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# AN AUTOMATIC SYSTEM FOR MEASUREMENT OF THE LATENCY IN POTENTIALS EVOKED BY TACTILE STIMULI

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**Abstract** – The paper faces the problem of recording and analyzing the sensory potentials evoked by tactile stimuli in a non-invasive way. These signals present a very low SNR. Therefore, at now, this very selective investigation technique requires harmful needle electrodes to acquire them. The paper proposes both a new recording method based on surface electrodes and a signal processing technique. This technique greatly improves the SNR of the signals. The new method has been validated measuring the latency on simulated as well as actual signals. The results of the validation phase are presented and discussed.

**Keywords**: Latency measurement, sensory potentials

## 1. INTRODUCTION

The study of the sensory potentials evoked by tactile stimuli represents a powerful tool for diagnosis and prevention of pathologies affecting the peripheral nervous system. Abnormal potentials are often an indicator of peripheral nervous system illness or injury. Abnormalities usually consists in a low Velocity Of Propagation (VOP) or some kind of irregular waveform.

VOP, measured on the potentials evoked by electrical stimuli, is the most commonly used indicator of the condition of peripheral nerves [1, 2]. However, these signals are not well suited for such purpose. In fact, they come from the indiscriminate activation of a number of nervous fibres that are morphologically and functionally different. Therefore, their study provides only a general view of the stimulated nerve status [3].

Instead, the analysis of the sensitive responses evoked by tactile stimuli is a better way to explore the peripheral regions. By using this technique, the functionality of a specified group of nervous fibres can be explored beginning from the thinnest endings, thus increasing the selectivity of the clinical examination.

The sensitive response is obtained by activating specific skin mechanoreceptors with a tactile stimulation.

By definition, the mechanoreceptors are sensory units activated by a harmless mechanical distortion of the skin. In particular, Meissner's receptors are responsible of the tactile discrimination in the glabrous skin of the fingertips [1].

Meissner's corpuscles are Fast Adapting (FA) sensory units, as they are activated at the beginning and at the end of the mechanical stimulus.

Fig.1 shows an image of the Meissner's corpuscles, obtained by examining, by means of co-focal microscope, a skin section processed with immunohistochemistry techniques.

The Meissner's receptors are only sensitive to mechanical stimuli with a sine waveform, low frequency and intensity. In other words, these corpuscles are sensitive to lasting but light pressures [1].

The current method to acquire the sensory response of these receptors consists of inserting long needle electrodes in particular monitoring points of the patient. In this way, it is possible to collect these very low amplitude signals near the involved nerves.

In the paper, a non-invasive method is described to record the potentials from the ulnar nerve, by activating the Meissner's mechanoreceptors with mechanical impulses.

Two Virtual Instruments (VIs) have been realized to acquire the response signal and to measure the VOP, in a harmless way, within the hospital routine.

In order to validate the accuracy of the measurement system, the measured VOPs have been compared with those obtained by needle electrodes.

In the following sections (i) the measurement hardware, (ii) the acquisition and processing method, and (iii) the first experimental results will be illustrated.

## 2. THE NEW APPROACH TO VOP MEASUREMENT

The acquisition, processing and displaying of evoked potentials are very complex operations. The tactile responses, in fact, consist in extremely low signals, whose amplitude is typically limited to fractions of μV, therefore they are very difficult to separate from the noise.

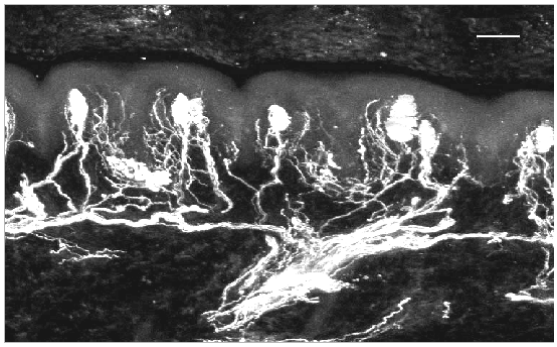

Fig. 1. Meissner's corpuscles.

