DESIGN OF A NEW EMG SENSOR FOR UPPER LIMB PROSTHETIC CONTROL AND REAL TIME FREQUENCY ANALYSIS

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ABSTRACT

Myoelectric prosthesis are aids that try to give back to patients a bit of autonomy and indipendence in their life. Several control techniques were explored in the past, but still the electromyographic (EMG) control remains the most widely used method. Most of the commercial EMG electrodes for prosthetic control available on the market modify the acquired signal acting a heavy frequency filtering, making the signal more clear and better suitable for prosthetic control even if the information related to its frequency behaviour are lost. This information instead would be precious for a frequency analysis, to face and solve the problem of musclular fatigue, an effect that arises in case both of repetitive movements and sustained isometric contraction, as literature reports, causing an amplitude increasing and a spectrum shift toward lower frequencies of the EMG signal. This, in turn, can cause problems in the control of myoelectric prostheses [1]. The aim of this work is hence to illustrate the design of a new EMG electrode suitable both for prosthetic control and frequency analisys, taking into account the problem of muscular fatigue.

INTRODUCTION

During the last decade several possible input sources for electric prostheses were explored, (neuro cortical control, foot control with wireless wearable insoles, control with implantable myoelectric sensors, with mechanomyographic sensors, ultrasonic sensors and vocal commands). But the most effective methodology still consists in using surface EMG (SEMG) signals from remnant muscles to control artificial prostheses actuated by electrical motors, so that the on/off states of the limb motors or the pwm duty cycle are controlled by the intensity of the muscular contraction over a certain threshold. This *classic* EMG control is not free from imperfections, and in this study we would like to focus the attention on the problem of muscular fatigue, that is the reason why we have designed a new EMG electrode for prosthetic control and real time frequency analisys.

THE MUSCULAR FATIGUE

Prolonged muscular activity or repetitive movements lead to a variation in the EMG signal, which is due to a decreasing of the velocity conduction (CV). This phenomenon is generally called "muscular fatigue"[2]. The variations in the EMG signal can be observed both in the time and frequency domains. Associated to this CV decreasing there is a power EMG spectrum compression towards lower frequencies [2].

Usually, the FFT analisys is the most used mathematical tool to estimate these spectrum variation, but there is also who uses wavelet analisys [3]. In this work we decided to use the FFT analisys also because nowadays there are several FFT algorithms that are optimized to be implemented on a microcontroller (the electronic core of our prosthesis) for real time frequency analisys. This is not true for the wavelet algorithms. Is not really clear what kind of index is more appropriate to estimate the power spectrum compression, even in relation to the type of muscular contraction (isometric, dynamic or repetitive). We choosen to use the median frequency. It remains, mostly of times, the preferred parameter because of the

relatively simple computational procedure needed to estimate it on line, and because of its lower sensitivity to noise [4].

THE NEW EMG ELECTRODE

The new electrode is a double differential electrode. Its harware structure is organized in four stages, as shown in figure 1.
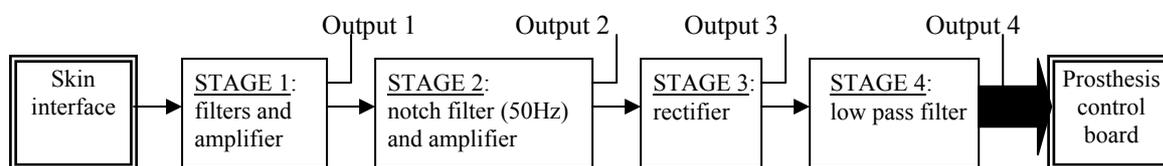

