# Recovery system-based textile actuators

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**ABSTRACT – REZUMAT**

**Recovery system-based textile actuators**

*This paper presents a medical recovery system based on electrical stimuli transmitted through textile electrodes based on copper microparticles. The textile electrodes are connected to an electronic device capable of generating transcutaneous electrical nerve stimulation (TENS) using low-frequency (0–100 Hz) (diadynamic or interference) electrical currents. To evaluate the system, the current intensity, frequency and supply voltage were measured using different multimeters (Agilent Technologies U3606A and portable digital multimeter), and the signal was analysed. Depending on the intensity of the transcutaneous electrostimulation program, obtained by varying the electrical parameters, such as electrical voltage (U, mV), current intensity (I, mA) and frequency (f, Hz), it is possible that the patient feels pinches or vibration.*

***Keywords:*** *textile, electrodes, stimuli, actuators, TENS, electrostimulation*

**Sistem de recuperare pe bază de actuatori textili**

*Această lucrare prezintă un sistem de recuperare medicală bazat pe stimuli electrici transmişi prin electrozi textili pe bază de microparticule de cupru. Electrozii textili sunt conectați la un dispozitiv electronic capabil să genereze stimulare electrică transcutanată nervoasă (TENS) utilizând curenți electrici de frecvență joasă (curenţi diadinamici şi interferenţiali având frecvenţa între 0 şi 100 Hz). Pentru evaluarea sistemului, intensitatea curentului, frecvența și tensiunea de alimentare au fost măsurate cu ajutorul unor multimetre (Agilent Technologies U3606A și multimetru digital portabil), iar semnalul a fost analizat. În funcție de intensitatea programului de electrostimulare transcutanată, obținută prin variaţia parametrilor electrici, precum tensiunea electrică (U, mV), intensitatea curentului (I, mA) și frecvența (f, Hz), este posibil ca pacientul să simtă ciupituri sau vibrații.*

***Cuvinte-cheie:*** *textile, electrozi, stimuli, actuatori, TENS, electrostimulare*

## INTRODUCTION

The transcutaneous electrical nerve stimulation (TENS) technique allows electrical stimulation of nerves and muscles and is frequently used for recovery, pain control, sports and fitness. By applying low-frequency currents, electrotherapeutic effects such as analgesic, neuromuscular stimulation, vasodilator, biotrophic and regulation of the neurovegetative system (SNV) can be obtained.

The electrostimulation effect is obtained by modulating the current, varying parameters such as frequency, amplitude and duration, to reduce accommodation to the stimulus because accommodation to the stimulus can decrease the sensory perception of the stimulus. Thus, the current with an inhibitory effect has a frequency of 100 Hz, and the current with a frequency of 50 Hz acts dynamically, determining the support of muscle tone, the elimination of edema, the reduction of pain and the increase of muscle tone [1, 2].

Transcutaneous electrical nerve stimulation (TENS) systems are mainly used in medical recovery therapy for pain control [3–6], and some researchers recommend using TENS following thoracic surgery [7]. There are concerns about integrating wearable electrodes into textiles through conductive yarns [8], embroideries [9–11], pads with integrated TENS [12] electrodes [10] for the knee or smart gloves for pain relief in the hand and forearm in cases of carpal tunnel syndrome [13], diabetic neuropathy [14], nerve stimulation for persons with fibromyalgia [15] or rehabilitation in cases of wrist stiffness secondary to distal radioulnar fracture [16].

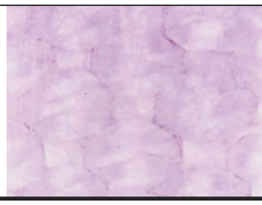
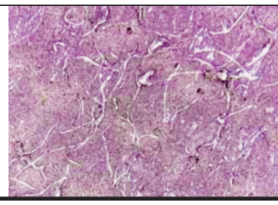
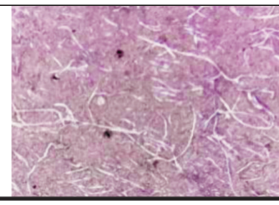
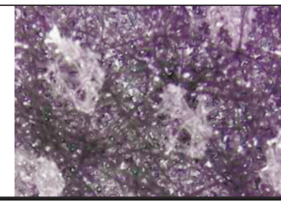
Some researchers have described the use of transcutaneous electrostimulation electrodes based on a conductive surface made by fabric immersion on commercial carbon-based dispersions (AquaCyl AQ0301 based on multiwalled carbon nanotubes (MWCNTs)) [17], electrodes embroidered with conductive wires (X-Silver and X-Static) for electrostimulation in the knee area [18, 19] or nanostructured electrodes based on Ti and Cu [20].

