Observations Concerning the Results of Capacitive Monitoring of Breathing and Heart Rate by the Means of Electrical Bioimpedance

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***Abstract*—In this paper, some observations concerning the capacitive measurements of respiratory and cardiac activity of human by using a custom made wearable measurement device – electrode shirt – in the form of electrode shirt, are discussed. Electrode shirt is described and the results of the measurements are presented together with the charts of the signals. The related aspects, originating from the observations, concerning the measurement results and the design of electrode shirt, have been characterized. The conclusions are made, related to the electrode positions and the availability of breathing and heart rate.**

Keywords—electrical bioimpedance; breathing measurements; capacitive measurements; heart rate measurements

I. INTRODUCTION

The monitoring of vital signs of human has already became a key topic in personal healthcare. The reason is the popularity of smartphones through the development of the technology, the growth of the interest to the personal health etc. The following of breathing and heart rate (HR) and thus, the gathered data, can be used to assess the overall condition of the human body. The totally new outputs unclose for the medical doctors to follow the health of the patients from distance, for football coaches to follow the status of the players on the ground etc.

Electrical bioimpedance (EBI) is a tool that proposes a possibility of monitoring the vital processes of human – it is used to describe the response of the living organism to an externally applied electric current or voltage [1]. The fact that these processes are variable makes it possible to follow the periodic changes in organs by measuring the EBI [2].

The variation in the volume of lungs during the in- and exhalation is causing the impedance of trunk to change – caused by breathing. The same effect can be seen in the case of HR – the conductive properties of the blood in the environment of relatively nonconductive tissues open the possibility to monitor the periodic changes. These changes can be caused by the variation of the diameter of the blood vessels because of the pulsating blood or directly near to the heart.

The usage of EBI for monitoring the vital signs is a subject of number of papers. A topic of the research has been the selection of the suitable positions for the electrodes on the trunk for monitoring the respiratory activity [3], the influence and the reduction of the effect of motions in the case of impedance pneumography [4], the study of the changes of impedance of the body, caused by breathing and HR [5] etc., i.e. the aspects of the measurements of EBI. Also, the ideas of wearable measurement devices have been research and prototypes prepared by many research groups.

Nevertheless, there is no readymade device available that is able to detect the cardiac and respiratory activity of human by using large plate surface electrodes in capacitive connection. The problems, discussed in current paper, relate to some important aspects which appear during such measurements – the influence of motions, the availability of HR etc.

For the experiments, a custom made measurement device in the form of electrode shirt (ES), containing 15 different electrode placement configurations (EPC), was prepared. A number of measuring experiments were carried out and the best ones were selected. The results of the measurements and an exhaustive discussion of some observations are introduced. All the described operations are directed to the design of wearable device for capacitive measurements of EBI.

II. DEVICES AND PROPERTIES

As a measuring device, HF2IS impedance spectroscope of Zurich Instruments with HF2TA trans-impedance amplifier was used in the experiments. The specification of these devices defines the frequency range up to 50 MHz using either two- or four-electrode measurements [6].

Single types of electrodes were used in experiments: large wet plate surface electrodes of type 22 4773 Electrosurgical Grounding Plates by Niko Medical Products. The contact surface of the electrode was of dimensions 80 mm x 170 mm, made of aluminum foil and covered with contact gel.

III. METHODS

A previously prepared custom made wearable measurement device – ES was used in the experiments (Fig. 1 and 2). ES is a cotton shirt of thickness of 0.5 mm, covered by

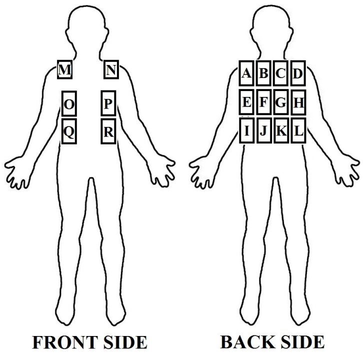

Fig. 1. Position of the electrodes on the electrode shirt [7].

Fig. 2. Picture of the electrode shirt.

large wet surface plate electrodes according to chosen concept. The locations of the electrodes were selected in a way that the whole back, shoulders and the sides of the trunk were covered with the goal of accessing the data of breathing and HR.

Altogether 18 pieces of indexed electrodes were used in the ES (Fig. 1). The indexing was needed to combine the electrodes into different EPC's and make the later documentation and analyse easier.

Fifteen different EPC's were experimented (Table I). In cases where there were more electrode positions used for one operation (measuring or exciting), electrodes were connected together with wires to achieve the required EPC's.