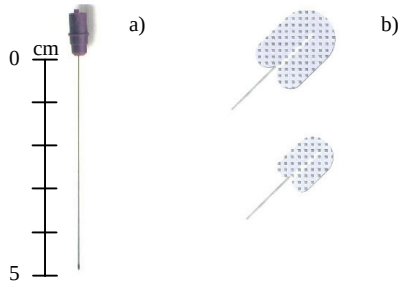

Fig. 2. a) Needle and b) surface electrodes.

The VOP is calculated in two steps. The former is the measurement of latency, defined as the delay between the application of the mechanical stimulus and the sensory response. The latter is the computing of VOP, obtained as the ratio between the distance between the stimulation point and the response recording point and the latency.

The latency is measured as the time distance between the instant corresponding to the first peak in the response signal and the stimulation instant. It is very difficult to detect the first peak in signals with very low SNR.

At now, needle electrodes are used to record the evoked potentials near nerve [4]. This reduces the attenuating effect of the biological tissue located between the fibre and the recording point. In this way it is possible to obtain signals with higher SNR, enabling an easier search of the first peak.

However, the recording by needle electrodes is an invasive (extremely annoying for the patient) method, so its use in the hospital routine is strongly limited. The use of surface electrodes could overcome this limit, but, the recorded signals have a SNR too low [5].

To address this problem, a VI has been designed and realized to activate the Meissner's receptors and to automatically record their sensory responses in a painless way, by using surface electrodes (Fig. 2b). It is composed of a hardware section, for the mechanical stimulation and the signal acquisition, a stimulation VI and an acquisition and processing VI, both developed in LabVIEW™ environment. The processing software implements a simply filtering technique to improve the SNR of the biological signals. Then, this VI measures the latency of evoked potentials as the time of occurrence of the first peak in the signal. The VOP of nervous fibres activated by tactile stimulation is then calculated from the measured latencies.

In order to find the simplest processing technique able in assuring an SNR improvement high enough to overcome the surface acquisition limits, a suitable model has been developed and validated for the sensory responses.

In the following subsections, the hardware section, the model and, finally, the adopted noise filtering solution will be presented.

*2.1 Measurement hardware*

As shown in Fig.3 the measurement hardware is composed of:

- A stimulating system.
- A recording system.

*2.1.1 The stimulating system*

A stimulating waveform is generated by means of a stimulation VI and a data acquisition board (DAQ) National Instruments AT MIO 16E-1. The waveform used for the stimulation is a square wave with the following characteristics:

- ✓ amplitude: 2.4 V;
- ✓ period: 1 s;
- ✓ duration: 200 ms.

The output of the DAQ board is sent to a power amplifier (Brüel & Kjær type 2706) that determines the amplitude of the tactile stimulation.

The amplified waveform drives a mini shaker (Brüel & Kjær type 4810) that acts as mechanical stimulator. The mini shaker is lodged on a double graduated slide. Therefore, it is possible to set its vertical and horizontal position.

The stimulator consists of a moving coil motor driving a cylindrical probe with a 3.14 $mm^2$ contact area. Tactile stimulation is applied with 1 Hz frequency to the fingertip at the vortex of the skin ridges. The stimulation rate is 152.29 μm/ms, with an acceleration of 75.94 $m/s^2$, the maximum indentation is 0.33 mm, the applied strength is 0.31 N.

*2.1.2 The recording system*

Tactile stimuli-evoked responses are recorded at the wrist and elbow of the patients by surface electrodes (commonly used to record the potentials evoked by electrical stimuli) at a constant surface temperature of 37°C (Fig. 4).

The signals, coming from the surface electrodes, are transmitted to the Counterpoint (Dantec MkII), where they are amplified with a $10^6$ gain and pass-band filtered between 0.05 and 50 kHz. Then, they are digitised by means of a second AT MIO 16E-1 board.