## EXPERIMENTAL PART

Development of the prototypes used textile electrodes obtained by coating the fabrics with conductive pastes based on nickel, which was previously hydrophilized using RF plasma oxygen technology using an RF generator in MHz (Ni1) and kHz (Ni2).

Table 1 shows the images obtained by electron microscopy (magnitude 60x):

Table 1

| ANALYSIS OF THE SURFACE TOPOGRAPHY OF TEXTILE ELECTRODES BY DIGITAL ELECTRON MICROSCOPY (SAMPLES P1, P2, P3, P4) | | | |
|---|---|---|---|
| **Magnitudine 60x** | | | |
| P1 | P2 | P3 | P4 |
|  |  |  |  |

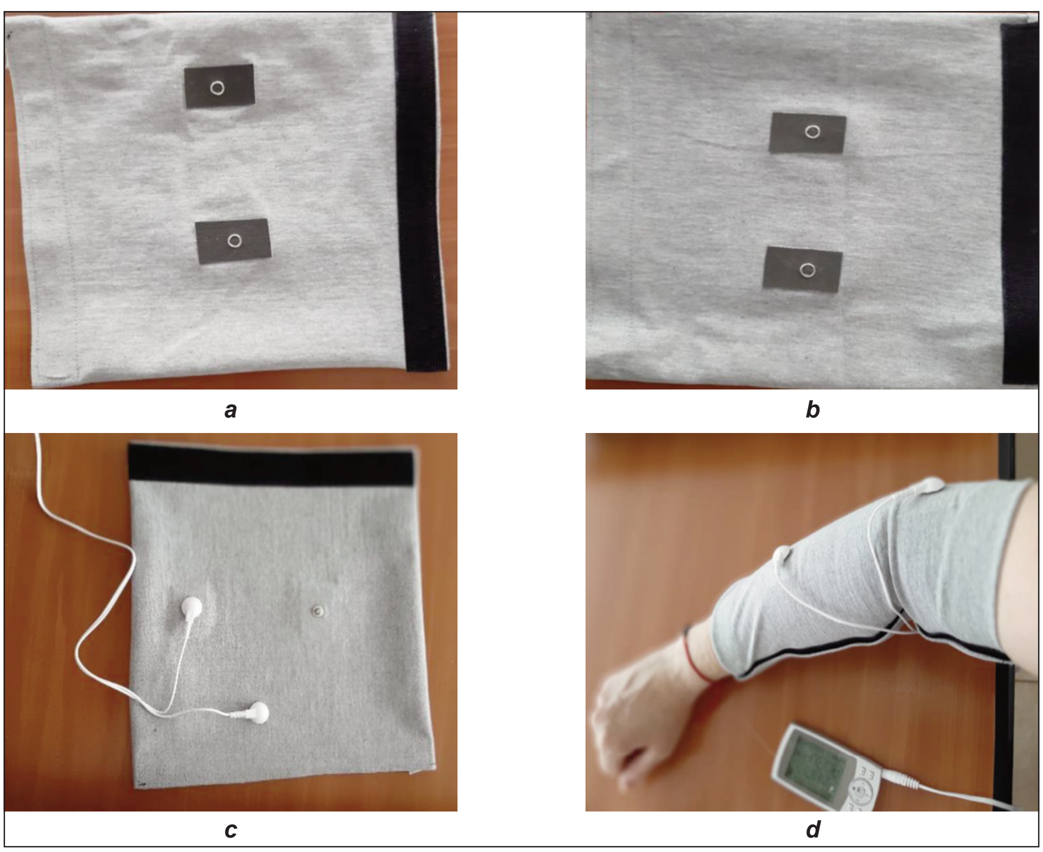
– P1 (raw fabric);
– Electrode P2 based on conductive paste with Ni microparticles deposited on textile P1 (treated in RF plasma $O_2$ using an RF generator in MHz);
– Electrode P3 based on conductive paste with Ni microparticles deposited on fabric P1 (treated in RF plasma $O_2$ using an RF generator in kHz);
– Classic electrode (P4) based on electrode gel.

