MOBILE SOLUTION FOR AIR QUALITY MONITORING AND RESPIRATION ACTIVITY MONITORING BASED ON AN ANDROID OS SMART PHONE

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Abstract − Air pollution is a major environmental risk to health causing premature deaths worldwide. In these conditions, the development of reliable and accurate mobile systems that measure the indoor air quality together with other parameters associated with health status of the people working or living in specified spaces represents an important challenge. The paper presents the design and implementation of a mobile air quality and respiration activity monitoring system including multi-channel Bluetooth compatible smart sensors that deliver the information to a smart phone running an Android operating system (OS). An embedded software developed in Java for the smart phone platform assures the air quality and respiration data processing, graphical user interface including alarm generation, and data synchronization with a remote database through Wi-Fi or 3G/UMTS service. Experimental results associated with air quality and subject's respiration sensing as well as the smart phone software implementation are included in the paper.

Keywords *air quality, solid state sensors, smart phone, and respiration activity.*

1. INTRODUCTION

According to the World Health Organization (WHO), air pollution is a major environmental risk to health and is estimated to cause approximately 2 million premature deaths worldwide per year [1]. There is a set of *WHO Air quality guidelines*, which represents the most widely agreed and up-to-date assessment of health effects of air pollution, recommending targets for air quality at which the health risks are significantly reduced. In order to know about the pollution levels that are related with the respiratory distress, which is the second most common symptom of adults transported by ambulance and is associated with a relatively high overall mortality before hospital discharge of 18% [2], different air quality monitoring systems are designed and implemented. Poor indoor air quality is becoming an increasing problem around the world because, in general, people are spending more time indoors and important part of the reported air quality monitoring systems are designed for indoor applications [3][4]. Our team have developed during the last decade different architectures for air quality monitoring systems, including sensor networks [5][6][7]. The use of air quality sensor networks is an important solution to assure the monitoring of temperature, relative humidity, and pollution gases concentration in different spaces, preventing undesired events such intoxication or asthma attacks [8]. The information from the sensors network is published on a personal computer (PC) or using situated displays in a pervasive computation context [9]. These architectures require an extended number of measuring nodes including sensors and acquisition and communication devices [10], which means high costs for reduced number of users and large spaces requiring a large number of measuring nodes. At the same time, the existing solutions are mainly expressed by the exclusive implementation of air quality measuring channels and do not include any vital status measuring channels of the people living and working in the monitored environment.

The paper presents a sensing platform that includes air quality measuring channels but also a respiration measuring channel using solid state sensors and an acquisition and wireless communication module mounted on a subject's chest. The human machine interfaces and the data logging and data synchronization are performed by a smart phone that runs an Android OS. The implemented software assures the data raw visualization, alarm generation and, from time to time, data synchronization with a remote data base for off-line processing of the data in order to extract the correspondences between the air quality level and the respiratory activity.

The paper starts with a mobile multi-channel smart sensor description that refers to the air quality sensing, respiration sensing, and acquisition and wireless communication of the information delivered by the sensors. The smart phone software design and implementation is detailed in the paragraph 3. Paragraph 4 presents the experimental results obtained with the smart sensor including the smart phone graphical user interface. The last part of the article includes the conclusions and the future work.

2. MULTI-CHANNEL SMART SENSOR ARCHITECTURE

Continuously monitoring of indoor air quality conditions (relative humidity, temperature, gas pollutants, and odours) as well as the respiratory activity is performed using a designed and implemented multi-channel smart sensor architecture that wirelessly delivers the information from the measuring channels to a smart phone used as the main data interface for the assisted people during normal daily activity. Additionally, the information stored in the smart phone is delivered to an air quality and respiration behaviour database for off-line processing of the information required from different smart sensor units. The designed and implemented architecture is presented in Fig. 1.

