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An intelligent bathroom

Adam Bujnowski, Arkadiusz Palinski, Jerzy Wtorek
Gdansk University of Technology, Faculty of Electronics, Telecommunications and Informatics,
ul. Narutowicza 11/12 80-233 Gdansk
Email: bujnows@biomed.eti.pg.gda.pl, arekpalinski@gmail.com, jaolel@biomed.eti.pg.gda.pl,

***Abstract*—Monitoring system for detection of person and his/her activity in the bathroom is described in the paper. It also detects and monitors person taking bath. The system consists of sensors measuring humidity, air and water temperature, spilled water, and state of bathtub. The bathtub state detector (BSD) allows controlling water level and its temperature. It also monitors of person's activity when being in bathtub. It is an essential part of the system. The BSD distinguishes between four cases: 1. the bathtub filled only with water, 2. the bathtub filled with water and occupied by person, 3. the bathtub filled with water and occupied by active (moving) person, and 4. empty bathtub. Presence and activity of the person is recognized by means of multifrequency impedance measurements.**

Keywords: Bath monitoring, intelligent sensors, bioimpedance

I. Introduction

HYGIENE is an important factor that may affects a health status of the human. Regular usage of the bath plays significant role in maintaining good health state and in preserving conditions of life. However, utilization of the bathtub may involve dangerous situations especially for persons living alone. Thus, it is important to monitor a process of the bathroom utilization in the case of the elders.

Tasks realized by such a system may be divided in two categories. First, is to provide a comfortable conditions, e.g. temperature of air and water used while another one is to recognize dangerous situations, including risk of sudden death, especially when temperature of the bath water is too high [6]. Thus, in the study we concentrated on two basic problems. One is a control system of the bathroom environment such as temperature and humidity of the air, water flames on the floor and the water temperature and its level when the bathtub was filling and/or filled. Another problem was to develop a monitoring system for person having a bath. It could be achieved by measuring signals generated by a human body, e.g. electrocardiogram (ECG) or generating and measuring signals which parameters would be affected by the human body. Moreover, the developed system had to be relatively cheap and had to preserve privacy demands. Additionally, the device had to be "invisible" (did not demand any control or adjust) for the person being monitored. Electrical impedance measurements has fulfilled above demands. In order to improve quality of the data a four-electrode technique was examined both theoretically and experimentally.

II. Methods

A. The system structure

A global structure of the system is based on a star topology. Thus, it is a sensor-actuator network. A central element of the network, called the central system, is a kind of computer equipped with communication interfaces. It receives all the information from the sensors and so called auxiliary systems. It can interact either with the supervised person, or installed actuators (valves, switches etc.) according to the information extracted from the data collected. The central system communicates with the external world by means of alerts broadcasted to relatives, caregivers, supervisors or physicians using different media (e.g. GSM, Internet, etc.). A simplified structure of the system is shown in Fig. 1.

The internal structure, decision rules and performance of the system must be adaptable to different demands. That is why it has a modular structure allowing its reconfiguration. The term "dedicated systems" in Fig. 1 stands for devices performing complete signal processing and taking decision. Thus, it contains an autonomic computation/processing unit. It is also equipped with own set of sensors and actuators.

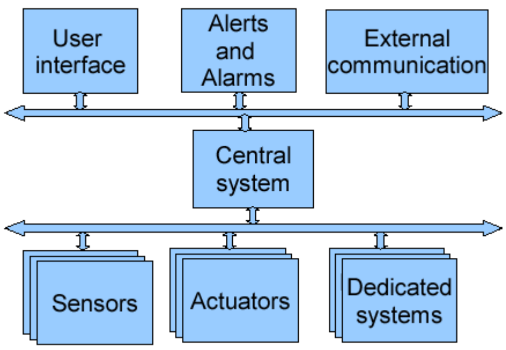

Fig 1: A simplified structure of the monitoring system

The dedicated systems communicate with the central one. These systems govern all resources and also collect data from the sensors directly connected to each and control the actuators.

