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Respiratory signal of bathing person - preliminary study *

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***Abstract*— The scope of this paper is analysis of applicability of modern biomedical acquisition system installed in bathtub towards reception of respiratory signals of bathing person. An analysis of the possibility of such measurement is shown as well as preliminary results.**

I. INTRODUCTION

Bathtub is a commonly utilized bathroom device in order to maintain hygiene or for relaxation purposes. In spite of the fact that nowadays a shower's usage is increasing the bathtub still plays a significant role in a daily life. Unfortunately, bath in the tub aside being a dangerous activity is also an intimate one. There are several reports on accidents during bath [1], [2]. Since the most of dangerous situations could also happen when the bathing person is alone there should be a method to pass an information about her/his vital signs and recognition and fast reporting of dangerous situations. Thus, a kind of supervision is a valuable solution taking into account possible effects. It is essentially important and invaluable when considering elderly or partially disabled people [3]. However, it should be taken into account that camera-based solutions are not acceptable. In result, other innovative solutions has to be considered.

The most widely used technique for person monitoring during bath is probably measurement of an electrocardiographic (ECG) signal remotely [4]. There are several attempts to built-in ECG electrodes in the bathtub. A capacitive coupling of the measurement electrodes to water was considered also as the way to hide them from the tub user and in result to make the measurement procedure unobtrusive to the bathing subjects and thus increase a comfort of basing person [5]. It could be expected that as the heart is moving inside thorax due to a respiration activity an amplitude of a QRS complex would be modified as a result [6]. Thus, a respiratory activity should be possible to be monitored also.

There are also several techniques applicable for person detection including scaling, pressure of the bathtub bottom monitoring [7] and impedance of bathtub infill measurement [8], [9]. It has been also shown that bioimpedance spectroscopy is a powerfull technique enabling detection of the living tissues presence in the bathtub despite various ingredients added to the water [10]. It has been shown that bio-impedance technique has significant advantage on=ver others as differentiating biological tissue from other. Thus, in combination with the ECG monitoring it enables recognizing the situation when the person stays in the tub and ECG signal is not available. Moreover, the bioimpedance technique is also widely recognized as a diagnostic tool for cardiac output estimation and also for the respiratory system diagnosis. These properties are also promising when considering the future development of signal processing methods that would lead to an increased confidence in the system.

II. MATERIALS AND METHODS

In order to measure respiratory activity an ordinary however, a slightly modified bathtub was used. It was modified by attaching several silver electrodes at its walls. Multiple number of electrodes allows an easy testing and evaluation the best electrode array configuration.

It was noticed, during experiment performed, that the ECG signals was easy to measure when water level was over the heart level. Unfortunately in the most cases bathtub infill is much less. This reduces significantly the measured signal and makes its interpretation difficult. However, adequately developed hardware allows such measurements. The various kind of ECG measurement circuits from custom made amplifiers with gain up to 20000 and narrow shaped bandwidth to commercially available integrated biomedical acquisition systems were examined. For the purpose of this paper a measurement system composed of MAX30001 [11] and the MAX30001 EVKIT [12] was developed. This is an integrated solution with complete ECG and a four electrode bio-impedance acquisition system. ECG measurement is also equipped with a hardware QRS detection circuit. ECG data are available with 18-bit resolution via SPI bus. Bio-impedance data are acquired with 20-bit resolution.

Measurement setup utilized in the study consisted of appropriately adapted tub, above mentioned measurement system and a computer Figure 1. As a respiratory control unit a thermistor mounted in an inhalation mask was used. Then resistance of the thermistor was measured using PIC12F1840 microconroller and sent to the PC by means of UART to USB converter (FTDI). Breathing control mask was mounted on the face of bathing person as whole airflow both for air intake and outtake must flow around thermistor.

