Microwave Doppler radar in unobtrusive health monitoring

To cite this article: P Silva Girão *et al* 2015 *J. Phys.: Conf. Ser.* **588** 012046

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P Silva Girão[1], O Postolache[2], G Postolache[3], PM Ramos[1], JM Dias Pereira[4]
[1]DEEC/IST/UL, IT, Avenida Rovisco Pais, 1, 1049-001 Lisbon, Portugal
[2]ISCTE-IUL, IT, Avenida das Forças Armadas, 1649-026 Lisbon, Portugal
[3]Escola Superior de Saúde, Universidade Atlântica, Oeiras, Portugal
[4]EST/IPS, IT, Rua do Vale de Chaves, Estefanilha, 2910-761 Setúbal, Portugal

E-mails: psgirao@tecnico.ulisboa.pt, opostolache@lx.it.pt, gabrielap@uatla.pt, pedro.m.ramos@tecnico.ulisboa.pt, joseper@est.ips.pt

Abstract. This article frames the use of microwave Doppler radar in the context of ubiquitous, non-obstructive health monitoring. The use of a 24GHz CW (continuous wave) Doppler radar based on a commercial off-the-shelf transceiver for remote sensing of heart rate and respiration rate based on the acquisition and processing of the signals delivered by the radar is briefly presented.

1. Introduction

Since described in 1842 by Christian Johann Doppler [1] in the context of star motion, the Doppler Effect has been used in many applications namely for the measurement of physical quantities such as speed, flow, temperature with impact in areas such as cosmology and meteorology. Because Doppler based sensing solutions require no contact of the sensor with the sensed quantity, they are particularly attractive for medical applications and thus are the support of various ultrasound based equipment used primarily for non-invasive, non-intrusive and unobtrusive medical diagnosis of conditions including detection of foetal heartbeat, detection of air emboli, blood pressure monitoring, detection and characterization of blood flow, and localization of blood vessel occlusions (e.g. echocardiogram, Doppler ultrasound). New small size radar integrated devices, developed namely for automotive applications, paved the way to medical applications that require or advise the unobtrusiveness and pervasiveness permitted by Doppler sensing.

As it is well known, the Doppler Effect consists on the shift in frequency emitted by a sound or electromagnetic source and the one sensed by a receiver when the distance between the source and the receiver changes. If the distance between the source and receiver decreases, the acoustic or electromagnetic waves become closer (smaller wavelength) and thus the frequency of the received signal increases; if the distance between the source and receiver increases, the inverse happens, that is, the frequency at the receiver is lower than the emitted by the source. The distance may change either (a) because the velocities of the source and receiver are different (Figure 1 (a)) or (b) because the source and receiver are stationary at the same place but the waves emitted by the source are reflected by a moving body (Figure 1 (b). The shift in frequency and can be expressed by

$$\Delta f = \frac{\Delta v}{c} f_s \tag{1}$$

where $\Delta f = f_r - f_s$ is the frequency shift (difference between the frequency at the receiver and of the source), $\Delta v = v_r - v_s$ is either the velocity of the receiver relative to the source (case (a) above mentioned) or the velocity of the moving body (case (b) above mentioned), c is the velocity of the waves in the medium and f_s is the frequency of the source.