Fig.1 Hardware structure of the electrode

The input stage (first stage), applies hardware low pass and high pass filters to clean the raw signal coming from the skin interface and the output of the precision instrumentation amplifier INA114 . This stage has a variable resistor, R_G, which is an 8 bit digital potentiometer, programmable via I^2C bus from 0Ω to $100k\Omega$, that sets the gain of the amplifier and consequently also its frequency band, that after this stage is 16-800Hz. The INA114 has a very good CMRR (more than 115dB), as recommended in [5] and a maximum common voltage applicable between the two inputs of about 80V. This allows to use this EMG sensor also with neuromuscular electrical stimulation. The second stage eliminates the 50 Hz noise signal coming from the powerline and amplifies again the signal. Here there is another digital potentiometer, programmable via I^2C bus, called R_N. The third stage rectifies and shifts vertically the voltage signal to obtain a new non zero mean signal with values between 0V and 5V. From the beginning of the acquisition chain until here, in fact, the signal is centered on a value of 2.5 V, that represents a virtual ground. In the final stage there is the third digital potentiometer, R_P. This stage performs a low pass filter function. The cutoff frequency is about 1.3Hz, lower than the cutoff frequency of the first high pass filter because the third stage, rectifing and shifting the voltage, introduces again a constant component in the spectrum.

TABLE I		
Stage	Gain range	Potentiometer step number
Input	1 - 4200	256
Notch	1 - 26	100
Final Low pass	1 - 101	100

The gain values of the three stages are shown in table I. The electrode gives the chance to choose a gain between 1 and about 10^7 in more than $2 \cdot 10^6$ steps. This can satisfy also a user with very poor EMG activity. The presence of three digital potentiometers programmable via I^2C bus allows this electrode to be software programmable also in real time, changing the gain of the stage to compensate for instance the arising of the muscular fatigue phenomena. Every one of the four stages has its own output pin: this means that one can take the output pin of the final stage to control the prosthesis and at the same time he can use the output pin of the notch filter to perform the frequency analisys. (we used the notch output because the rectifier stage performs non linear operations, in the sense that while it rectifies and shift the EMG signal, the shift is not exactly equal to the mean value of the raw emg (2.5V) but is a little bit less. This is to avoid that the envelope goes under zero. So the output of the notch stage, even if is less amplified that the next one, replies more faithfully the original emg signal).

DATA ANALYSIS AND RESULTS

To test the good quality of the new EMG electrode, we used as skin interface the same as the one of a double differential Otto Bock electrode for prosthetic control. Then we put the new sensor on two muscles, the carpi radialis flexor and the brachi radialis biceps (often used as EMG signal sources for upper limb amputee patients) of several able bodied people , we acquired the output of the notch stage with a dSpace ds-1102 analogic/digital board and performed a FFT analysis with Matlab Simulink®, calculating the median frequency of the power spectrum.

To align this study with the literature of the frequency analysis of SEmg signals, the parameters used in the frequency analysis were in the range of the most commonly used, that is sample frequency = 2500 Hz, frequency band = 10-500 Hz, windowing function: Hamming and frame length= 256. The signal was acquired from the output pin of the notch stage, then we subtracted from it the mean value of the recordered signal without contractions (i.e. the mean of the noise in absence of signal), as recommended in [6]. The simulink model (Fig. 2) then applies to the data a digital band-pass filter, with cutoff frequency of 10Hz and 500Hz .
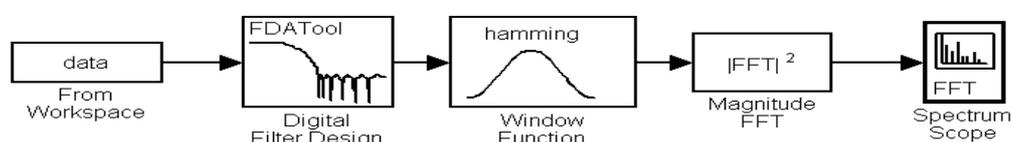

Fig. 2 The simulink model

In Fig. 3 are shown the results of these experiments. It can be seen that in both cases the spectrum shifts towards lower frequencies, decreasing the value of the median frequency (from 290Hz to 215Hz for the carpi radialis flexor and from 300Hz to 135Hz for the biceps brachii).

The fatiguing conditions were obtained, for the carpi radialis flexor, simply contracting ten times the muscle with the maximum voluntary contraction force, bending the wrist for 90° with the hand closed and the forearm horizontal, and for the biceps simply doing ten consecutive contractions (100%MCV) without any load , with 90° between the arm and the forearm and between the wrist and the forearm, this last one horizontal. These movements without load were chosen just to recreate the same conditions of a real patients that contracts his muscles to overcome the intensity threshold.