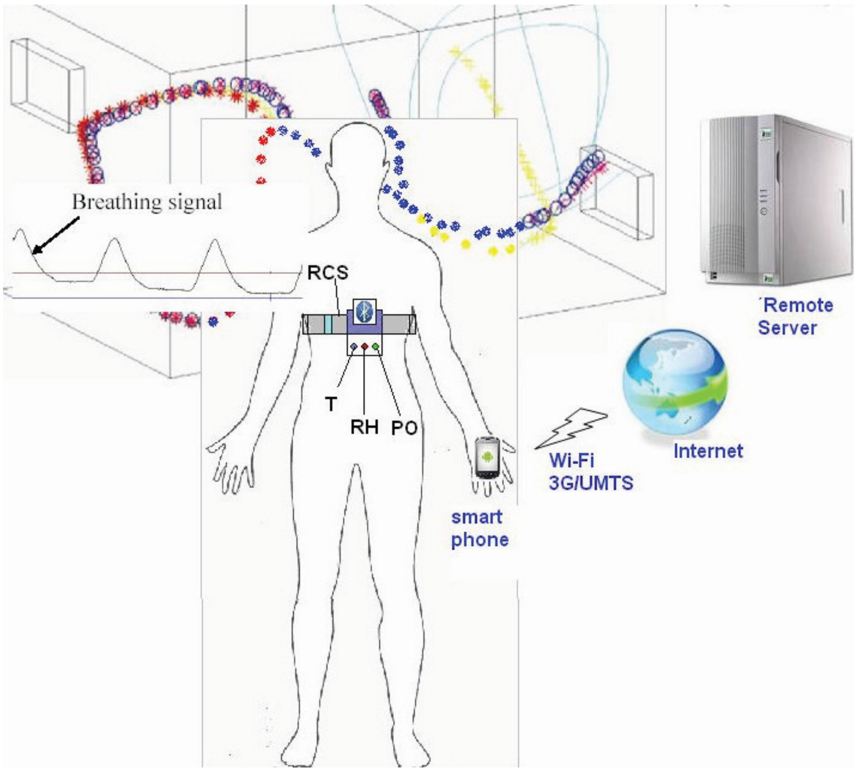

Fig. 1. Air quality and respiratory activity monitoring architecture (RCS-respiratory chest strap sensor, T – temperature sensor, RH – relative humidity sensor, PO – pollution and odour sensor)

2.1. Air quality sensors and conditioning circuits

The system includes three integrated sensors, HIH4000 for relative humidity (RHS), LM35 for temperature (TS) and NAP-11AS (XairQS) that has excellent sensitivity to low concentration of air pollution components as well as to various chemical irritants generated in normal living environment (Fig. 2).

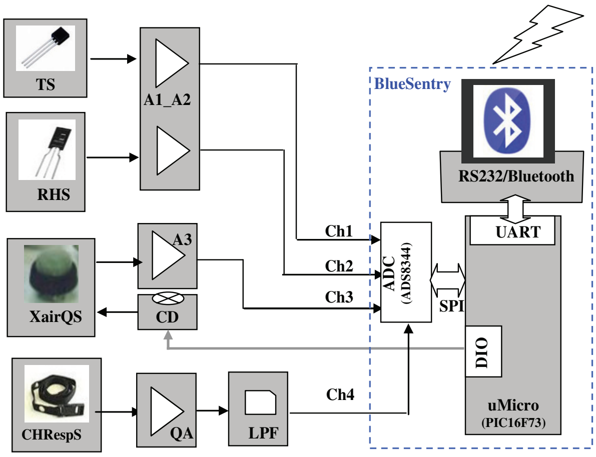

Fig. 2. Sensing, conditioning circuit, acquisition and Bluetooth communication – multi-channel smart sensor block diagram

In Fig. 2 TS represents temperature sensor, RHS the relative humidity sensor, XairQS the air quality index sensor, CHResp the chest strap respiration sensor, QA is the charge amplifier, A1, A2, A3 are non-inverter amplifiers, CD is a current driver and LPF is a low pass filter.

The specifications of RHS are: ±2%RH accuracy, ±0,5%RH repeatability, ±0,5%RH linearity, voltage supply 5 VDC, current supply 200uA and the output voltage signal, V_{RH}, according with the RH sensed values in the 0,8 -3,9 V voltage interval. Considering the data processing limitation of the mobile computation platform, a linear relation between the measured V_{RH} acquired voltage and the RH was considered.

$$RH[\%] = \alpha \cdot G_2 \cdot V_{RH} - \beta \quad (1)$$

where G_2=1,5 is the A2 gain, α=32,25 V^{-1}, and β=-25,80 are constants for the given sensor.