All the measurements were done by using four-electrode method at the frequency of 10 MHz and excitation voltage with the amplitude of 500 mV. The choice of the relatively high excitation frequency is explained by the properties of the ES – the shirt was a commercial cotton shirt of regular fit that is not in reliable contact with the skin. The peculiarities of capacitive connection were expected to appear. To artificially increase the capacitive element, another cotton shirt of thickness of 0.5 mm was placed under the ES.

In the experiments, only a single individual was employed. As the locations of the parts of respiratory and circulatory systems in human body are, with small differences, the same, this is acceptable.

IV. Measurement Results

A number of measurement experiments were carried out by using different EPC's. As the outcome of the measurements, the real part (ReZ) of total impedance (modulus |Z|) was used as an instantaneous value without calculations. This was chosen because of the property of biological objects to have mostly active character [8].

The assumption for the measurements was: the pulsation of the blood flow in the blood vessels and the change of the volume of air in the lungs during breathing are causing a portion of measured ReZ to change. The object was dressed into the ES and asked to fulfil certain program of movements.

To evaluate the EPC's, two parameters were retain [7]:

1. the ratio of change of ReZ, caused by the respiratory and cardiac activity of total ReZ;
2. the ratio of change of ReZ, caused by the respiratory and cardiac activity of the interval of ReZ, caused by motions.

The results of the measurements can be seen in Table I. The table shows the results of breathing and HR separately: the ratio of change of ReZ, caused by breathing and HR of total ReZ; the ratio of change of ReZ, caused by breathing and HR to interval of ReZ, caused by motions [7].

TABLE I. The Results of the Measurements with the Electrode Shirt [7]

EPC. nr.	EPC	Ratio of breathing from total ReZ (%)	Ratio of breathing from interval of ReZ of motions (%)	Ratio of HR from total ReZ (%)	Ratio of HR from interval of ReZ of motions (%)
1	Exc. MN and IJKL, meas. ABCD and EFGH	44 - 83	34 - 71	0,3 – 0,7	0,4 – 0,7
2	Exc. AEIN and DHLM, meas. BFJ and CGK	54 - 90	34 - 50	0,6 – 1,0	0,1 – 0,2
3	Exc. MN and OP, meas. ABCD and EFGH	66 - 90	80 - 90	1,6 – 5,3	1 – 4
4	Exc. O and P, meas. ABEFIJN and CDGHKLM	33 - 62	56 - 87	0,5 – 2,0	0,9 – 1,3
5	Exc. NP and MO, meas. ABEFIJ and CDGHKL	21 - 62	77 - 83	0,7 – 3,0	1,5 – 8,3
6	Exc. AB and KL, meas. CD and IJ	40 - 60	34 - 48	0,4 – 0,8	0.6 – 1,0
7	Exc. NA and MD, meas. B and C	32 - 42	7 - 10	0,4 – 0,8	0 – 0,1
8	Exc. NPR and MOQ, meas. EFIJ and GHKL	64 - 90	44 - 90	1,4 – 3,6	0,7 – 1,8
9	Exc. EFIJ and GHKL, meas. O and P	80 - 90	43 - 70	1,5 – 3,6	0,4 – 0,9
10	Exc. NPR and MOQ, meas. ABEFIJ and CDGHKL	21 - 27	21 - 30	0,5 – 1,2	0,6 – 1,4
11	Exc. NPR and MOQ, meas. FJ and GK	38 - 90	44 - 90	0,2 – 0,7	0,4 – 0,7
12	Exc. PR and OQ, meas. ABCD and IJKL	74 - 90	24 - 30	1,2 – 2,2	0,2 – 0,3
13	Exc. MN and OPQR, meas. ABCD and IJKL	28 - 90	80 - 90	1,2 – 2,3	2,0 – 8,3
14	Exc. MN and OPQR, meas. EFGH and IJKL	47 - 90	50 - 90	1,3 – 2,2	0,9 – 1,0
15	Exc. BFJ and CGK, meas. NPR and MOQ	73 - 90	51 - 59	0,7 – 0,8	0,2 – 0,3

