Microwave FMCW Doppler radar implementation for in-house pervasive health care system

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Abstract— **In recent years, the research in the area of ubiquitous healthcare has intensified. There are many technological advances regarding the development of unobtrusive sensors for cardiac and respiratory activity, but the current scenario is still far away from an everyday life fulfilled with ubiquitous healthcare systems. In this paper, it is described the usage of 24GHz microwave FMCW (frequency modulated continuous wave) Doppler radar (MDR) as one of the main components of a pervasive biomedical system that is part of an assistive environment for the people with less mobility or people with long term health condition. As parts of the present work, in this paper are mentioned the design and implementation of an assistive environment based on a MDR sensor, an experimental study concerning the microwave Doppler radar characteristics and remote sensing of heart rate and breath rate, based on acquisition and processing of the signals delivered by the used radar.**

Keywords- ubiquitous healthcare system, unobtrusive sensors, microwave Doopler radar

I. INTRODUCTION

In many countries, demographic developments, social changes, and the rising costs of health and social care, considering the people with chronic diseases, elderly population or people with less mobility, imposed the introduction of electronic health records (EHR) as a solution to improve health care efficiency and safety. Furthermore, efficient pervasive health care architectures, mechanisms and systems can alleviate the problem of supporting and caring for people with a long term condition and less mobility. Ubiquitous or pervasive healthcare has the main goal of building sensing and computing systems that permit long-term health assessment of the human subjects and health critical events signaling for high level of unobtrusiveness. Ubiquitous healthcare systems defined like "in-house" implementations permit the long-term health status assessment of subjects affected by chronic diseases, elderly people, and people with less mobility, among others. On the other hand, comparing with the ambulatory healthcare, the ubiquitous healthcare as part of telemedicine systems can permit, in the future, to stabilize the actual tendency of healthcare rising costs caused by demographic changes [1].

As an important part of the pervasive health care systems are the sensing units, the computation units and the communication units that are directly related with the implementation costs of these kind of systems, but also with the easy acceptance by the users. Referring to the sensing units, the non-invasive and the unobtrusive characteristics are important requirements taking into account the acceptance from the user. As for the unobtrusive solutions, it can be mentioned the usage of non conductivity electrodes for ECG recording, where the electrodes are embedded on the chair [2], a set of implementations for ballistocardiography sensing, where the sensing part is embedded in bed, chair [3] or wheelchair [4], in furniture and photoplethismography based on reflection measurement scheme [5] .

Sensing units, as part of ubiquitous systems, which work without mechanical and electrical contact, represent a big challenge. Nowadays, the developments in the area of Doppler radar permit to develop unobtrusive cardiac and respiratory activity measurements that satisfied the above mentioned requirements. Doppler radars in continuous wave (CW) version have, recently, been introduced to various applications, including home monitoring, research and rescue operations [6][7][8]. Such devices are basically a moving target indicator working in the RF range, frequently with used frequencies being 1215MHz, 2.4GHz and 10GHz. Using these frequencies, heart and respiratory movements of a human subject can also be sensed [9].

The CW Doppler radar [10] uses the Doppler Effect to measure the radial velocity of targets in the antenna's directional beam, being useful for vital signs remotely monitored. As a drawback of CW Doppler radar is the impossibility to determine the range of the target.

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Continuing the previous work in the area of the health status monitoring in ubiquitous context [5][11][12], the article reports a set of architectures based on microwave FMCW (Frequency Modulated Continuous Wave) Doppler radar to perform the cardiac and respiratory activity assessment in an unobtrusive way, embedding this kind of sensors in different elements (bed, chairs, wheelchairs) associated with a ubiquitous healthcare system. The implementation of contact free sensing unit based on a Doppler radar and results regarding the FMCW Doppler radar characterization are part of this work. Elements related with the acquisition and processing of radar ballistocardiography (R-BCG), which are used to extract the heart-rate and the respiratory rate, are described as well as a comparison with the results that were obtained using EMFi sensors embedded in a chair and in a wheelchair.

II. PERVASIVE HEALTH CARE ARCHITECTURE

The proposed architecture was done to provide automatic health care information as a biofeedback, taking into account the acquired and analyzed vital signals values. User-friendly information on risks associated with measured physical efforts must be signaled, avoiding critical situations.