B. Dedicated systems

The dedicated systems controlling events in the bathroom (Fig. 2) are described in the following paragraphs of section. One of them is devoted to control air conditions in the bathroom. Another one is dedicated to detect a presence of the water on a floor. Next one allows controlling of temperature

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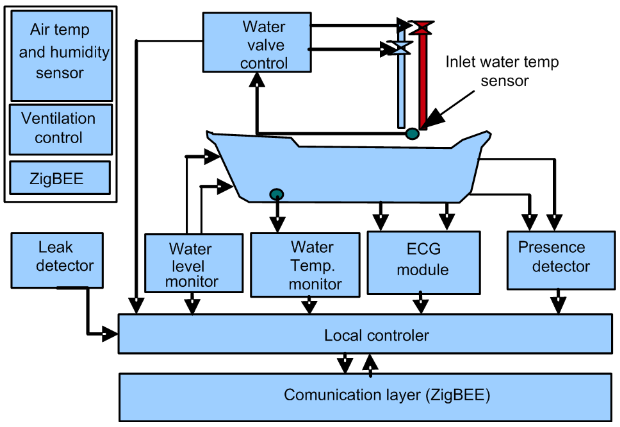

Fig. 2. A block diagram of the bathroom dedicated systems (devices)

and level of the water in a bathtub. And the last one presented in the paper enables detection of human body presence in the bathtub. Together, all of them, together with a central system, form the system for monitoring events and conditions of the bathroom when it is being utilized.

i. Air conditions device

The bathroom is a space with specific air conditions. Usually, it is the warmest chamber in a house or in a flat. Moreover, because of using hot and evaporating water, a humidity of the air is higher than in other chambers.

High humidity and temperature of the air, aside being uncomfortable for elders, may create perfect conditions for growing and developing of moulds which in turn, also may be dangerous for the health. Thus this space requires special care in order to maintain the appropriate conditions. Mechanical ventilation is a typical method to keep a proper humidity level. However, it must be controlled as excessive ventilation may lead to significant decrease of temperature in the bathroom. Thus, temperature controller and mechanical ventilation system to maintain low level of the humidity has been designed. It is built around the microcontroller PIC24F equipped with ZigBee module, temperature and humidity sensors (Fig. 3). Basing on measured data appropriate procedure controls the fan performance. It also allows reporting value of humidity and temperature of the air to the central system via ZigBee. Basing on theirs values adequate efficiency of the ventilation system is adjusted.

In order to achieve compatibility of the ventilation controller with the central system and other devices it has been equipped with ZigBee and the communication protocol [6]. At the moment, the bathroom air-conditions are controlled by means of mechanical ventilation. However, it can be extended to a more sophisticated system by including other actuators (e.g. heating device) or sensors.

ii. Water level and temperature monitor

Water filling control module consists of electrically controlled valves for cool and warm water with water temperature measurement and two-level detector (Fig. 4). The valves are controlled by means of the microcontroller (PIC24F16) equipped with sensors. It enables analogue

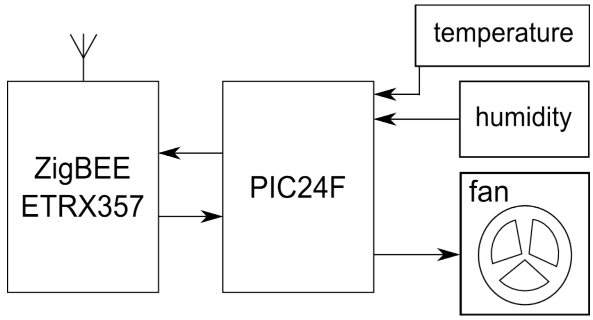

Fig 3: A block diagram of bathroom conditions controller

temperature measurement and water level detection. Water level is determined by measuring electrical impedance between electrodes. A reference electrode is placed close to the sink-hole and two other electrodes are located at two places indicating a low level and a high level of the water. Output data are transferred to microcontroller and by means of ZigBee module are available for the local controller or the central system.

Similar, the temperature of the water in the bathtub can be measured during process of taking bath. If the temperature will be too low an alert suggesting end of the bath can be raised.

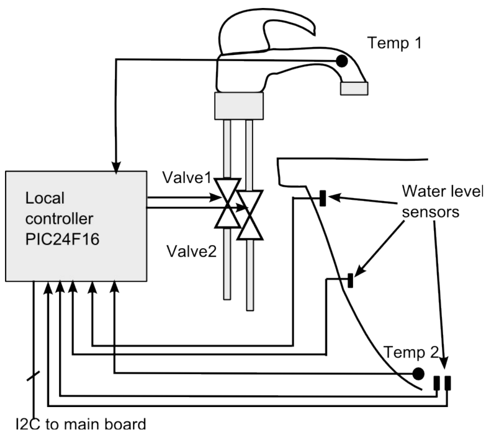

Fig. 4. A block diagram of system controlling the process of bathtub filling with water by measuring its level and temperature

