Biopotential Conducting Polymer Electrodes Design and Realization for ECG Measurement

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Abstract: The paper deals with the design and consequent realization of the alternative non-metal bio-potential electrodes and leads made from conductive polymers: polyaniline and polypyrrole. These alternative non-metal biopotential electrodes and leads are intended for measurement of the ECG signal from chest by sensory T-shirt. The electrodes and leads are fixed on the T-shirt for continuous measurement and monitoring ECG signal. The alternative electrodes and leads were tested and compared against Ag/AgCl electrodes and common (metal) electrodes.

1 INTRODUCTION

The ECG measurement has essential role in a clinical practise. On the base of the ECG signal, it can be discovered whether a patient suffers from a heart disorder or heart disease which may not immediately appear. Measuring of the whole 12 lead ECG may not be for certain patients comfortable, can be stressful and requires patient visit on a clinical workspace. The future vision is allowing for measurement of ECG signal from their home. Patient would wear specially adjusted T-shirt with placed electrodes and leads. ECG measurement would goes from their home without presence of medical staff. Practically commonly used bio-potential electrodes (Ag/AgCl) has number of disadvantages as if necessity of electro-conductive gel or paste, inability of their using during CT examination and Magnetic resonance, therefore, from the view of patient comfort and effectivity, they are inappropriate for ECG detection from T-shirt. (Le, 2016), (Vabiral 2011),) (Wang, 2016), (Guttler, 2016) (Augustynek 2011) For this reason, attention should be paid on new materials which could allow for manufacturing alternative bio-potential electrodes for user easy and comfortable ECG measurement by T-shirt. (Cerny 2008, Cerny 2009) One of these materials is conductive polymers. Polyaniline and polypyrrole against other materials have a great advantage. Each surface can be covered by these electrodes they do not require presence of conductive gel or paste and exhibit electric conductivity on the level of semiconductors without any metal in their structure. By this way, electrodes and leads made from polyaniline and polypyrrole would be used even during CT and Magnetic resonance examination. (Peng, 2015), (Penhaker 2013, 2012) (Posada-Quintero, 2016), (Chen, 2016), (Jekova, 2016) (Marek 2015) (Penhaker 2011)

2 REALIZATION OF POLYMER ELECTRODES

After applying standard polyaniline on fabric, this fabric becomes so called polyaniline electrode (PANI electrode). If that fabric is covered by globular polypyrrole, it creates polypyrrole electrode (PPy electrode).

2.1 Fabric Polymerisation by Standard Polyaniline

Standard polyaniline was applied by the following approach:

- For preparation of 100ml standard polyaniline, 2.59 g 0.2M Aniline HCl and 5.71 g 0.25 APS was added.

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- Aniline HCl was given into bowl (50ml) with distillated water. We had Aniline HCl dissolved itself. This approach was repeated also for APS.
- For ensuring even soaking solution into whole fabric and prevention of their movement, it was necessary to fabric stretch and consequently fix on wooden frame.
- Fabric fixed on the wooden frame had to souse several times into aniline HCl solution.
- By this way, we let fabric in solution for 30 minutes.
- After taking 30 minutes, content with APS solution was added to disinfection bowl.
- Fabric fixed on wooden frame was prewashed by reaction mixture until that time than the fabric reactionary colored.

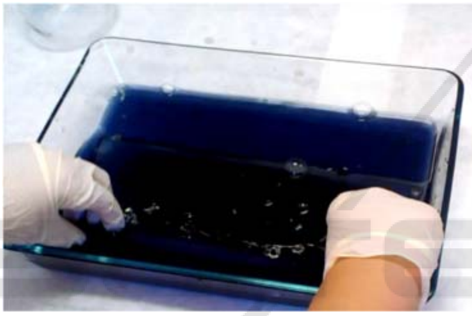

Figure 1: Fabric prewashing fixed on wooden frame in the reactionary mixture.