First, we identify guiding lines, principles and requirements, for a proper design of the desired architecture. Although, initially, we did not have the concern to implement ambient information systems [13], we think that the architecture should be directed to follow, as much as possible, the requirements and characteristics of these systems. The other principles are natural options to what was pretended.

The architecture specification is based on the detection of persons involved, mostly, in their everyday life activities with passive interactions, which can be considered as natural and "incidental", with the computational and sensing augmented objects (e.g., wheelchair, bed). In the pretended scenario of application, the basic aim is to ensure that only the detection of the user's co-presence near (or using) the object will activate the presentation of health care information as a biofeedback, or just update it in the system. The notion of "incidental interactions" describe actions that are co-opted by the system to serve a purpose other than the one initially thought [14]. An incidental interaction can be seen as a situation where actions, executed for another purpose, are interpreted in order to improve future interactions in everyday life.

Furthermore, in most of the cases, it is pretended to augment the considered objects by providing the biofeedback information embedded in the context/scenario. A scenario of application may contain one semi-public display or even a large number of display devices, casually available to the users of the space, distributed closely to corresponding stationary objects (e.g., beds). The aim is to provide contextual information at decision points, which are where the sensing objects are placed or exist. Following this principle, it is essential to point that the information presentation is made where and when is needed, being as unobtrusive as possible, and with passive interaction [15], since the system does not require active interaction from the users.

The architecture can integrate a second level of interaction. Though triggered by a passive interaction, even "incidental", coming from the co-presence of the user in the environment, there can be active interactions with the object/system, using for this purpose handheld mobile devices (e.g., smart phones, PDA's). These devices also allow the provision of additional information in a private and mobile mode.

The elements of the proposed pervasive healthcare architecture are presented in Fig. 1. As users are mentioned the elderly or other people with severe healthcare problems in various contexts: lying in bed [4], using a smart wheelchair like reported in [3] and [5] or even who can walk for small distances in the spaces of pervasive environment, with sensing smart units for biomedical signals assessment. A second category of people (users) that interact with the proposed architecture are the accompanying person (e.g., nurse, familiar), the "observer", who watches the subject in a long term health assessment. A third category is represented by the health caregiver (e.g., a doctor, nurse, physiotherapist), that can also be an "observer" and can take decisions according to the values provided by the implemented system.

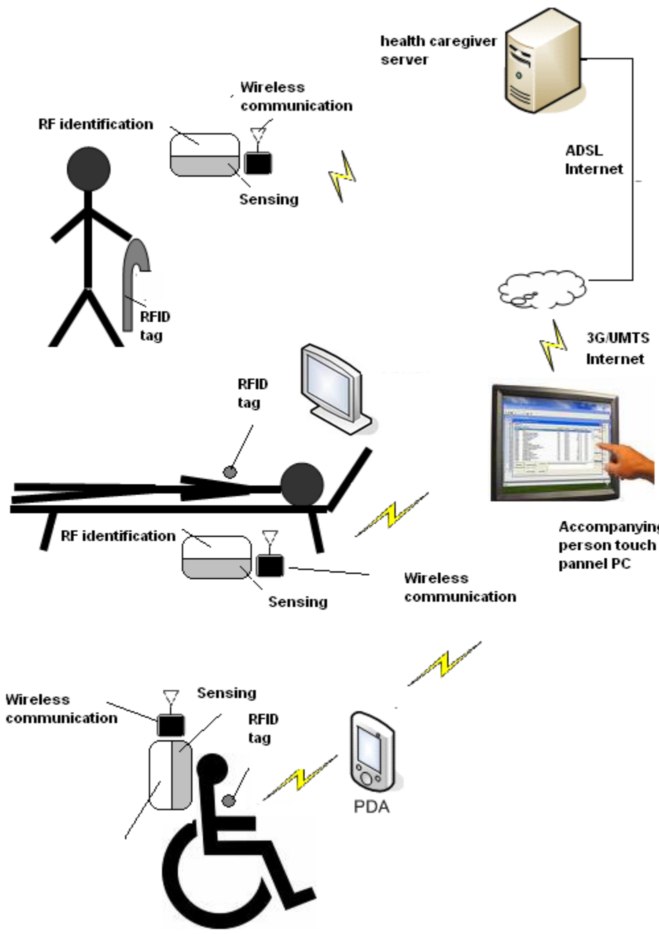


Figure 1. Pervasive health care architecture

It was intended to use the RFID technology (e.g. UHF technology) previously used by the authors [16] for the detection and identification of the system users, which allows the computation of co-presence to be embodied within the real–world [17].