The textile electrodes P2–P3, having a surface resistance of $10^3$–$10^5$ Ω, were used to develop prototypes M1–M2 by integrating electrodes P2 and P3 into knitted sleeves.

Textile electrodes connected to the transcutaneous electrostimulation (TENS) device (figure 1, *c* and d) using low-frequency (0–100 Hz) (diadynamic or interference) currents were used for testing. Using low-frequency currents can obtain electrotherapeutic effects such as analgesic, neuromuscular stimulation, vasodilator, biotrophic and neurovegetative system (SNV) regulation.

The electrostimulation effect is obtained by modulating the current, varying parameters such as frequency, amplitude and duration, to reduce accommodation to the stimulus because accommodation to the stimulus can decrease the sensory perception of the stimulus. Thus, the current with an inhibitory effect has a frequency of 100 Hz, and the current with a frequency of 50 Hz acts dynamically, determining the support of muscle tone, the elimination of edema, the reduction of pain and the increase of muscle tone.

Depending on the intensity of the transcutaneous electrostimulation program, which is obtained by



*a* *b* *c* *d*

Fig. 1. Electrodes used for the transcutaneous electroneuro-stimulation recovery system (the surface view that comes into direct contact with the skin): *a* – M1 prototype based on $Ni_1$-based textile electrodes; *b* – M2 prototype based on $Ni_2$ textile electrodes; *c* – prototype M1 based on textile electrodes (front view); *d* – testing the M1 prototype

varying the electrical parameters, such as electrical voltage (U, mV), current intensity (I, mA) and frequency (f, Hz), it is possible that the patient feels a slight vibration.

The functionality of the prototypes is based on transcutaneous electrostimulation consisting of generating electrical impulses similar to those produced in the body, which are transmitted to nerves or muscle fibres through electrodes.

The study aims to investigate the data from transcutaneous electrostimulation devices (e.g., voltage, current intensity and frequency) produced during electrostimulation activity and passing the textile electrode barriers. The study's results consist of investigating the output data from the transcutaneous electrostimulation devices (voltage, current intensity and frequency) produced during the electrostimulation activity and passing the textile electrode barriers. To evaluate the prototypes, the current intensity, frequency and supply voltage were measured using multimeters (Agilent Technologies U3606A (figure 2) and PC-Link digital multimeter (figures 3, 4 and 5). Figures 3, 4 and 5 present the waveforms for current intensity, voltage and frequency transmitted through the TENS device using surface electrode textiles. The Oy axis represents the amplitude of the signal and time on the Ox axis.

Figure 6 shows the digital signals (245 samples of frequency in Hz, intensity in mA and voltage in mV) as multiple series.

Figure 7 shows the power spectral density for the spectra of the acquired digital signals (245 samples:

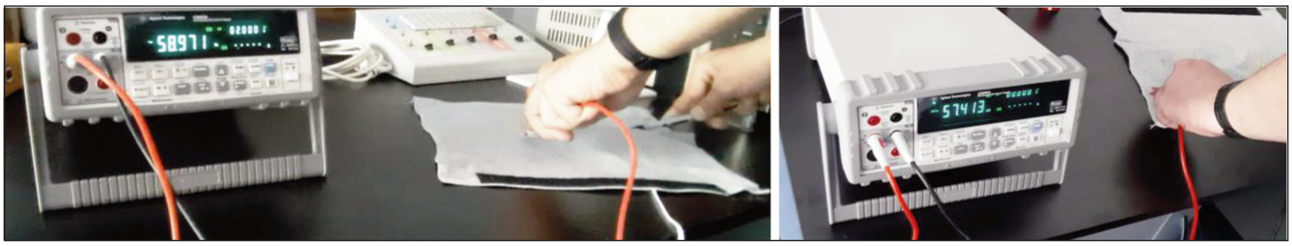


Fig. 2. Determination of the variation of the electric current in the conductive textile electrodes and of the frequency