Figure 2: Cotton fabric covered by standard polyaniline.

Figure 3: Carbon fabric covered by standard polyaniline.

2.2 Electrical Resistance Measurement of Polymer Fabric

Electrical resistance was measured on all polymers fabrics with using of multi-meter ESCORT 3146A and two measuring probes L4130. An electrical resistance was measured in the distance 1, 10 and 16 cm between measuring probes. The resulting resistance was determined as average resistance value from these distances. Resistance values are summarized in Tab. 1.

Table 1: Electrical resistance of all polymer fabrics.

Fabric	Electrical resistance at 1 cm distance\\ [Ω]
Cotton fabric (PANI)	11.10^3
Cotton fabric (PPY)	108
Carbon fabric (PANI)	51

2.3 Adjusting of PANI and PPy Electrodes for ECG Measurement

In order to electrodes allow for easy fixing to chest strap (optionally T-shirt), Velcro was used. Electrodes are made by that way that same pieces were cut from each fabric (with sewn Velcro) with size 2x3 cm.

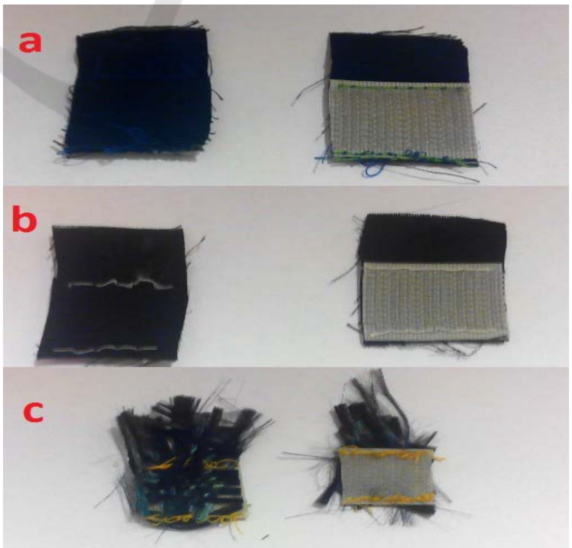

Figure 4: Obverse and reverse (a), PANI cotton electrodes (b) and carbon electrodes PANI (c).

2.4 Adjusting Chest Strap to ECG Measurement

Strap consisted of upper and lower part intended for ECG measurement was made from rubber bandage ESMARCH with size 60x1250 mm. By this way placing of electrodes for consequent one-lead ECG measurement is reached.

Figure 5: Strap with PPy electrodes connected by conductors.

2.5 Testing of Polymer Electrodes

For pilot testing PANI and PPy electrodes, one-lead ECG device with bio-amplifier g.USB were used. The measurement went according to measuring flow chart. Three polymer electrodes of same kind were fixed by Velcro on predetermined spots. Individual polymer electrodes were connected to the bio-amplifier by common wires. One-lead chest ECG on chest was measured step by step with all polymer electrodes (PANI – cotton electrodes, PANI – carbon electrodes and PPy cotton electrodes).

Figure 6: Measurement of one-lead ECG on chest with using of strap.

2.6 Signals and Results Testing

Measured ECG was recalculated on millivolts with using MATLAB software (reflecting real values).

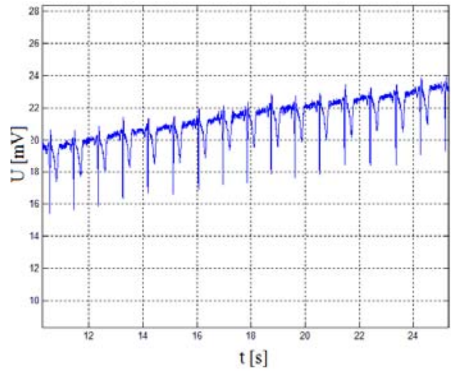

Figure 7: One-lead ECG measured by clip electrode Ag/AgCl.