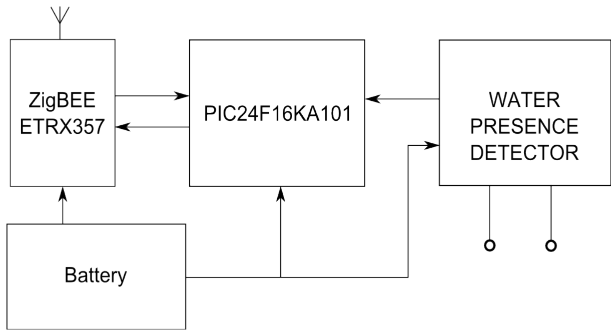

Fig. 5. A block diagram of the leak detector

It is also possible to stop the filling process (using actuators controlled by this system). As the microcontroller is connected to the ZigBee communication module the central system may also control (supervise) temperature of the water in the bathtub. Moreover, it controls the process of filling the bathtub with water basing on information obtained from the system detecting presence of person in the bathtub. It prevents the water from overflowing the bathtub.

iii. Water leak detector

Next device already examined is a water leak-detector (Fig. 5). It is a portable and battery-operated device and it detects water presence on the floor. As it is a portable device it may be also utilized in other chambers exposed to water, e.g. kitchen. It consists of a microcontroller (PIC24F16KA101), water presence detector, ZigBee communication module and battery power supply. We have utilized low power microcontroller using advanced sleep modes to maintain long live time of the battery. Thus, we can use single lithium battery (Minmax ER14505M) for a very long period (at least one year).

iv. Monitoring system of a human body presence in the bathtub

Human body consists of electrically dispersive materials. I.e. its electrical properties, e.g. complex permittivity, depend on frequency of electrical field. The dispersion of electrical permittivity occurs in a few frequency ranges named respectively α, β, and γ dispersion. The α-dispersion appears at relatively low frequency range. On the other hand, water exhibits invariable properties in this frequency range. This suggests a simple method of human presence detection based on electrical impedance measurements. However, there were some problems to be solved before utilizing this technique. Determination of an optimal electrodes position, providing adequate sensitivity of the method independently on body position and localization in the bathtub, was one of them. A Finite Element Method was used for performing simulations. It allowed selecting adequate shape, size and localization of electrodes in the bathtub. An example of 2D model is presented in Fig. 6. As a result a four-electrode technique was selected for experiments. Thus, also the developed measuring system utilized a four electrode technique (Fig. 7). It was built around the AD5933 integrated circuit devoted to measuring impedance.

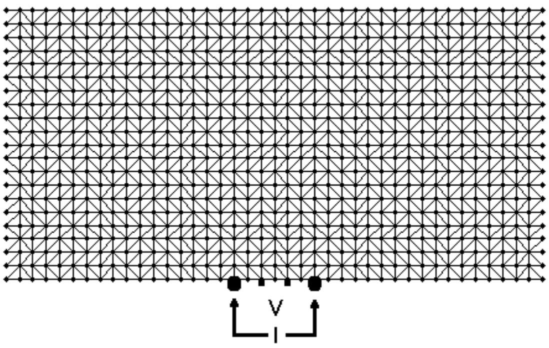

Fig. 6. Sensitivity plot for the selected geometry

However, originally this integrated circuit utilized a two electrode technique. The two-electrode technique is very susceptible to electrode impedance arising from polarization phenomenon. Thus it was necessary to equip the AD5933 with additional circuits (converter V/I, instrumentation amplifier and high-pass filters see Fig. 7) what allowing its utilization in four-electrode technique. The circuit performing

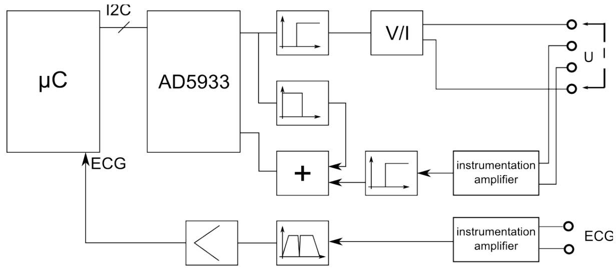

Fig 7. Block diagram of patient detection module enhanced with ECG measurement unit