Breathing control mask was mounted on the face of a bathing person as whole airflow both for air intake and outtake must flow around thermistor. To measure ECG and bio-impedance the MAX30001 evaluation board was used. It enabled simultaneous measurement of the ECG signals and bio-impedance by means of 4-electrode technique. We

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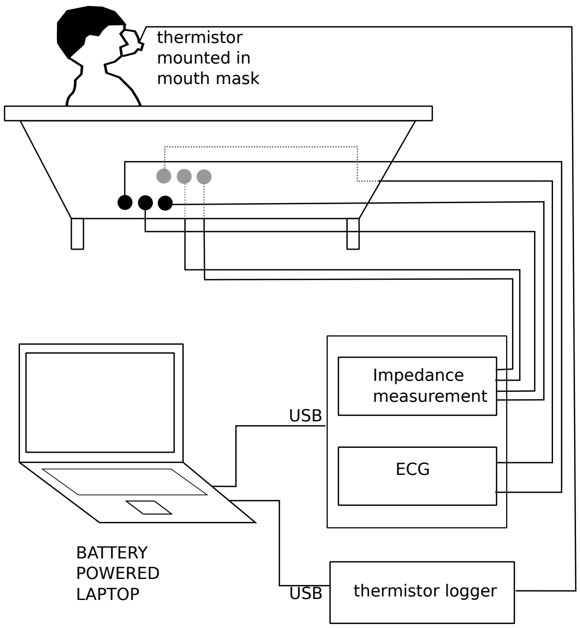

Fig. 1. Block diagram of measurement setup

have utilized separate silver electrode array for ECG and bio-impedance measurements. They were conducted using a variable electrode position and body posture. We used average water level inside bathtub - approx 30 centimeters without person inside the tub. Water level allows fully cover straight legs by the water during sitting position(see Fig. 2) and additionally fully cover thorax when person was lying down (as in Fig. 6).

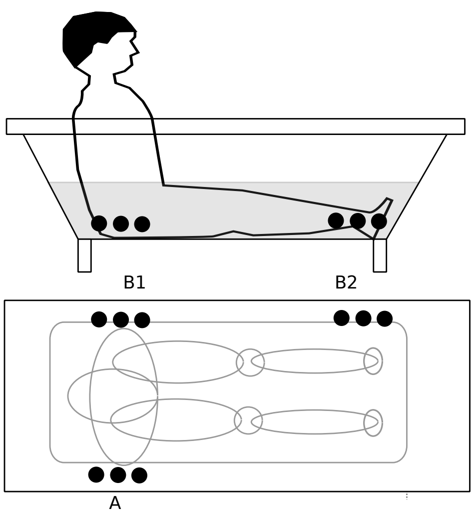

Fig. 2. Electrode positioning, body posture and bathtub infill for measurements in sitting position

In all cases the measurement setup consisted of a battery powered laptop for data collection and no other units were powered from the mains network to maintain the bathing person an electrical safety. During all experiments additional person was assisting the bathing one to assure safety and perform measurements. Data were collected into CSV file

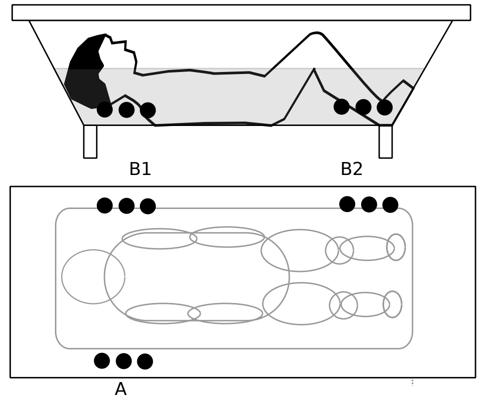

Fig. 3. Electrode positioning, body posture and bathtub infill for measurements in lying position

with maintained time synchronization with events.

ECG signals were recorded using $128Sa/sec$ sampling rate, the bioimpedance signal was sampled $64Sa/sec$ while thermistor resistance was monitored with $100Hz$ sample rate. MAX30001 allows to select frequency for bioimpedance measurement. In Experiment a frequency of 81kHz was used.

During measurements volunteer was asked to reduce whole body movements to minimum, relax and breath normally. Accidentally volunteer has been asked to hold breath for few seconds and perform a rapid breathing to allow better visualization of synchronized data series.