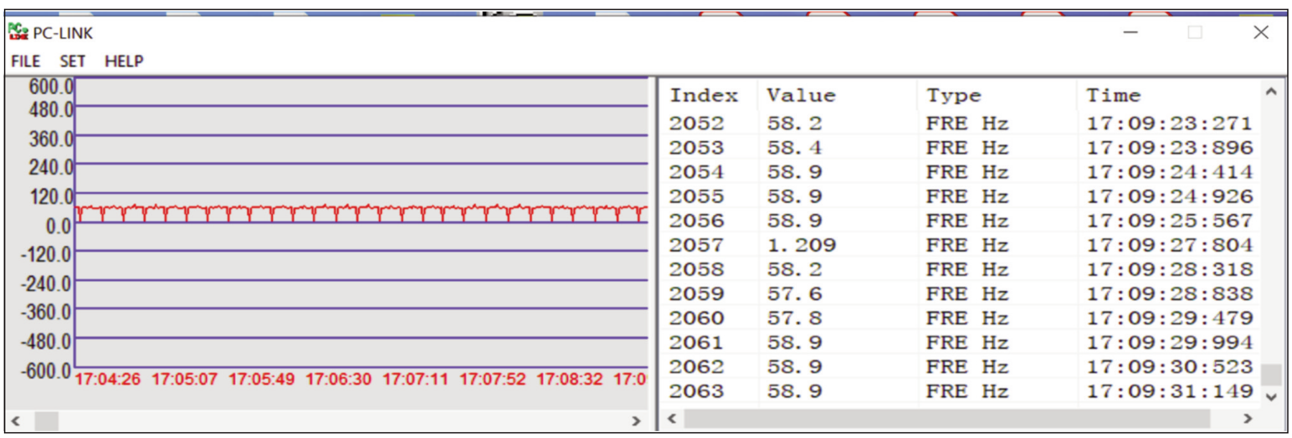



Fig. 3. Frequency measurement using PC-Link graphical view of the acquired digital signal for frequency (f, Hz)

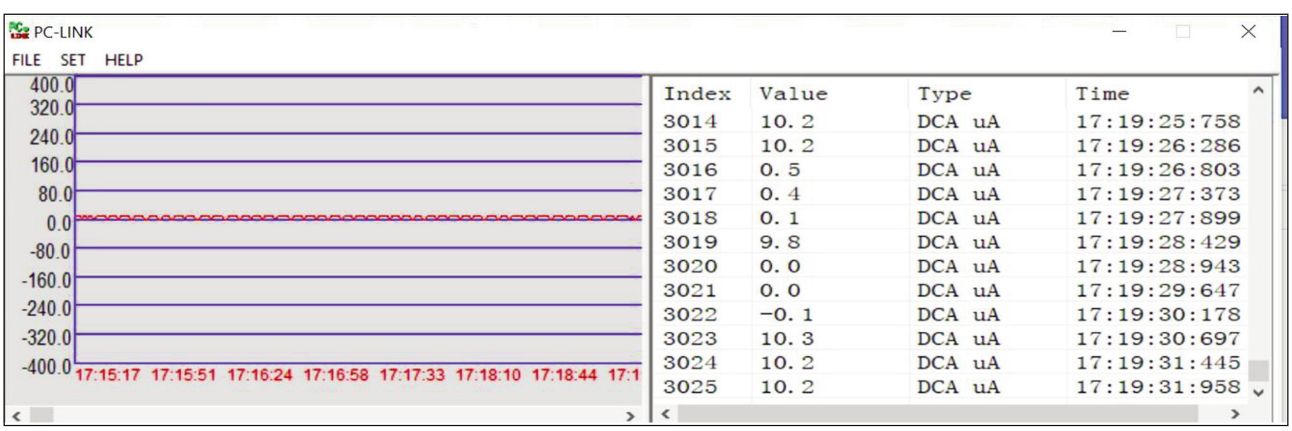



Fig. 4. Current intensity measurement using PC-Link graphical view software of the acquired digital signal for electric intensity (I, μA)