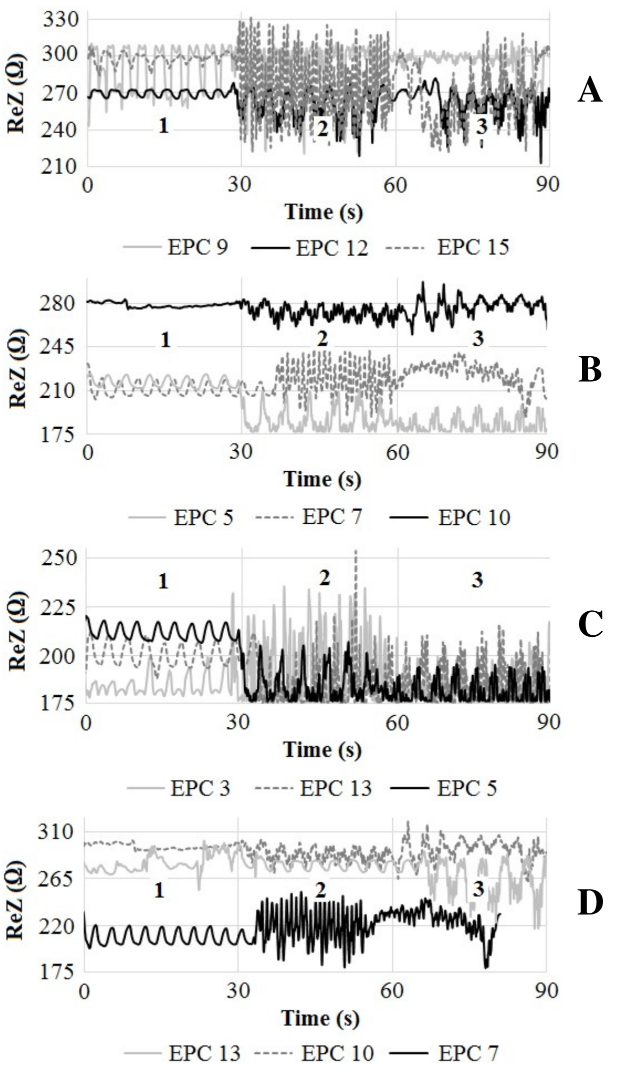

Fig. 3. Comparison of 3 best (A) and 3 worst (B) results of measurements of breathing of parameter 1 and 3 best (C) and 3 worst (D) results of measurements of parameter 2 in the cases of deep breathing (1), squatting with deep breathing (2) and splurging the hands while holding the breath (3).

In current paper, the results are presented in percentages, separately for respiratory and cardiac activity, showing the outcomes of repeated measurements for each EPC. The reason is the high dependability of the measurement results to motions and the variation in wide range.

The best and worst results of breathing concerning parameter 1 are EPC's 9 and 10 respectively. The best and worst results of the same parameter of HR are EPC's 3 and 1. The best and worst results of breathing concerning parameter 2 are EPC's 3 and 7. The best and worst results of the same parameter of HR are EPC's 13 and 7. During the experiments, the sets of data were gathered and saved for later generation of the illustrative charts. The charts are composed of 3 best and 3 worst results and can be divided in two groups: respiratory activity and cardiac activity.

Breathing is visually available in majority of the cases of charts. Nevertheless, the amplitude of HR is low enough to disappear in the cases of representing it in the same scale with

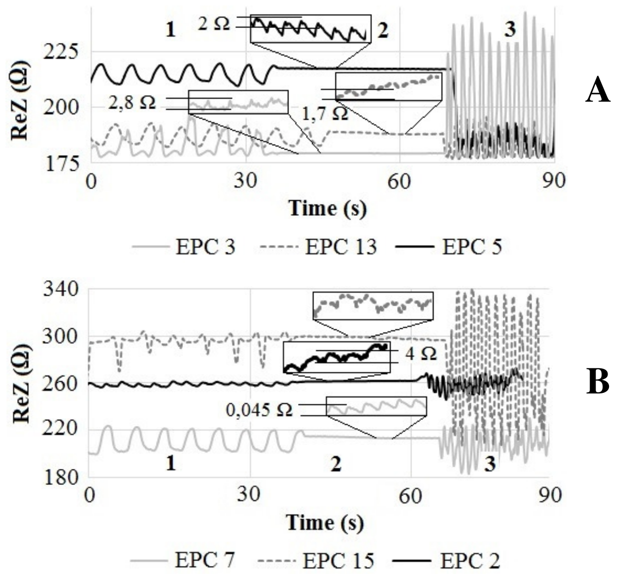

Fig. 4. Comparison of 3 best (A) and 3 worst (B) results of measurements of HR of parameter 2 in the cases deep breathing (1), standing still while holding the breath (2) and imitating the swimming while holding the breath (3).

the affection of the movements (Fig. 4). For this reason the magnification of the shape of the signal of HR is shown in bordered box nearby. This is the reason, why only two charts, representing the three best and three worst results of parameter 2 (Fig. 4), are shown in current paper.

V. Discussion

The results can be evaluated according to Table I and Fig. 3 and 4. Subsequently, some relevant aspects and observations are discussed in the frames of the usability of experimented EPC's in a lineup of wearable measurement garment. The thorough analyze of the represented results is available in [7].