A. Data processing

All sampled data were stored in CSV vectors which included also a time information. It enabled tie synchronization for the measurements. Recorded files contained automatically detected R-R episodes, however data observation during measurements indicated malfunction of automated R wave detection inside MAX30001. Resulting, for further data analysis Pan-Tompkins[13] algorithm was used for the QRS complex detection. Detected R-waves allow measurement of QRS complex amplitude. A custom Octave script prepared by Hooman Sedghamiz was utilized. Script is available in the Internet and contains detailed explanation on QRS complex amplitude calculation [14].

During acquisition data and configuration of the electrodes were described in separate text file.

The time of R-wave out of ECG signal and amplitude of the QRS complexes were collected in a separate table. As obtained data were non-uniformly sampled - for further analysis they were interpolated and uniformly re-sampled by means of spline interpolation.

Additionally bio-impedance and thermistor data were re-sampled to achieve the same sampling frequency ad ECG signal. It allowed to perform frequency-domain analysis of recorded signals as well as time-domain.

III. RESULTS AND DISCUSSION

Preliminary bath session was performed and data were collected. Exemplary ECG recordings for sitting and lying position are collected in Fig. 4. In experiment ECG signal was recorded 45 seconds in still position sitting in bathtub following change position to lying. During transit period recorded signal contained high amplitude motion artifacts and it is noticeable that QRS amplitude in lying position is greater from one noticed for sitting pose. During measurements it was noticed that MAX30001 tends to miss R-peaks however it performs better for huge signal changes.

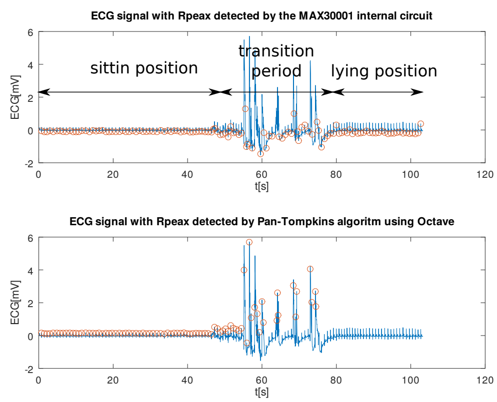

Fig. 4. ECG data versus body posture. Circles are indication detected R-wave using MAX30001 hardware and Pan-Tompkins algorithm

In Fig. 5 comparison of the ECG signals for lying and sitting position is done. For measurement performed in sitting position overall amplitude of signal is weaker but T-waves are noticeable and overall signal quality is good.

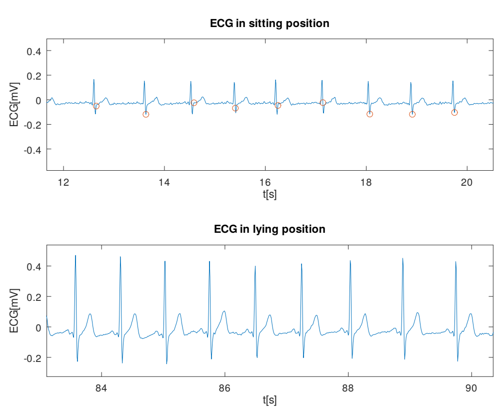

Fig. 5. Measured ECG signal with detected QRS episodes using Pan-Tompkins algorithm

Figure 6 is showing corresponding impedance data and thermistor values in relation to Fig. 4. It shows that in both cases the QRS amplitude and impedance data are corresponding to respiratory signal obtained from thermistor mounted on a mask. In Fig. 7 results of different data set is shown, where volunteer was asked to perform exercise with breath holding and faster respiration for few periods. Just observation of registered data shows high similarity of recordings.

