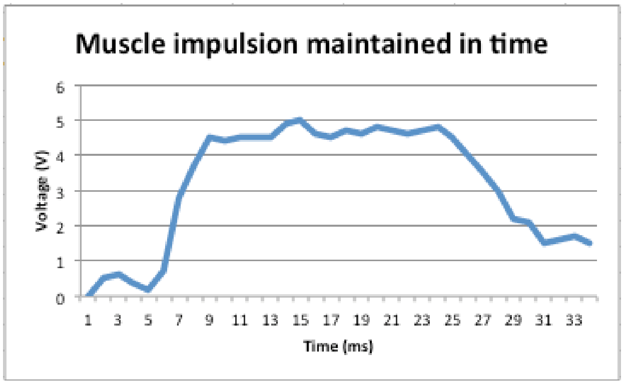

Fig. 4 Observation of the regularity of the electric pulse inside the muscle

This kind of movement permits us to control the opening of the prosthesis. To do this, the patient just has to maintain a contraction during a few milliseconds.

There are several parameters to be set to having a good result: the optimal electrode placement, the right muscle, and the right movement. On the one hand, the tests we conducted show that the optimal placement of EMG electrodes varies with each individual.

As you can see on Fig. 1, the wrong placement of the electrodes creates artefacts and non-usable data.

The interface that we have developed allows the patient to optimize the proper placement of the latter. On the other hand each movement corresponds to a different contraction therefore a different voltage. [10] There is a variation of the same voltage as a function of the intensity of movement. Viewing this dependent intensity of the recorded voltage is possible thanks to the LED disposed on a test wafer. In addition, these data are stored concurrently in an Excel file. Our program combines a voltage to the microcontroller for a movement, and everything is transmitted to the robot arm. The signal is therefore recovered, processed and then amplified to be transmitted to the Arduino so that calculations are performed there. The processed signal is however a digital signal derived from the analog signal. This allows us to recover an electrical signal that oscillates between 3V and 5V. Then control is passed to the arm. Through a registration system, the patient can check the evolution of the strength of his muscles. It can also recaliber the prostheses in case of degeneration of the nerves causing voltage changes that will affect the movement of the prosthesis. A lack of muscle activity sometimes causes degeneration in amputees. Patients and physicians can use recorded data. An amputee is always followed (more or less regularly depending on the severity of the case); therefore, it is information in addition to the physician, which can lead to "personalized rehabilitation" for each person.

V. Conclusion

Through our project Bioarm, we demonstrated the feasibility of conducting prostheses with two degrees of freedom at a low cost (less than 300 euros). However, the essential point of our project was to show that it was possible to capture non-invasive nerve messages, analyse and transcribe them into movements using electronic systems. To go further, we have achieved significant results we show that it is possible to adapt the system for capturing nerve messages to any electronic device that can overcome a disability, by multiplying the number of nerve messages and analysing the degree of freedom. The drainage system, analysis and transcription of the Bioarm's information works with a robotic arm but it could also fit a wheelchair: each muscle contraction intensity would correspond to a speed, action or direction of the wheelchair.

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