The temperature sensor LM35 is an accurate low cost integrated-circuit temperature sensor whose output voltage is linearly proportional to the Celsius temperature. The LM35 does not require any external calibration or trimming to provide typical accuracies of ±0,25°C at room temperature. However, its low impedance requires the use of an amplification scheme that is part of the A1-A2 dual non-inverter amplifier based on an operational amplifier.

Detection of low concentrations (tens of ppm) of air pollutants, for example cigarette smoke, CO, or methane is performed using NAP-11AS from Nemoto that assures the sensing of conditions that can lead to asthma attacks monitored by the CHResp channel. The solid state sensor is based on a In_2O_3 semiconductor and a heater to heat up the sensing element up to 300°C. The sensor resistance variation versus detected pollution gases or odours is given by:

$$R_s = R_{s\,ref} \cdot \left(\frac{C}{C_{ref}} \right)^{\varphi} \quad (2)$$

where Rs is the electrical resistance of the sensor, Rsref is the electrical resistance of the sensor for reference condition (clean air: no pollution, no odours), φ is NAP-11AS specific constant, Cref is the gas concentration considered for reference condition, and C is the measured value of the pollution gas. A current driver circuit is connected to the heater when a voltage V_{RL} associated with pollution detection is amplified by amplifier A3. The dependence between VRL and the air quality index XairQ (with XairQ=100% for indoor clean air and XairQ=0% indoor high pollution conditions) is given by following relation:

$$X_{airQ} = \gamma \cdot G_3 \cdot V_{RL} + \delta \quad (3)$$

where γ and δ are specific parameters obtained in the air quality measuring channel calibration phase (γ =-40/V, δ=100) considering the voltage V_{RL0} obtained from clean air and $V_{RLmax}=V_C=5V$, G_3 represents the gain of A3 amplifier (G3=1). The on-off heater control is done including a power switching scheme based on a 2N2222 bipolar transistor controlled by the digital port of microcontroller (uMicro).

2.2. Chest strep respiration sensor

Considering the capabilities of the EMFIT R-series sensing device, and continuing our previous work on developing vital signs sensors based on EMFI material [12], a chest strap respiratory sensor was designed and implemented. Referring to the R-type sensing element, it is based on Emfit film and 3 layers of polyester film with aluminium electrodes. Emfit is an elastic, permanently charged ferro-electret film that converts mechanical stress (due to an applied pressure) into charge variation, ΔQ. Caused by pressure associated to the human breathing activity the EMFIT film air void thicknesses are changed leading to electrical charges movement that will originates a voltage at the output of the charge amplifier (QA). The circuit uses a ½ TLC2274 quad low-noise rail-to-rail operational amplifier (OP), and a parallel combination of R_Q=10MΩ, C_Q=20pF and additional resistances (R1 and R2) that assure the QA gain (Fig. 3).

Because of the interferences caused by high frequency signals, an active low pass filter is designed and implemented taking into account the normal values registered for breathing rate (BR), BR<18 breath/min. The two poles active filter has an f_c=0,3Hz cut-off frequency, the output signal V_{resp} being applied to the Ch4 analogue input of the acquisition and Bluetooth communication module (ACM).

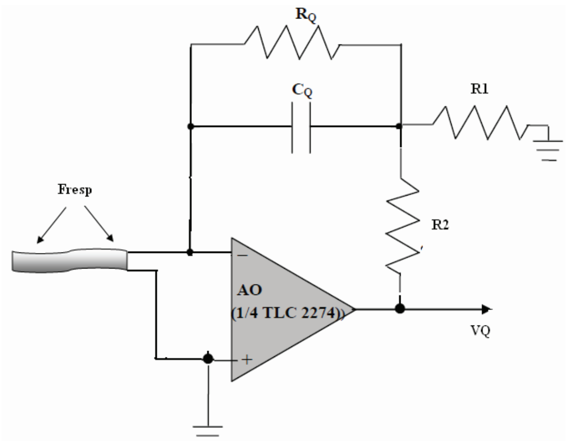

Fig. 3. CHResp (EMFI R-type) sensor and the charge amplifier (QA) implemented scheme

2.3. Acquisition and communication module

V_{RH}, V_T and V_{RL} and V_{resp} voltage signals delivered by sensors conditioning circuits are acquired by Ch1, Ch2, Ch3 and Ch4 analog inputs of the acquisition and Bluetooth communication module (BlueSentry)[13]. The module is based on a PIC16F73 microcontroller that communicates through an SPI interface with an 8 analogue input channels 16-bit ADC (ADS8344). The acquired values of the voltage signals are converted into hexadecimal, formatted and transmitted through an USART interface to the serial to Bluetooth converter that is included in the ACM. Considering that the AirQ sensor is used in the switching mode to diminish the power consumption, a digital output port provides the control of the bipolar transistor included in the current driver circuit associated with the NAP-11AS sensor heating circuit.