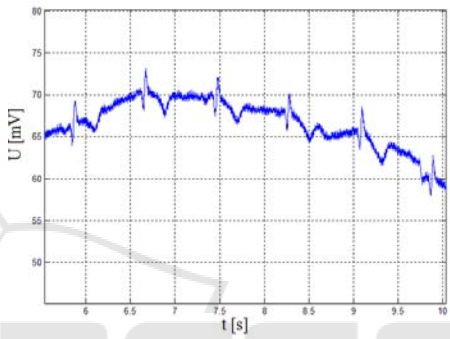

Figure 8: One-lead chest ECG measured by cotton PANI electrodes.

Chest ECG from cotton electrodes (Fig. 8.) is affected by movement artefact.

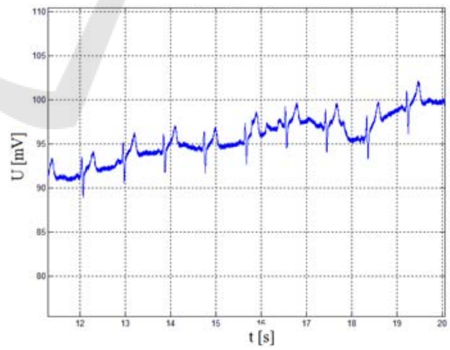

Figure 9: One-lead chest ECG measured by carbon electrodes.

The movement artefact is present on all electrodes (PANI, PPy). After connecting wires via crocodiles, it went to badly fixing of crocodiles, polymer electrodes movement during measurement. This movement caused movement artefacts. For this reason it was necessary to adjust connection between conductor and polymer electrode by the way, so that movement artefacts were eliminated. Crocodile stabilization was performed by adhesive tape. One of the advantages is easy reproducibility of measurement.

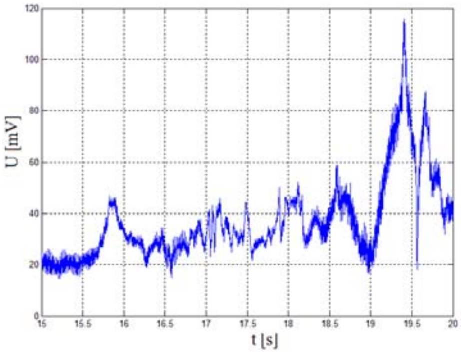

Figure 10: One-lead chest ECG measured by cotton PPy electrodes.

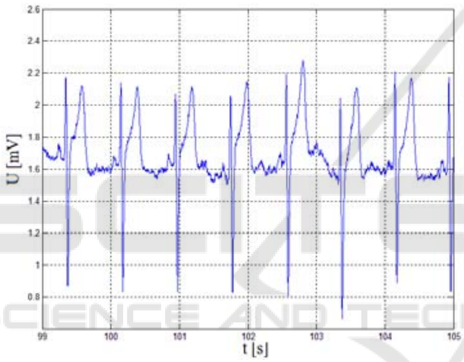

Figure 11: One-lead chest ECG measured by cotton PANI electrodes after adjusting measurement chain.

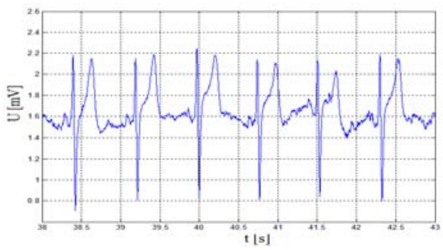

Figure 12: One-lead chest ECG measured by carbon PANI electrodes after adjusting measurement chain.

Individual ECG curves measured by all polymer electrodes were without movement artefacts. Sticking crocodiles to human body electrode movement caused by conductor heaviness was prevented.