The new electrode has demonstrated to be a very useful tool for the frequency analisys of the EMG signal, but also the other task had to be performed in the best way.

To test the quality of this electrode as input source of a prosthetic device, we hence designed a sort of prosthetic simulation box with the same hardware of a real prosthesis. The only difference was that instead of the motors, our outputs were only sound beepers. Using this electrodes, over a certain level of muscular contraction the beeper advised us that the intensity threshold was overcame. Wearing this box for a dozen of days and for about eight hours per day, we were able to verify that this electrode works as well as the standard electrodes in the prosthetic field. The electrode had a reasonable low number (<1%) of positive false (situations in which the electrode has a non zero output with no contraction), similar to that of a standard SEMG electrode for prosthetic control (the false positive are caused for example by movements of the patients that disconnect, even if for few instants of time, the electrode from the skin, causing a sudden variation of the input impedance).
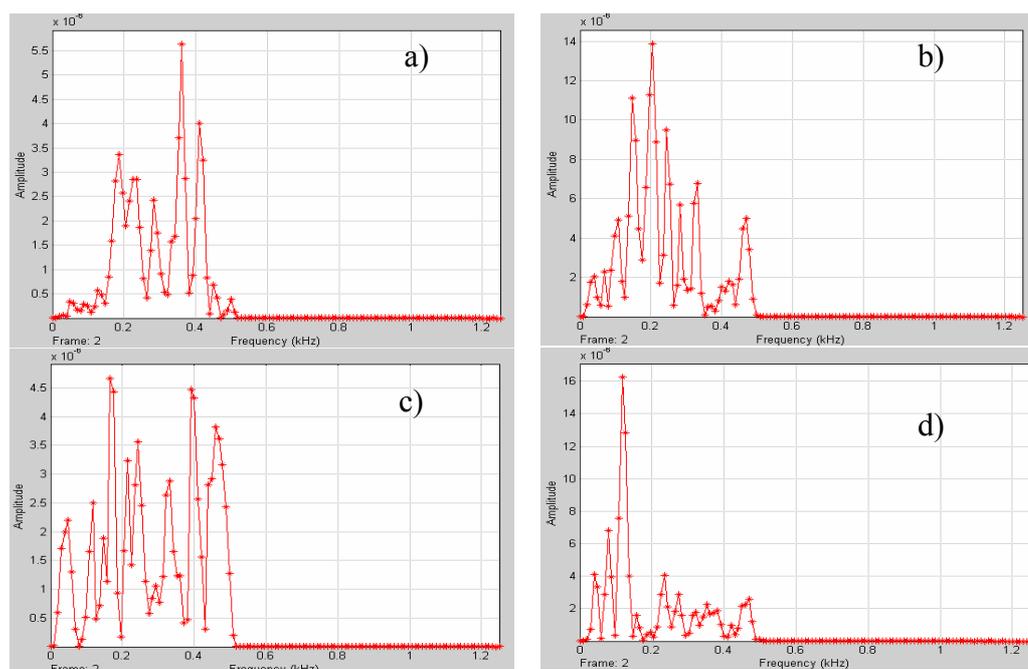
Fig. 3 a) b) non fatigued and fatigued carpi radialis flexor   c) d) non fatigued and fatigued biceps brachii

CONCLUSION

We have designed a new double differential electrode suitable for prosthetic control and frequency analysis, with excellent characteristic in terms of CMRR and signal to noise ratio (the SNR value comes from the ratio between the amplitude of the EMG signal with the maximum contraction at every stage and the amplitude of the noise signal when the inputs of the electrode are in a short circuit condition. The measured SNR of the last three stages is: $SNR_N \approx 23.3$, $SNR_R \approx 34$, $SNR_F \approx 48.4$.)

The electrode has been tested on able bodied people with good performances in both cases. The presence of the three programmable digital potentiometer allows the real time modification of the electrode's gain, to compensate in case of muscular fatigue. Future work will regard finding proper strategy to change the gain depending on the muscular fatigue entity.

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