The information in the table can be misleading in some aspects – mainly in the numerical and visual representation of the results. Namely, according to Table I an EPC may belong, concerning a chosen parameter, among the worst ones, but shows in visual checking a very distinctive representation of result. As a sample, EPC 7 can be named, showing the visually clear cycles of breathing in the case of deep breathing but obscuring totally the possibility of identifying the same process in the case of squatting with deep breathing (Fig 3, chart D).

The reasons for this phenomenon may be different and depend on the choice of the placement of the electrodes. One of these can be that, in EPC 7, the configuration of exciting at both of the shoulders and measuring at the center of the back, is used. The assumption is: during the squatting, the object held his hands outstretched, while during the standing, the hands were hanging vertically of the trunk. The position of the ES might have dislocated or continuously changing its position relative to the skin surface and interfering the results by varying the value of capacitive element of the connection with the body.

Second important observation hereby is the measurement result of breathing in the cases of splurging the hands while holding the breath (Fig. 3, charts A and B, part 3). During the experiments, it was seen that splurging the hands can be used to imitate breathing while holding the breath during the measurement of impedance. By analyzing the charts, this can be observed in the case of EPC 5 (Fig. 3, charts B and C), splurging of the hands clearly resembles the shape of the signal of deep breathing. At the same time, in the case of EPC 9 (Fig. 3, chart A), the shape of the signal, caused by splurging the hands is visually clearly distinguishable from deep breathing.

One of the reasons for the described property is assumed to be the same as already presented in this chapter – the displacement of the ES is causing the measured impedance to vary because of the periodical movement of the hands. Nevertheless, the reason might also be anatomical – splurging the hands stretches the lungs and increases its volume. The outcome might be the same that can be seen in presented charts: the change of the measured value of ReZ of the trunk that, in visual study, seems to represent breathing. A research of this phenomena is described in [9], where a specific six-electrode configuration is utilized to suppress the body related movements.

When designing a wearable measurement device in the form of garment, more than one EPC for following breathing or HR is suggested to be utilized. If a person, wearing the garment, is moving, the clothing is most probably dislocated. In some body positions, some EPC-s may be able to access the data of respiratory and HR, in other positions, the other EPC's may be usable to achieve the beneficiary signal.

Another important aspect binds to the results of the measurements of HR. The difference between the maximum and minimum values of the peaks of waveforms, caused by the respiratory and cardiac activity, are large and not visually available in the same scale – shown already in [7]. The latter fact can be seen in Fig. 4 (charts A and B), where the comparison of cardiac activity with the signals of breathing and affection of motions is visible. The analyze of Table I concerning parameter 1 of HR shows that it is reasonable to assume that the cardiac activity is available on top of the waveform of breathing and also on top of the waveform of motions. By taking a close extract of the signal, this corresponds to the truth (Fig. 5).

The latter observation gives a promising base for the hope that, by the help of signal processing, HR can be detected. Nevertheless, it can be assumed that during the intensive moving of the body, the motion artefacts are still interfering the signal of HR. The suggestion is, that the extracting should not be implied to be done continuously – the algorithm can be set to follow the shape of the signal and detect HR periodically. The idea is to recognize the starts of the potentially fatally interfered periods of time of the signal and tell the machine to hold the last value.

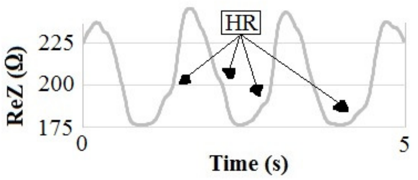

Fig. 5. A snapshot of the result of the measurements by using the EPC 3 with showing the visible peaks of HR in the case of imitating the swimming while holding the breath.

VI. Conclusions

A number of conclusions were presented, related to the results of the experiments and the described observations. The capacitive measurements of EBI of the trunk of a human by using a custom made ES demonstrated the availability of breathing and HR. The visual availability of beneficiary signal may differ from the numerical result – the reason is assumed to be the displacement of the shirt during the movements. The splurging of the hands while holding the breath may generate a waveform that resembles breathing. The signal of HR is available even in the case of movements of the body – it is carried by the larger waveform and is suggested to be extracted by using special algorithms.

The novelty of the current paper can be found from the usage of wet surface plate electrodes, attached on a cotton shirt as capacitive measurement devices, for monitoring EBI. Several EPC's were experimented to evaluate the availability of breathing and HR and a number of related aspects were discussed.

The plans for the future include the preparation of the next version of the ES, where the electrodes are placed onto the best known placements, presented also in this paper. The discussed observations and ideas will be keep in mind together with the ideas of varying the size and type of the electrodes. The long-term and already ongoing task is to develop an electronic device, installed into the garment, for monitoring the impedance of the trunk to determine the breathing and HR.

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