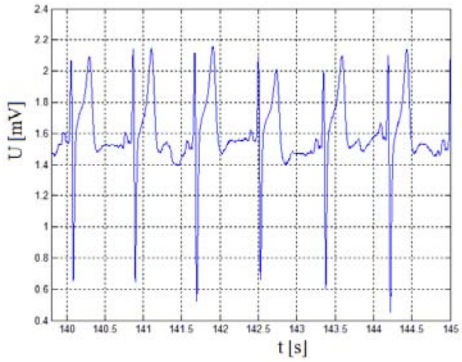

Figure 13: One-lead chest ECG measured by PPy electrodes after adjusting measurement chain.

Since chest ECG was measured by polymer electrodes and limb ECG was measured by clip Ag/AgCl electrodes, it was not possible to compare measured ECG values. They were not measured from a same spot and measurement by polymer and Ag/AgCl electrodes did not go in the same time, thus individual ECG signals can be different in pulse having significant influence on ECG signal.

2.7 Summarization of Chest and Limbs Measurement

On the base of the ECG curves is obvious if we ensure sufficient pressure (contact) of polymer electrode with skin, ECG can be measured with accuracy comparable as if Ag/AgCl electrodes. This fact is proved by correlation coefficient (Tab. 2.) from limbs measurement where we ensured sufficient contact with skin.

Table 2: Correlation coefficients comparison for chest and limbs measurement.

Polymer electrode	Correlation coefficient - chest	Correlation coefficient - limbs
Cotton PANI	0.9332	0.9944
Cotton PPy	0.9515	0.9935
Carbon PANI	0.9349	0.9835

Correlation coefficients for cotton PANI and PPy electrodes were around 0.99. These correlation coefficients are generally much greater than for chest measurement where the highest correlation coefficient (0.95) was achieved on cotton PPy electrode.

3 DESIGN AND REALIZATION OF T-SHIRT FOR ECG MEASURING

A reliable T-shirt for ECG measurement should be slim and copy shape of human body, so that pressure of polymer electrodes to body would increase. For achieving required contact polymer electrode with human body, bandages were sewn to given spots of T-shirt (upper part of chest and stomach area).

PPy cotton electrode (2x2 cm) was fixed to Velcro. PANI carbon conductor with length 60 cm isolated by tubule was placed between electrode and Velcro and firmly connected with electrode. Velcro was used for easy undoing electrodes from bandage.

Figure 14: T-shirt with stich bandage and placed polymer electrodes.

3.1 Prototype T-shirt Testing

Three PPy electrodes with isolated PANI conductors were fixed by Velcro on defined T-shirt spots. Close to PPy electrodes, disposable stick AG/AgCl was stick which was connected via common wires with second one-lead ECG. Both ECG devices were connected to same A/D converter which was connected with PC. ECG in stable position and during selected movements (run, gait and knee-bend) was measured by such measuring chain. Run and gait simulation were simulated on one spot due to short conductor length.

Figure 15: Measuring chain for measuring one-lead ECG from T-shirt by PPy cotton electrodes with PANI carbon conductors and in the same time by stick Ag/AgCl electrodes (placed on the human body) with common wires.

3.2 Measurement Results

For objective comparison of two measured and recalculated ECG curves. Such time interval was selected, so that it contains 10 ECG curves detected in the same time as if PPy cotton electrodes with PANI carbon conductors. From these extracted ECG curves, their difference and correlation coefficient was calculated. Maximum, minimum, average value and dispersion of calculated difference were calculated as well. In the case of movement simulation, recalculated ECG curves were drawn to graphs.

ECG curves in sitting position measured in the same time by PPy cotton electrodes with carbon PANI conductors and stick Ag/AgCl electrodes (placed on human body) and common wires and graph of the calculated difference of both extracted and recalculated are shown on Fig. 16. ECG curve measured by Ag/AgCl electrodes with common wires is shifted about +1.2 mV, so that do not cover itself with measured ECG signal by PPy cotton electrodes with PANI carbon conductors.