For each of the possible scenarios presented in figure 1, such as subject lying in the bed, subject walking inside the pervasive environment, or subject using a wheelchair, a set of three units expressed by RF identification, health status and motion sensing and acquisition and wireless data communication are considered.

To materialize the sensing units associated with the cardiac activity and respiration monitoring and to provide an unobtrusive way to estimate the user motor activity a microwave FMCW Doppler radar was used. In the next Section, the implementation and characterization of the sensing units based on a microwave radar are undelined.

III. SENSING BY MICROWAVE DOPPLER RADAR

FMCW Doppler radar, which performs the velocity and range measurement, was considered a good solution as part of the ubiquitous healthcare system in order to materialize a contactless sensor for cardiac and respiratory activity as well as for motor activity monitoring.

The characteristics of the used FSK/FMCW-capable K-Band VCO-Transceiver with two integrated patch-antennas and IFpre-amplifier are: advanced PHEMT-oscillator with low current consumption, split transmit and receive path for maximum gain, stereo (dual channel) operation for direction of motion identification, IF-pre-amplifier, and bandwidth limited for lowest noise performance.

An additional conditioning circuit was developed to deliver the appropriate tuning voltage for the radar and a set of filters were also used to obtain the signals corresponding with low amplitude motion, which are related to contactless ballistocardiography signal. The block diagram of the implemented conditioning circuit is shown in Figure 2.

A signal generator (SG) module, which is controlled by the Bluetooth data acquisition module (DAQ), delivers a V_{tune} voltage applied to the FMCW Doppler radar. The radar output signals are filtered using a set of two active filters based on LM324. Using a LPF, the very low frequency component from IF signal is extracted as human subject breath signal. Using a HPF, the quick oscillations associated with cardiac activity are obtained. Additionally, a set of two programmable gain amplifiers is used to amplify the obtained signals. The signals are acquired by a 16bit ADC of the DAQ (BlueSetry from GridConnect) and transmitted to the accompanying person touch screen PC (it could be a server PC and IP network displays).

Digital filtering and detrending algorithms, based on digital wavelet transform [5], were implemented to assure accurate extraction of the heart rate and respiratory rate, even for low amplitude motion of the human subjects. However, better results on vital signs monitoring was obtained on stationary human since only the cardio respiratory motions are present in the field of view of the radar. Thus, the AC part of the radar output signal expresses the monitored physiological signals while stationary objects, in the background or even localized between the radar and subject body, result in the DC part of the output signal.

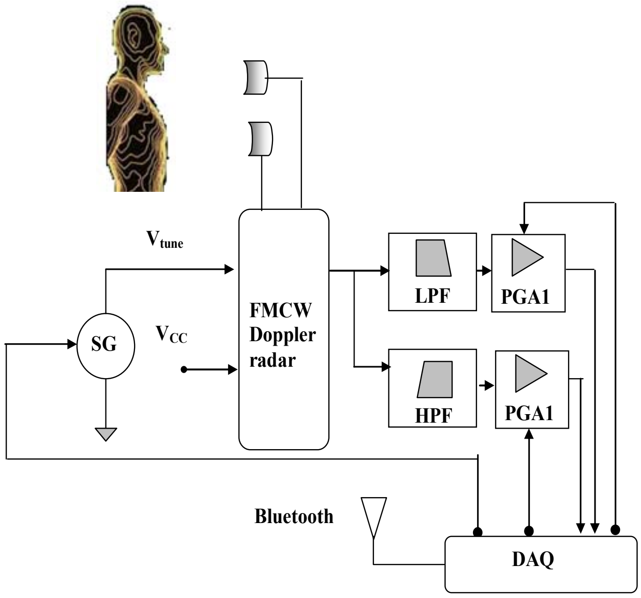


Figure 2. Sensing unit signal conditioning and data acquisition used architecture

The user motion and the distances between the radar and the user are also sensed and used to evaluate the subject motor activity during a specified period of time (e.g., daily motor activity).