The stimulation signal, corresponding to the acceleration of the mini shaker, is recorded as well. In order to remove low frequency noise, the acceleration output of the mini shaker is high pass filtered by the charge amplifier.

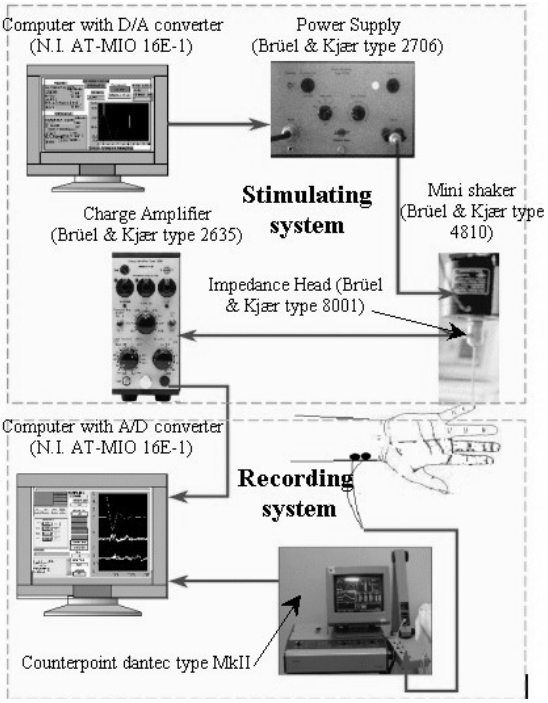

Fig. 3. Measurement station.

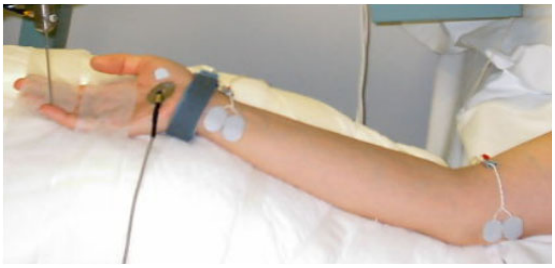

Fig. 4. Recording surface electrodes.

The same device amplifies the signal to make its level compatible with the DAQ board inputs. Finally, the signal is acquired by the same DAQ board used for recording the response.

The acquisition is managed by a VI, developed in LabVIEW™. The same VI processes the incoming sensory responses and measures the VOP, as it will be explained in the following sections.

The VI acquires 130 ms time records from the stimulation and the sensory response signals, starting 30 ms before the stimulating impulse. Therefore, within the first 30 ms, only noise is present, and, on the next 100 ms, there are the useful signals too.

The trigger event corresponds to the descending front of a square impulse with the following characteristics:

- ✓ amplitude: 5 V;
- ✓ period: 1 s;
- ✓ duration: 5 ms.

This time is used (i) to define the useful acquisition interval after the 30 ms pre-trigger, and (ii) as a reference to measure the latency.

The whole system is activated after a delay of 5 ms, taking in account the trigger impulse duration. The tactile probe reaches the maximum acceleration with a delay of 0.5 ms. For these reasons, in order to synchronize correctly the stimulation phase with the acquisition one, the origin of the stimulation square wave has been delayed of 4.5 ms in respect of the trigger.

By using this measurement station, the ulnar nerve of 12 healthy informed volunteers has been studied. Fig. 5 shows two example signals recorded by means of surface electrodes placed at the wrist (a) and the elbow (b) of a patient.

*2.2 Signal processing*

As it can be seen in Fig. 5, the signal acquired from surface electrodes is very noisy, the typical SNR is in the [0.03÷3] dB range. In order to obtain a reference signal free of noise, a model of the potentials has been developed. Then, the reference has been used to design a FIR filter able in removing a part of the additive noise. The filter pre-processes the acquired data before measuring the latency, which is used to calculate the VOP. In the following sections, the steps of the proposed approach are better described.