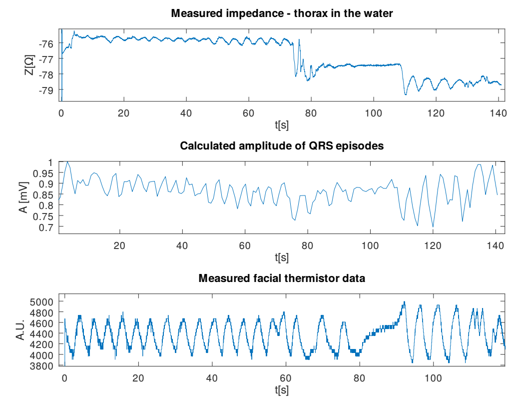

Fig. 6. Measured impedance, amplitude of QRS ant facial thermistor data vs time

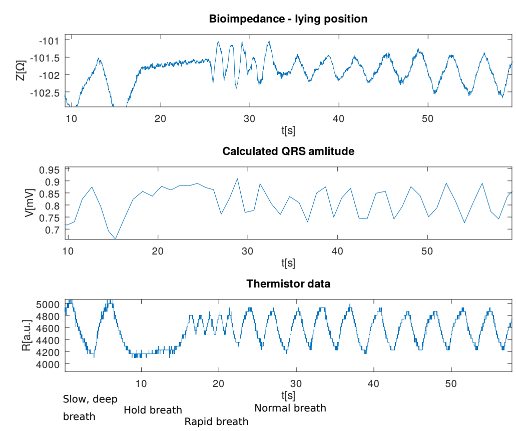

Fig. 7. Bioimpedance data, calculated amplitude of QRS episodes in ECG and respiratory thermistor data. Experiment with breath hold to show data consitency

However in Fig. 8 exmaple of readings for sitting position is shown. It is almost worst case of measurements where thorax of person is over water level. Despite of that in measured QRS amplitude it is possible to derive respiratory data. Measured impedance data also indicate small influence of respiratory signal.

Figure 9 is a result of frequency-domain analysis of received signal from Fig. 8. Since amplitude of QRS periods is non-uniformly sampled and both thermistor and impedance data have different sampling frequency all recordings were interpolated by means of spline interpolation and re-sampled. Thus in Fig. 9 magnitude of spectrum of all signals is shown. In all plots components components of about 0.3Hz are easy to identify and it is average frequency of typical respiration. Also Bland - Altman analysis of data (Fig. 10) is proofing performance of both methods.

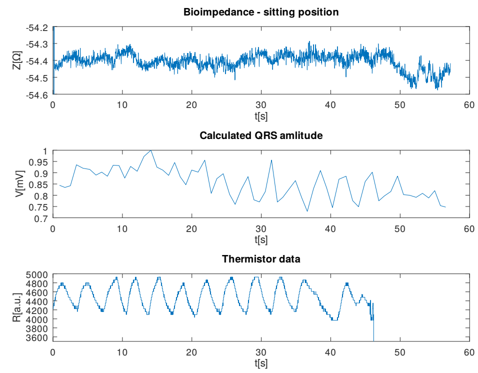

Fig. 8. Bioimpedance data, calculated amplitude of QRS episodes in ECG and respiratory thermistor data for sitting position

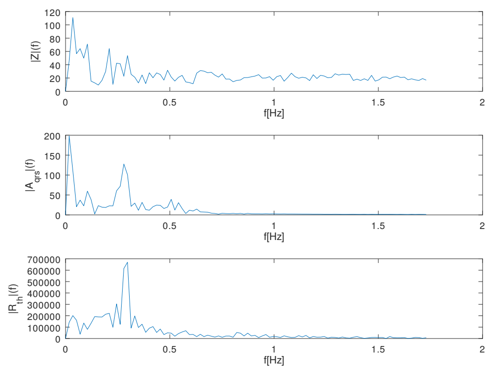

Fig. 9. Spectrum of bioimpedance , QRS amplitude and thermistor data respectively (after spline interpolation , X axis - not yet scalled)

IV. CONCLUSIONS

The principal goal of this work was to check possibility of respiratory signal extraction out of measurements performed in the bathtub. Two major techniques were applied - ECG measurements and bioimpedance. Additionally authors verified performance of MAX30001 integrated circuit which performs surprisingly well. It is possible to measure ECG signal with good quality by means of electrodes located on the bottom of bathtub located on line of hips of bathing person. Additionally MAX30001 allow measurement of bioimpedance with 20-bit resolution. Accuracy of measurements allows to investigate respiratory signals of bating person even in relatively low level of water. We have also tested MAX30001 against person movements. The recovery time from motion caused artifacts is less 4 seconds. Limited movements, eg just moving of the hands is allowed during measurement. Although it will alter derived respiratory rate.