IV. RESULTS AND DICUSSIONS

This work reports the first implementation of the cardio respiratory sensing units based on FMCW Doppler radar. Reliability tests were carried out with healthy volunteers sitting on the wheelchair.

In order to assure an optimal positioning versus the assessed subject, a set of measurements of the radar RF signals were done using a 40-40 GHz Rohde&Schwarz spectrum analyzer. Several tests were done for different distances between the Doppler radar and the target. One of them was done for minimum measurable distance, R_{min}=0.75m, as a distance between the radar and the 24GHz antenna attached to the spectrum analyzer. In Figure 3 is presented the spectrum evolution for 3m distance between the spectrum analyzer and radar antenna.

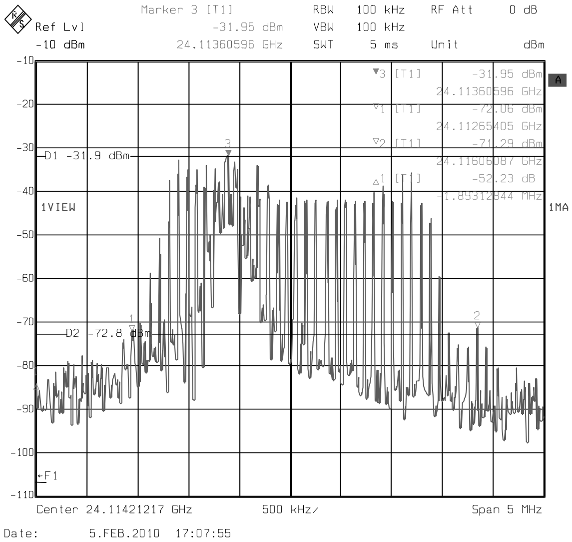


Figure 3. The FMCW Doppler radar spectrum for 3m distance between the spectrum analyser and radar antenna

A set of additional tests were done using the system described in Figure 1 and with the radar placed in front of the subject sitting on the wheelchair. Additionally, a reference BCG signal is delivered by an electromechanical film sensor (EMFi) embedded on the wheelchair level. Some results for 5s acquisition time are presented in Figure 4 and Figure 5.

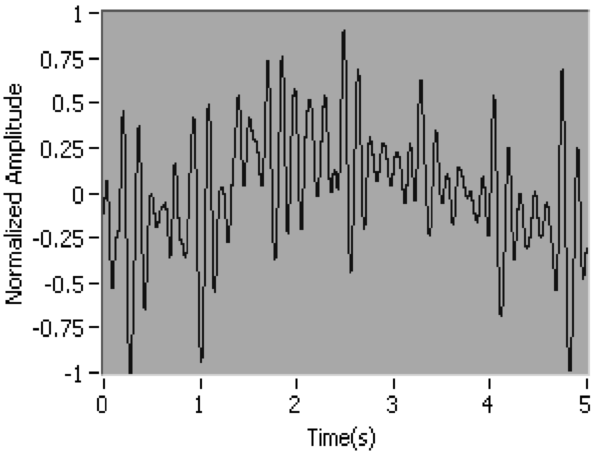


Figure 4. Reference BCG signal obtained from a EMFi ballistocardiography sensor localized ion the wheelchair seat

Analyzing the results presented in Figure 5 and Figure 6, the detection of the respiratory wave, by both used sensing units, can be underlined. The BCG signal measured, using an electromechanical film sensor, appears modulated by the respiratory signal (Figure 5). Using the high pass filter, characterized by f_c=0.5Hz, the BCG signal provided by the radar (rBCG) is acquired and processed to extract the heart rate. The rBCG signal for 60s time interval is presented in Figure 6.