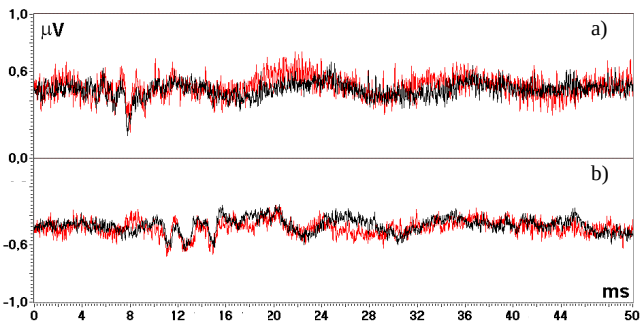


Fig. 5. Tactile stimuli-evoked responses at (a) the wrist and (b) the elbow of a patient.

*2.2.1 Model of the evoked potentials*

In order to develop an affordable method for recovering the actual potentials, evoked by tactile stimuli, from the acquired signals, a model of them has been realized. It consists of the sum of the responses obtained from each nervous fiber, with different time delays, due to different paths.

The response x(t) of each fibre (spike) can be modelled as the composition of 3 Gaussian base functions as:

$$x(t) = \sum_{i=1}^{3} K_i \exp\left[-\left(\frac{t-t_i}{\sigma_i}\right)^2\right] \qquad (1)$$

where t is the time, $\sigma_i$ are the standard deviations, $K_i$ are amplitude coefficients, and $t_i$ are fixed delays. $K_i$ assume both positive and negative values, with $K_2$ being larger and with opposite sign than $K_1$ and $K_3$ [6].

The values for the constants have been fixed according to [7]. The waveform modelling the single spike, obtained in Matlab, is shown in Fig.6.

The tactile stimulus produces a deformation of the skin, which activates the receptors in asynchronous mode. The activation mechanism of the sensitive units is usually compared to the effect of the launch of a stone in a pond [3]. The propagation of the resulting deformation is shown in Fig.7.

The proposed model is illustrated in Fig. 8. The activation of each mechanoreceptor is modelled as a switch, according to the behaviour of actual ones [3]. As above mentioned, the different paths of the spikes are simulated by delaying the single spikes according to a Rayleigh type probability density function [4,8]. The overall potentials evoked by tactile stimuli consist of the sum of as many spikes as the activated fibres.

*2.2.2 Noise filtering*

The analysis of the noise-free modelled potentials in the frequency domain made possible to identify the frequency range where the evoked potentials are mainly concentrated [9, 10]. This enabled the removal of a large amount of the

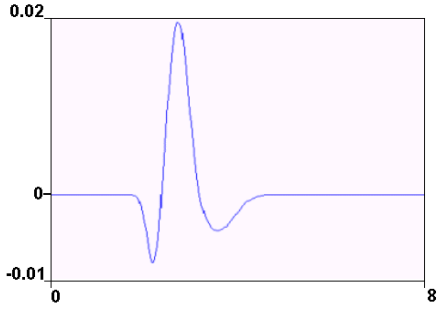


Fig. 6. Simulated spike.

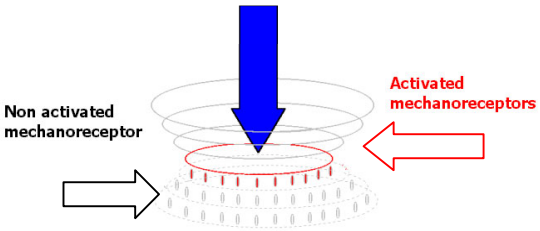


Fig. 7. Propagation of skin deformation.

noise power by filtering the acquired signals with a 100th-order band-pass FIR filter with cut-off frequencies of 0.2 and 1.5 kHz, respectively.

The filter has been applied to signals simulated by using the proposed model and adding white Gaussian noise.