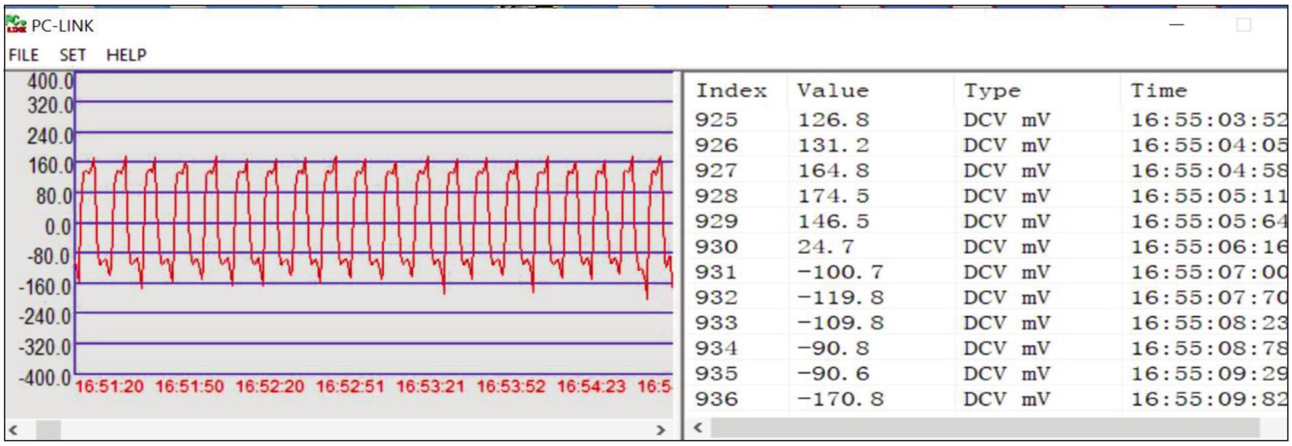



Fig. 5. Measurement of electrical voltage using software PC-Link graphical view of the acquired digital signal for electrical voltage (U, mV)

$f(t)$, $I(t)$, $U(t)$). The spectrum of a signal $X(t)$ (for example, $f(t)$, $I(t)$ or $U(t)$) represents all the components in the frequency domain and is defined by the Fourier transform of that signal:

$$X(f) = \mathrm{F}\{x(t)\} = \int_{-\infty}^{+\infty} x(t) \cdot e^{-j2\pi f t}\, dt \qquad (1)$$

The power spectral density ($S_x(f)$ [W/Hz]) of the signal $X(t)$ represents the power distribution of the components in the frequency domain:

$$S_x(f) = \lim_{T\to\infty} \frac{\overline{|\mathrm{F}\{X_T(t)\}|^2}}{T} \qquad (2)$$

where $X_T(t)$ is the restriction of the random signal $X(t)$ to the interval $[T/2, T/2]$.

## RESULTS AND DISCUSSION

In the test performed using the textile electrodes attached to the arm/forearm areas, the electrical stimuli transmitted by the conductive textile electrodes did not generate pain in contact with the skin. Electrical impulses transmitted to the tissue via textile electrodes affect neurotransmission in neural circuits, synapses, and muscle groups. The effect of electrostimulation is evident after repeating the procedures.