measurements of electrical impedance was enhanced with unit devoted to electrocardiographic signal measurements. Since the person taking the bath is immersed in the water almost all the time it is possible to measure ECG signals of the person. In typical application signal is processed and only HR parameter is reported to the central system. However, in case of arrhythmia or other situations recognized as dangerous, collected ECG waveforms can be transferred for further analysis. We decided to attach the measuring electrodes at the both sides of the bathtub while the reference one was put at the bottom of the bathtub. They were combined with a bath-tub carpet. It simplified system service and allowed removing of the carpet for cleaning or exchange. In such way almost any bathtub may be adopted for such measurements. At first stage of the study a separate set of electrodes was used for both types of measurements, i.e. electrocardiographic and impedance. However, it was assumed that the final solution would utilize the same set of electrodes for measuring simultaneously both signals. Up to now, we have achieved results from separate electrode matrices. To perform experimental tests we have used a FriendlyARM mini2440 embedded board.

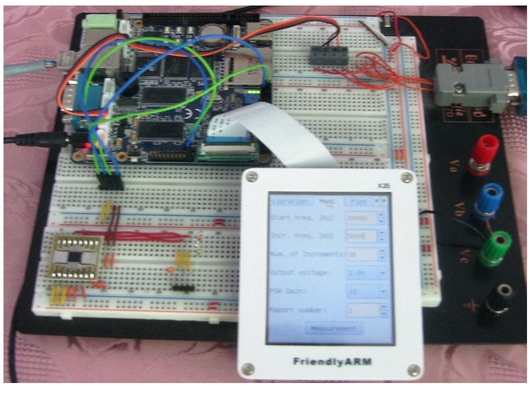

Fig 8. Prototype of the impedance measuring circuit with the host embedded computer

It consisted of main board with CPU S3C2440A, ARM920T (Samsung) with 64MB of 32-bit SRAM, Solid State 256MB NAND Flash hard disk. Additionally board was equipped with 640x480px graphic display and resistive touch-screen. The board was working under GNU/Linux operating system. Therefore using of IIC bus was native. We utilized a custom board with the AD5933 circuit (Analog Devices) and the developed analogue front-end (See Fig. 8). An application for communication to the AD5933 impedance analyzer has been created. Additionally a graphic front-end using the QT libraries has been created in order to communicate with the application and to present the results.

A reliability of ECG measurement would be affected by many factors. At first we needed to know if the person is in the water. As it was already mentioned, detection of the person presence in the bathtub was done by the electrical impedance measurements. The impedance spectroscopy measurements were performed for a set of selected frequencies (200 Hz – 100 kHz).

III. Results

A. Theoretical model

The Finite Element model of the bath and electrodes was simulated using Matlab package. At first we have calculated spatial sensitivity distribution. Values of the sensitivity shown in Fig. 9 are both positive and negative. Thus, it is necessary to answer if, and how it will affect the

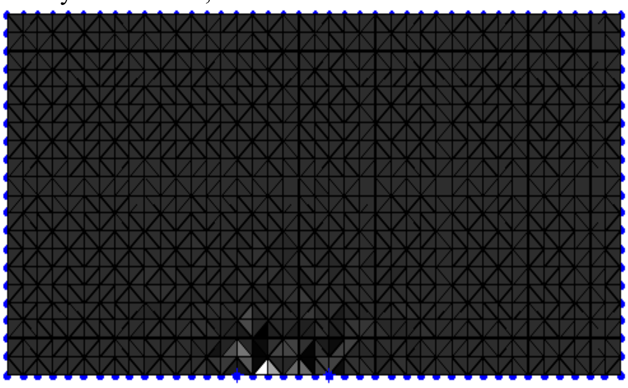

Fig. 9. Sensitivity plot for the selected geometry

measurements. A different localization of human body in respect to position of electrode matrix has been simulated. A dispersive property of human body has been assumed. In general, the model of the dispersive object immersed in non-dispersive media (tap water) has been examined assuming different localization of the object. In such case the dependence of impedance on frequency takes form of semicircle (Fig. 10). Position of the center and the radius of the semicircle depend on distance between the body and surface of the electrode matrix.

The bigger is the distance the smaller radius of impedance plot and in fact the lower value of impedance. This may be explained by the fact that increasing the distance between the body and the matrix of electrodes reduces amount of measurement current flowing through the body. Thus, the body impedance is paralleled by impedance of water. The higher volume of water localized between the body and electrodes the smaller value of impedance. It appears that the impedance of bathtub filled only with water for low frequency, was lower than that of the body.