The effect of filtering can be graphically retrieved from Fig. 9 by comparing the filtered signal with the non processed one.

Fig.9 evidences the entity of denoising action of the filter, which ensures a good SNR increase. In particular, the non processed signals have an SNR within the range [0.03÷3] dB, while the SNR of the processed ones is in the range [11÷20] dB.

*2.2.3 Latency and VOP measurement*

As above reported, the latency is defined as the delay between the stimulation instant and the time corresponding to the first peak in the signal. In order to measure it, the residual noise peaks should be ignored.

This has been obtained by starting the peak search from the overcome of an opportune threshold. By supposing that the noise is a zero mean Gaussian one, the acquired noise in the first 30 ms of recording, is used for such a task [8]. As previously specified, in fact, in the first 30 ms, no stimulus is applied.

In this hypothesis, the standard deviation (σ) of the overlapped noise can be estimated.

By considering an opportune covering factor (K), it is possible to find an amplitude interval [-Kσ, Kσ] within which the probability of finding the evoked potential is very low. Instead, the amplitudes that exceed the calculated

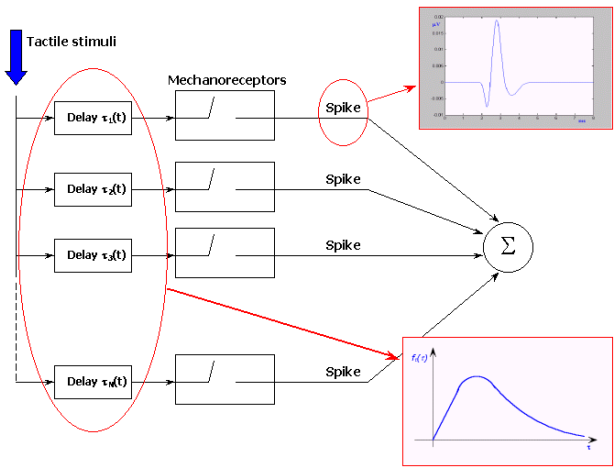


Fig. 8. Block diagram of the proposed model.

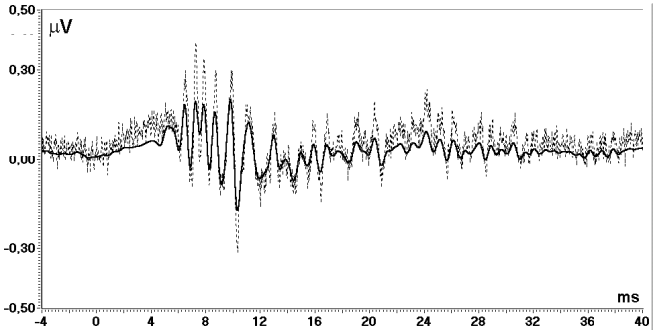


Fig. 9. Filtered and non-filtered signal.

thresholds can be referred to the evoked potential.

By finding the first peak successive to the noise threshold overcome, it is possible to obtain an estimation of the latency, as it is shown in Fig.10.

## 3. EXPERIMENTAL RESULTS

The proposed method has been validated on simulated as well as on actual signals.

Initially, in agreement with the block diagram of Fig.11, the method performances and the accuracy of the latency measurement have been verified in simulation. The evoked potentials have been simulated by using the proposed model. After having added white Gaussian noise the latency measured by using the proposed method has been compared with the one measured on the noise free simulated signals.

The proposed method supplied a percentage error of about 4% on the latency estimation.

Then, the method performances have been evaluated on actual signals coming from hospital patients.

The VOPs, measured at the wrist and the elbow of those patients, have been compared with those obtained with needle electrodes, reported in [2, 11], as it is shown in Tab.1.

The agreement between the results, obtained by using the two recording techniques (invasive and non-invasive), establishes the validity of the proposed method versus the invasive one.