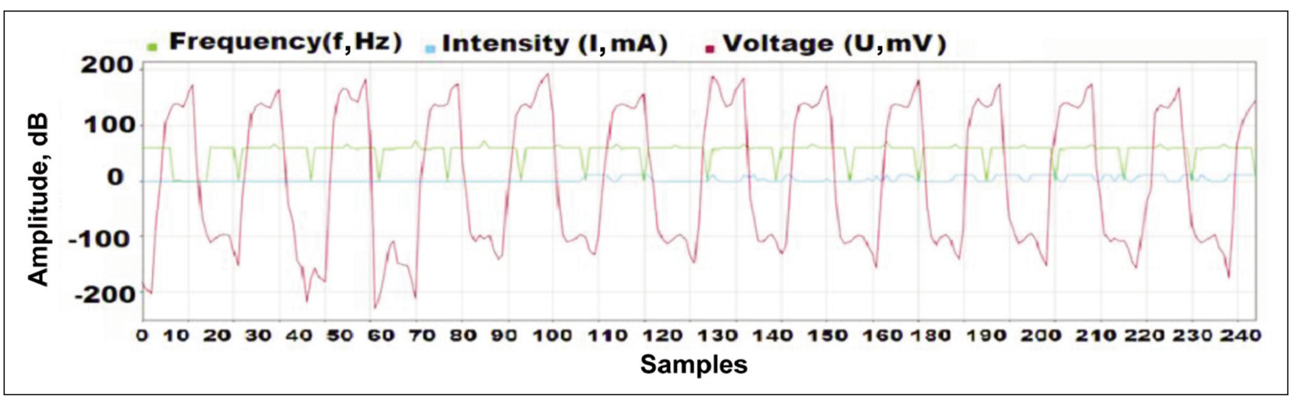



Fig. 6. Digital signals represented as multiple series

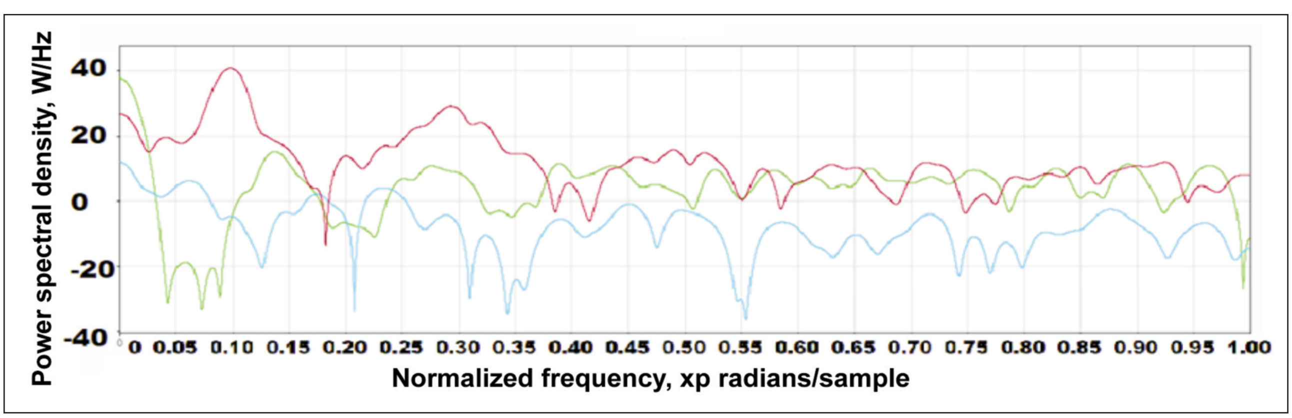



Fig. 7. Power spectral density $S_x(f)$, where $x \in \{f, I, U\}$) of the acquired digital signals $f$, $I$ and $U$ $x\pi$ radians/sample

Overall, it can be appreciated that electrodes made of textile materials remove the disadvantages known in the case of using gel, such as:

1. small amounts of gel may remain stuck to the skin;
2. drying the gel on the electrode makes its use practically impossible.

Testing the prototypes of a knitted sleeve with integrated textile electrodes and a TENS highlighted that transcutaneous electroneurostimulation can be generated using surface electrodes based on textile materials.

## CONCLUSIONS

In conclusion, by analysing prototypes M1–M2, the following can be concluded:

- Textile materials covered with conductive pastes based on a polymer matrix and metal microparticles (Ni) can be used in systems based on actuators as electrodes to transmit low-frequency currents (0–100 Hz) for transcutaneous electrostimulation at the skin level;
- Comparatively analysing the classic (wet) electrodes based on conductive gel and the textile (dry) electrodes, it can be appreciated that the electrodes made of textile materials remove the disadvantages known in the case of using gel;
- Experimental models M1 and M2 (with a surface resistance of $10^3$ Ω) allow better transmission of electric current and are recommended for use as surface electrodes for transcutaneous electrostimulation systems.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