Major limitation of applied technique is no-moving condition. Artifacts caused by the movements causes much higher data variation over physiological. It is noticeable both in ECG and bioimpedance. However movement in the bathtub should be regarded as an activity signal and can be potentially useful in bathing person supervision.

This is preliminary study, where measurement setup was proposed, data processing algorithms were created and conclusions were taken. Obtained results are satisfactory. Further study must involve tests on more volunteers and involve research in presence of typical bathing ingredients as well as optimal placement of the electrodes, ideally located on the bathing mat, which will not require original bathtub modification.

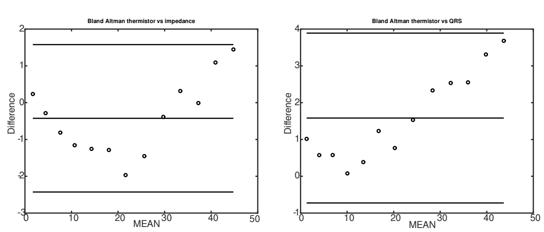

Fig. 10. Bland-Altman graphs comparing data between reference thermistor and a) amplitude of QRS and impedance data b)

REFERENCES

[1] Nicholas Bakalar. Watch your step while washing up. https://www.nytimes.com/2011/08/16/health/research/16stats.html, August 2011.

[2] Bathtub deaths do occur. here's what you should know. https://fit.thequint.com/health-news/bathtub-death-do-occur-what-you-need-to-know, 2018.

[3] R. Ogawa and T. Togawa. Attempts at monitoring health status in the home. In *1st Annual International IEEE-EMBS Special Topic Conference on Microtechnologies in Medicine and Biology. Proceedings (Cat. No.00EX451)*, pages 552–556, 2000.

[4] J. Gomez-Clapers, R. Casanella, and R. Pallas-Areny. Multi-signal bathroom scale to assess long-term trends in cardiovascular parameters. In *2012 Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, pages 550–553, Aug 2012.

[5] Motoi Kosuke, Yamakoshi Yasuhiro, Yamakoshi Takehiro, Sakai Hiroaki, Tanaka Naoto, and Yamakoshi Ken-ichi. Measurement of electrocardiograms in a bath through tap water utilizing capacitive coupling electrodes placed outside the bathtub wall. *BioMedical Engineering OnLine*, 16(1):12, Jan 2017.

[6] P. Przystup, A. Poli?ski, A. Bujnowski, T. Kocejko, and J. Wtorek. A body position influence on ecg derived respiration. In *2017 39th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, pages 3513–3516, July 2017.

[7] K. Watanabe, Y. Kurihara, and H. Tanaka. Ubiquitous health monitoring at home sensing of human biosignals on flooring, on tatami mat, in the bathtub, and in the lavatory. *IEEE Sensors Journal*, 9(12):1847–1855, Dec 2009.

[8] A. Bujnowski, A. Palinski, and J. Wtorek. An intelligent bathroom. In *2011 Federated Conference on Computer Science and Information Systems (FedCSIS)*, pages 381–386, Sept 2011.

[9] Adam Bujnowski, Arkadiusz Palinski, Piotr Koscinski, Lukasz Skalski, Anna Skurczynska, and Jerzy Wtorek. Detection of person presence and its activity in the bathtub. *Journal of Physics: Conference Series*, 434(1):012035, 2013.

[10] A. Bujnowski, K. Osinski, A. Polinski, T. Kocejko, J. Wtorek, and A. Andrushevich. Electrical propterties of solution mixtures for bath supervision in ambient assisted living. In *2018 11th International Conference on Human System Interaction (HSI)*, pages 268–273, July 2018.

[11] Maxim. Ultra-low-power, single-channel integrated biopotential (ecg, r-to-r, and pace detection) and bioimpedance (bioz) afe, 2018.

[12] Emre Eken. Max30001-max32630fthr ecg evaluation system, 2018.

[13] J. Pan and W. J. Tompkins. A real-time qrs detection algorithm. *IEEE Transactions on Biomedical Engineering*, BME-32(3):230–236, March 1985.

[14] Hooman Sedghamiz. "matlab implementation of pan tompkins ecg qrs detector", 03 2014.