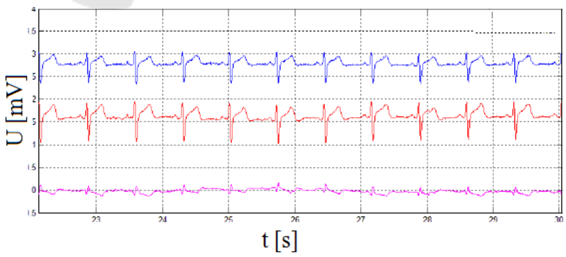

Figure 16: ECG curve in sitting position, common Ag/AgCl electrodes (blue), PPy cotton electrodes (red) and their difference (violet).

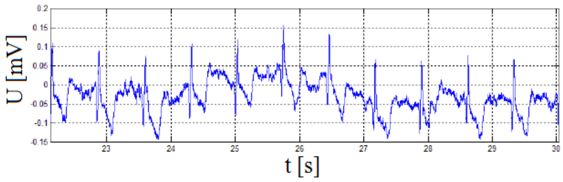

Figure 17: Curve of ECG signals difference.

The statistical results of ECG measured simultaneously from T-shirt by PPy cotton electrodes with PANI carbon conductors and stick Ag/AgCl electrodes (placed on body) with common conductors are summarized into Tab. 3.

Table 3: Statistical parameters of sitting position by PPy cotton electrodes with PANI carbon conductors and stick Ag/AgCl electrodes with common conductors.

Calculated parameter	Parameter value
Maximum of difference	0.15 mV
Minimum of difference	-0.14 mV
Average value of difference	-0.031 mV
Dispersion of difference	0.0021 mV
Correlation coefficient	0.96

4 FINAL CONCEPT OF T-SHIRT FOR ECG MEASUREMENT

The first T-shirt prototype did not allow for one-lead ECG measurement during exercising given activities representing common physic load. One of the causes could have been moving connection of polymer conductors and crocodiles. The second cause could have been decreased contact of electrode fixed to lower bandage placed to lower T-shirt part. On the base of these circumstances, it was approached to design of final T-shirt prototype for ECG measurement with directly placed Velcro on T-shirt without using of bandages. Velcro was placed close to right and left breast and to the area between chest and hip-bone. Connection of PPy cotton electrodes and PANI carbon conductors were same as in the previous case, only there is the difference of isolation. Electrical isolation was performed by electrician tubing. The design of final T-shirt prototype for ECG measurement is depicted on the Fig. 17.

Figure 18: Final design of T-shirt prototype for ECG measurement.

5 CONCLUSIONS

The main aim of our research was design and practical implementation of the polymer bio-potential electrodes including their leads with using conductive polymers of polyaniline or polypyrrole. Final output is the T-shirt prototype intended for continual detection and monitoring of ECG signal. Electrodes were manufactured from cotton fabric with polyaniline, cotton fabric with polypyrrole and carbon fabric with polyaniline. All three types of electrodes were compared from the view of detected and transmitted signal quality against common Ag/AgCl electrodes with electro-conductive gel. All electrodes allowed for ECG measurement from both chest and limbs. The best results from the view of quality and amplitude strength were achieved by PPy cotton electrodes.

On the base of the polymer electrodes and conductors testing it was approached to realization of polymer electrode and polymer conductor connection and their placing on the T-shirt. The best results during testing were achieved by PPy cotton electrodes and PANI carbon conductors, therefore, the most optimal combination of these electrodes was selected for ECG measurement by T-shirt.

Our research contributes to manufacturing of new non-metal polymer electrodes and conductors. ECG measurement from T-shirt was successfully tested in lab conditions. We achieved good results (conformity 96.7%) on sitting position. On the other hand, ECG results during performing of predefined exercises we achieved results affected by artefacts. The significant movement artefact could have been caused by technological fixing of polymer electrodes and connecting polymer conductors with lead conductors of ECG device. The possible direction of future polymer work could be testing on CT (Computer Tomography) and MRI (Magnetic resonance), multi-lead T-shirt realization and ensuring of resistance against movement artefacts.

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