Increasing volume of the body in comparison to volume of the water leads to wider dispersion (Fig. 11). In this experiment the distance between the electrodes and the body remained constant. The volume of the body was being increased by expanding it laterally and toward upper limits of the model.

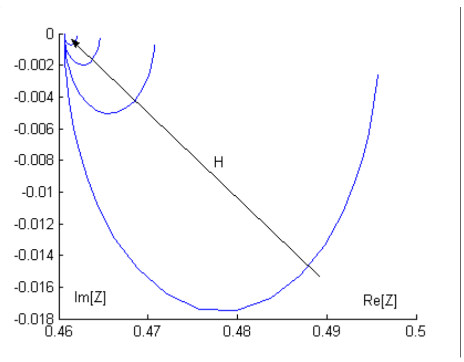

Fig. 10. Influence of the height of the dispersive object above electrode level on spectroscopic measurement (result of simulations)

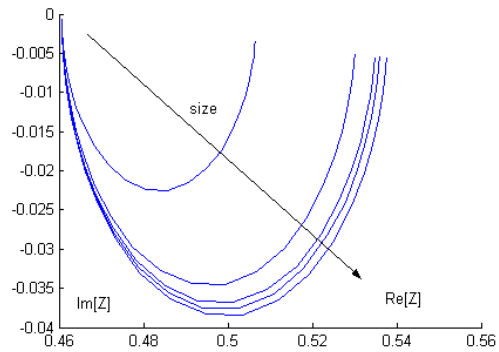

Fig. 11. Influence of the size of the object on the measured impedance values

It was achieved by substitution of water by body tissue in the model.

B. Phantom measurements

We have also performed experiments with a body immersed in the bathtub. Measurements have been performed using a developed model of the measurement system. Before attempting measurements in the bathtub a phantom studies were performed. We used a plastic tank filled with ordinary tap water. At the bottom of the tank a set of Ag electrodes was placed. After calibration we have immersed different objects (hand, leg, etc.) into tank and performed measurements with frequency range 200 Hz to 100 kHz.

Data have been collected using specially developed software (Fig. 12). Results of such measurements are presented in Figs. 13 and 14. However, when immersing the hand or leg in the tank led to quite big current leaks to surroundings at high frequency. So, we decided to reduce the range of current frequency to 80 kHz. It also resulted from low accuracy of measurement system for higher range of frequency. Nevertheless, a character of the measured impedance plot is similar to that obtained from simulation study.

Another presentation of impedance data is shown in Fig. 14. The curves were obtained for the following conditions: f1 – small part of biological tissue around electrodes, w1, w2 – bathtub filled only with water, b1, b2 – the human body directly on electrode matrix, b3 – the human body at distance (a few centimeters) from the electrode matrix.

Finally, measurement of ECG was performed with person sitting in the bathtub filled with a tap water. A three

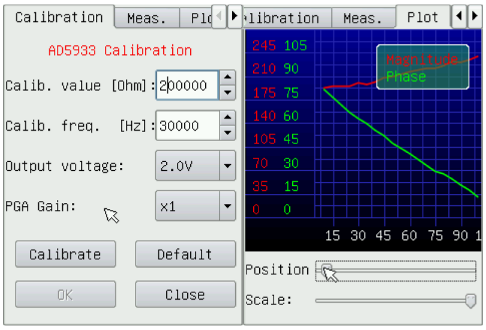

Fig. 12. An example of screen-shot from the embedded application

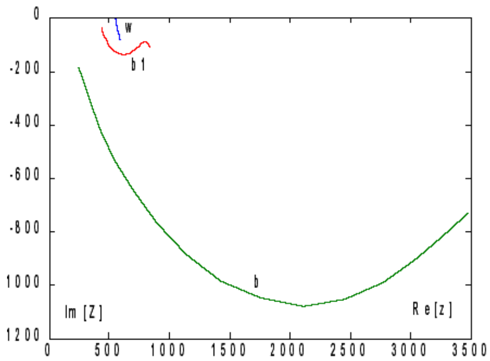

Fig 13. Real measurements of the measured impedance over frequency range from 200 Hz to 80 kHz: b – body directly on electrodes, b1 – body about1cm above electrodes, w – water only.