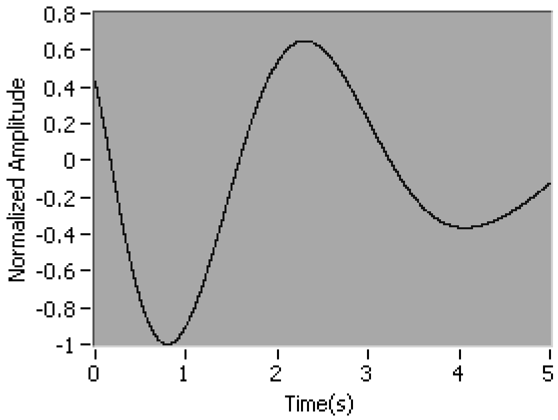
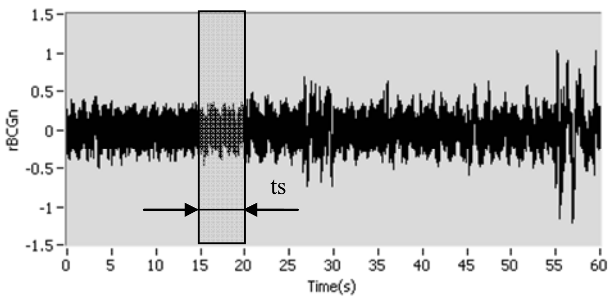
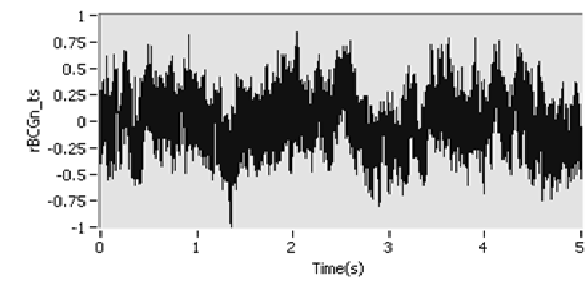


Figure 5. Processed FMCW Doppler radar output signal

As it can be observed in Figure 6.b, the exclusive usage of analog high pass filtering conducts to a rBCG characterized by high interference of the power line signal. To improve the signal-to-noise ratio (SNR) of the rBCG additional band pass digital filtering is applied. In the present case, different digital filtering algorithms were tested. Thus, for 5th order IIR Butterworth band pass filter characterized by $f1_c$=0.5Hz, $f2_c$=15Hz the signal obtained for 5s time interval is presented in Figure 7.a. In Figure 7.b is presented the reference BCG signal (BCGrefn) obtained from the EMFi L-series mounted on the seat of the wheelchair. The same digital filtering structure was used to filter the BCGrefn that is also affected by the power line interferences.



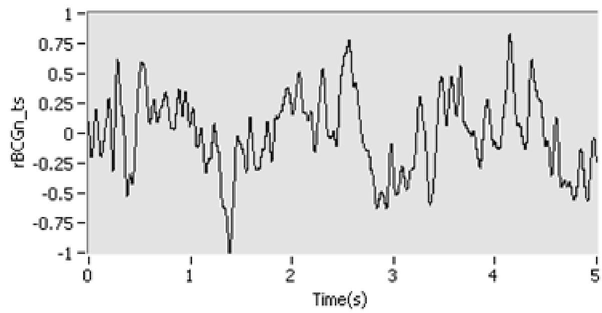
a)



b)

Figure 6. rBCG signal obtained after high pass analog filtering: a) normalized rBCG for 60s time interval; b) normalized rBCGn detail corresponding to ts=5s time interval

As it can be observed in Figure 7, the rBCG is still affected by artifacts. Digital wavelets detrend algorithm was included on the processing software in order to better highlight the I, J peaks of the rBCG, increasing the accuracy of the peak detection procedure used to extract the heart rate value.