The acquisition and heater switching on/off control, the data processing and data storage of the acquired voltage signals, the alarm generation for particular values of air quality and respiration rhythm as well as the Bluetooth communication and remote control of the ACM are performed by the smart phone (HTC Desire that runs the Android 2.2 mobile OS) using an embedded software developed in Java.

3. SMART PHONE ANDROID OS SOFTWARE

The smart phone embedded software was developed in order to perform different tasks including smart sensor searching and identification, smart sensor measuring channels data reading and processing, human computing interfacing and data communication with an air quality and respiration activity database. Regarding the implemented Bluetooth service, it is used to receive the data from the smart sensor according to ASCII commands for different implemented functionalities such as: number of the measuring channel (up to 4 in the present case), acquisition rate selection (up to 20S/s), and acquisition mode selection (continuous or one time data acquisition). Primary processing of data including the respiration wave filtering and breathing rate estimation algorithm, voltage-to-temperature conversion, voltage to relative humidity conversion and voltage to XairQ conversion is implemented by the smart phone software. The developed software is based on Android SDK and Java programming language [14][15]. As important elements of the embedded software deserve mention the Activity Classes mainly related to the implementation of the graphical user interface. For the present prototype, a set of activity classes were implemented namely, *Sync.java*, which permits to manage all the information regarding the application; *DashBoard.java*, which assures the numerical and graphical representation of air quality and respiration activity parameters. Using the *aiCharts* graphical library were implemented a set of classes associated with graphical representation of the air quality and respiration wave time variation.

4. RESULTS AND DISCUSSIONS

The implemented smart sensor that combines a set of air quality sensors and a novel architecture of a respiration sensor was tested in two stages. In the first stage, software implemented in a PC with Bluetooth was developed in LabVIEW to validate the smart sensor measuring channel operation under different conditions artificially created in the laboratory using an air conditioning system. In a second stage, the smart sensor for air quality monitoring and the respiration assessment in humans was tested considering fully functionalities including the Bluetooth wireless communication and remote control performed by the embedded software implemented in the smart phone running Android OS. The data from the sensors is visualized in the smart phone display. Two of the main graphs that can be selected through the graphical interface are presented in Fig. 4 and Fig. 5.

Fig. 4. The graphical user interface implemented in the smart phone –RH case

Analyzing the figures one can be observe in Fig. 4 the evolution of the relative humidity in time while Fig. 5 presents the evolution of the respiration wave (for a moving time widow of 20s) and also the values of the estimated respiration rate. Additionally, the audio alarm was implemented for the critical air quality and respiration behaviour cases. (e.g. asthma attack conditions).

Fig. 5. The graphical user interface implemented in the smart phone –respiration case

5. CONCLUSIONS AND FUTURE WORK

A long term human respiratory activity monitoring sensing system for specific air quality conditions using a multi-channel smart sensor and pervasive computing materialized by a smart phone was designed and implemented. A smart sensor architecture including a novel chest strap EMFI respiration sensor and air quality sensors assures the assessment of the respiration behavior signaling critical situations associated with air quality conditions. The acquired data is wireless transmitted to a mobile computing unit expressed by a smart phone. An Android SDK and Java based smart phone application allows the information from the smart sensor to be received through Bluetooth communication, to be processed and graphically represented using a graphical user interface adapted to the assessment tasks. Automatically selected data update rate (up to 20 updates/s) permits a real-time visualization of data coming from the smart sensor using the smart phone display. Several tests of the smart sensor and smart phone embedded software were carried out proving the effectiveness of the implemented solution. Future work is related with the extension of air quality parameter measurement including specific gas concentration sensors but also new elements regarding the physiological parameters measurement. Additionally, and advanced processing software module will be implemented in the smart phone to highlight the correlation between the measured values of air quality parameters and critical situation associated with the respiratory activity.

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