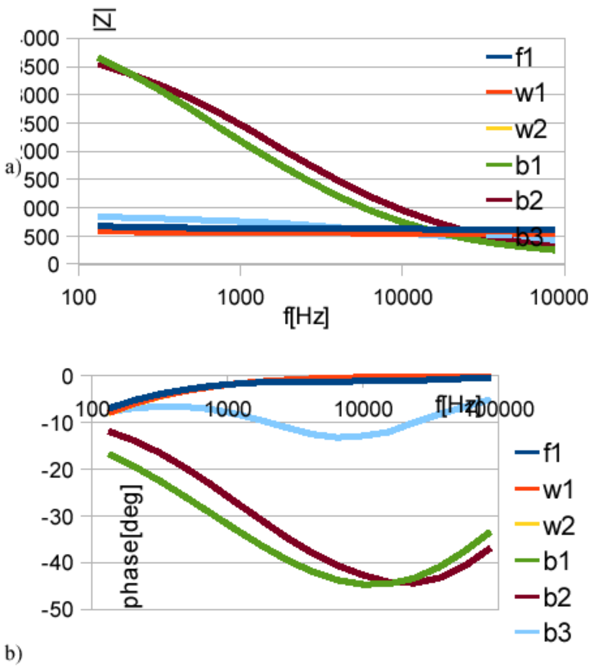

Fig 14. Dependence of impedance modulus and phase on frequency (details in the text)

electrode technique was employed. The result of measurement is presented in Figs. 15 and 16. Impedance was measured only for one frequency of current equal to 10 kHz.

It appeared that person sitting on electrodes used for measuring impedance drastically increased its value

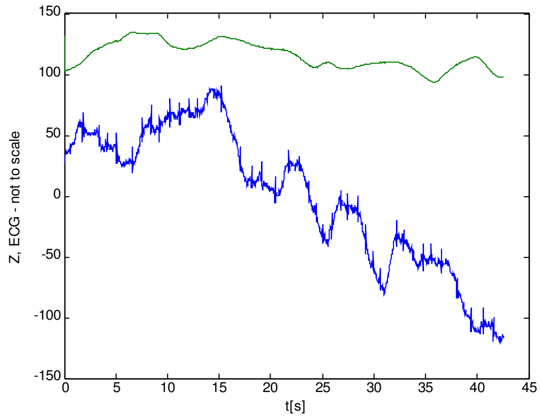

Fig. 15. Impedance measured at 10 kHz and ECG using separate matrices of electrodes

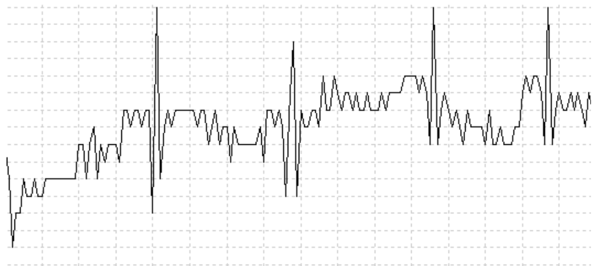

Fig. 16. Example of the ECG recording

in comparison to that obtained from theoretical studies by means of FEM method. However, the measured value was smaller, as expected, than that obtained in phantom studies. It was mainly due to much bigger object (bathtub vs. tank). As it is seen in Fig. 15 the recorded ECG contains a large component of very low frequency. Also, power frequency interference is very high. However, it is possible to monitor heart rate as QRS waveform is easily distinguished form other components of the signal.

IV. Discussion

Home automation and so called intelligent buildings are regarded as an expensive toy for rich society. This is caused by cost of such installations. However, some parts of such installation becoming installed, besides the price – for example alarm systems. Similarly when considering protection and safety of elders some installations can be regarded as affordable. We are presenting such example of intelligent supervision of the bath.

Quality of the signals obtained during experiments suggests that further improvement has to be done yet. Nevertheless, it is shown that it is possible to detect the presence of the person in the bathtub and moreover it is possible to evaluate heart rate of that person. Thus, dangerous situations may be recognized, e.g. arrhythmia, additional excitations, etc.

This information is sent to caregiver and appropriate decision has to be taken.

However, to make the system a more reliable (to reduce a number of possible false alarms) another form (additional) of monitoring person's state when taking a bath is also considered.

V. Conclusions

We have showed that it is possible to detect presence of the person in the bathtub and to measure heart rate. However, quality of the recorded signals still has to be improved. Additionally it is possible to estimate person's activity by means of the impedance spectroscopy.

When the impedance measurements are stable it is possible to record ECG signal properly. Usage of readily available embedded platform reduces cost of development and reduces time of development. Additionally, popular operating system with well documented libraries allows easy development of modern applications.

Acknowledgment

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