Finally, in order to assert the accuracy of the proposed method on actual signals, it has been chosen to record the biological signals adopting both superficial and needle electrodes, at the same time and on the same patient. The potentials acquired with needles have been used as reference signals, thanking to their good SNR.

Therefore, at the wrist and elbow of the same patient, superficial and needle electrodes have been applied to acquire the evoked potential with both recording techniques (Fig. 12).

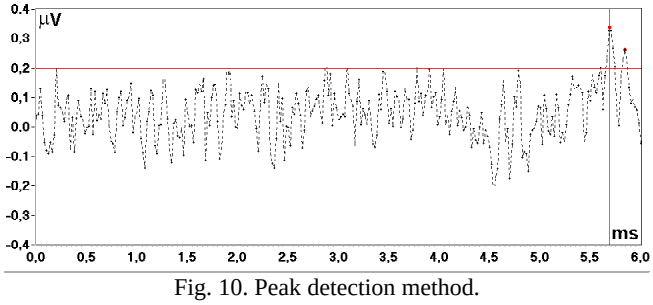


Fig. 10. Peak detection method.

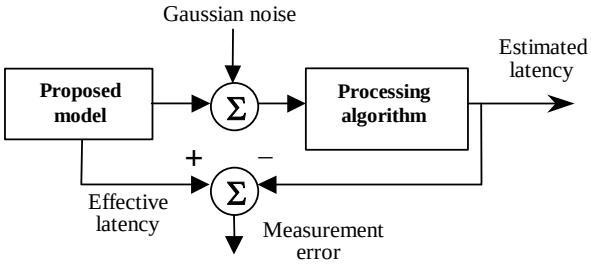


Fig.11. Method used for validating the processing algorithm.

The VOP measurement method proposed in Section 2 has been executed on the signals acquired with both recording techniques and the resulting latency measures are shown in Tab. 2.

From the analysis of the Tab. 2, it is possible to observe that the proposed peak detection technique gives an accurate estimation of latency. In fact the value obtained for the VOP of the evoked potentials by tactile stimuli is almost the same by using both the classical recording technique and the proposed approach.

## 4. CONCLUSIONS

The paper has presented an automatic system to acquire the tactile stimuli evoked potentials and to measure their VOP, in a non invasive way. The first results of the validation of the VOP measurement instrument on simulated and actual signals, acquired by hospital patients, have been very good, in comparison with those presented in specific literature.

By substituting the previous painful measurement method with the proposed one, further experimental investigations can be carried out in a hospital environment, gathering a lot of information that today is not accessible.

This could give a new impulse to the research on such peripheral nervous system illnesses.

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| Electrode Type | Number of subjects | VOP [m/s] | |
|---|---|---|---|
| | | Wrist | Elbow |
| Needle | 13 | 37,5 | 58,0 |
| Surface | 12 | 38,4 | 54,3 |

Table 1. Comparison between results obtained with the two recording techniques.

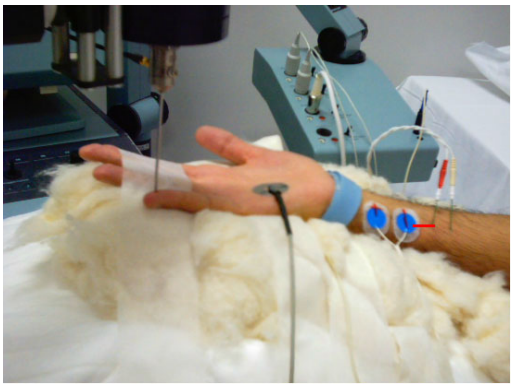

Fig. 12. Recording with needle and surface electrodes of the evoked potentials by tactile stimuli.

| Electrode Type | Distance finger-wrist [mm] | Latency finger-wrist [ms] | VOP [m/s] |
|---|---|---|---|
| Needle | 160 | 4,12 | 38,83 |
| Surface | 180 | 4,62 | 38,92 |

Table 2. Results obtained by means of the peak detection method.

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