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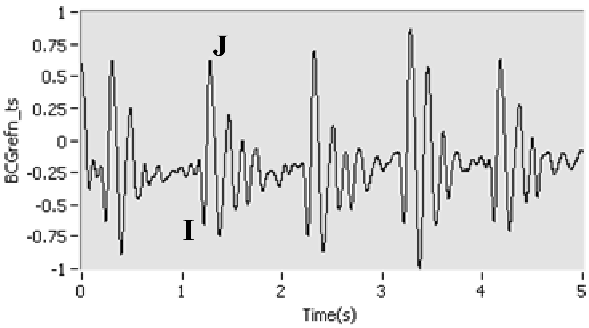
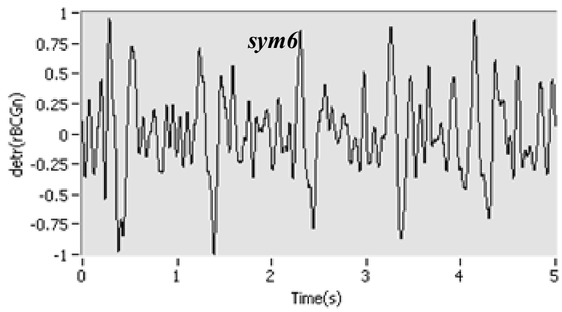
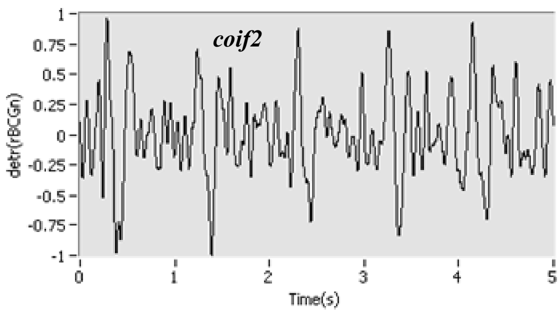


b)

Figure 7. Graphical comparison between the normalized rBCGP for ts time segment (a), and the normalized BCGref signal (b)



a)



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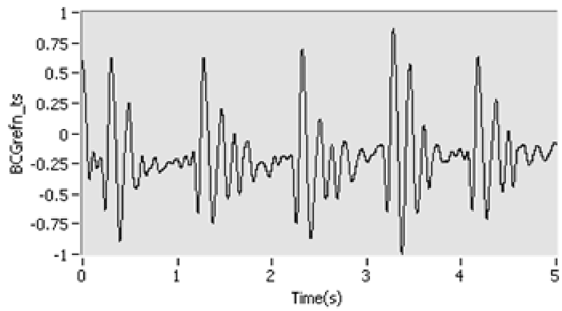

c)

Figure 8. Radar BCG signals - Wavelet detrending results: a) wavelet detrending based on 6th order symllets wavelet; b) wavelet detrending based on 2th order coiflet wavelet; c) reference BCG signal obtained from the EMFI sensor

The tested wavelets functions for discrete wavelet transform analysis were of orthogonal type (Haar, Daubechies (db*xx*), Coiflets (coif*x*), Symmlets (sym*x*)) and biorthogonal type (FBI, Biorthogonal (bior*x_x*)), where *x* indicates the order of the wavelet. Good results were obtained for high order of applied Coiflets and Symmlets mother wavelets. Figure 8 presents a graphic comparison between the detrending results when sym4 and coif4 were used.

After the application of the detrending procedure, the peak detection algorithm [18] was applied for 60s time segments for radar BCG signal and BCG ref signal and the heart rate are calculated. For signals of a set of five volunteers simultaneously acquired, the registered errors on the heart rate estimation, using the rBCG, were greater in about 2% than the registered errors when the BCG ref signal is used.

V. Conclusion

The work presents a pervasive healthcare architecture including sensors embedded in a wheelchair, bed and even on a wall. A set of conditioning circuits was designed and implemented in order to assure the control and analog signal processing of the signals associated with FMCW Doppler radar. A characterization of the used 24GHz radar was carried out and a comparative study regarding vital signs obtained using an EMFi sensor as reference for ballistocardiography was carried out. Experimental results concerning the respiration and cardiac activity assessment through the signal processing of the signals provided by the radar show the viability of this kind of sensor for unobtrusive health monitoring. A practical approach concerning wavelet based detrending techniques was done underlining the capabilities of coifet and symlett mother wavelets usage for rBCG signal.

Future work will focus on on-line signal processing and data presentation algorithms using low cost embedded processing platforms with limited processing capabilities.

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