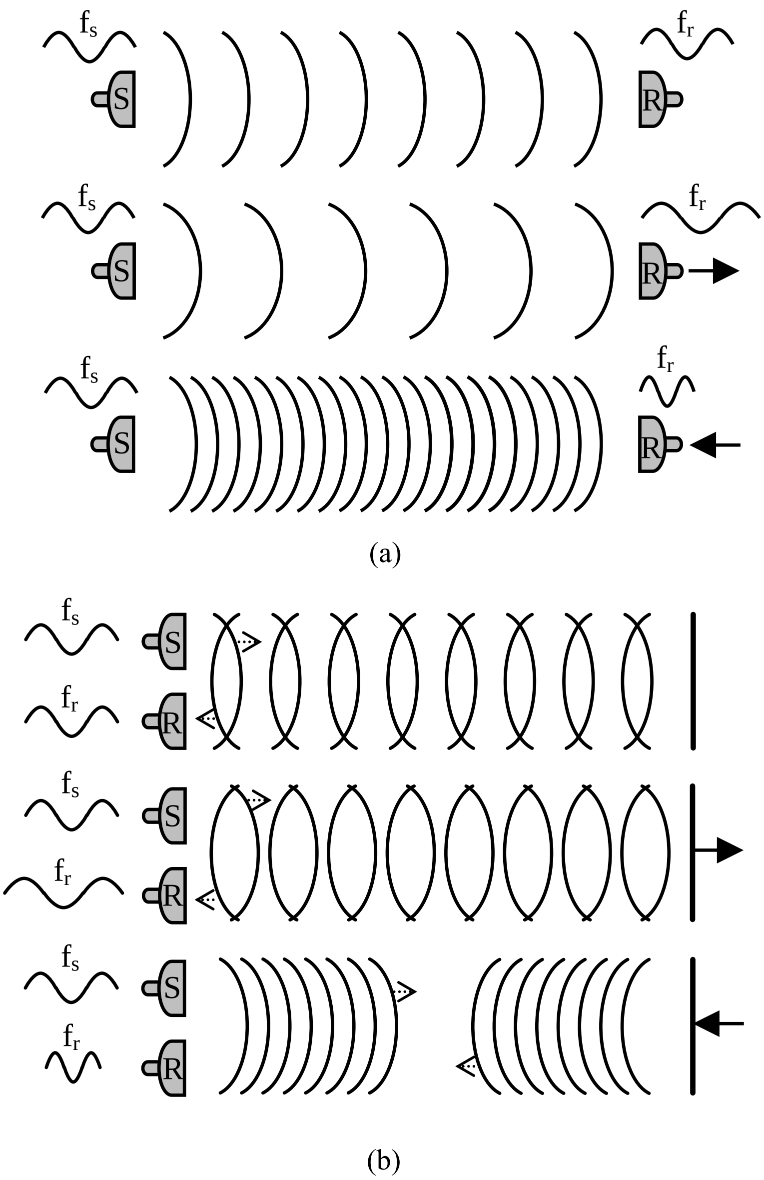


Figure 1. Doppler Effect: S – source; R – receiver; f_s and f_r frequency of signal at the source and at the receiver, respectively. (a) from top to bottom: distance S-R constant → $f_r = f_s$, distance S-R increasing → $f_r < f_s$, distance S-R decreasing → $f_r > f_s$; (b) from top to bottom: the same three situations but when S-R are stationary and the emitted wave face an obstacle (case that interests most biomedical applications

2. Health monitoring

Medicine – *ars medicina* in Latin, the art of healing - is an applied science and, as such, a never ending subject for research in all the three major aspects involved: diagnosis, treatment, and prevention of disease. Along the time, Medicine and been changing from a treatment centred science to a preventive one. Demography, social changes, and the rising costs of health and social care have driven that tendency: the health quality of people increases and the costs of health systems are reduced if illness is kept as low as possible and the first move in this direction is through prevention and early detection and diagnosis of diseases.

Health monitoring encompasses different activities namely clinical analysis, screening tests, diagnostic tests, medical exams, and self-exams. Image based tests have already reached the possibility of identifying molecules in a laboratorial environment [2] but no one will be surprised if in the future diseases can be detected, identified and perfectly characterized based only on image based common equipment. In the meantime, image equipment based on the Doppler Effect using ultrasound have been assisting health technicians in health monitoring, either in diagnostic but also for supporting continuous health care services.

In a recent work, The College of Fellows, American Institute for Medical and Biological Engineering (CF-AIMBE) considers that two of the six major challenges for medical and biological engineering in the 21st are e*ngineering personalized health care and engineering solutions to injury and chronic diseases* [3]. Personalized health care is only possible if appropriate data on each individual is available. This is the objective of electronic health records (EHRs) [4]. The authors have been working on this subject in Portugal and under a Portuguese funded project, are developing a platform for EHR filling, storage, and search and query. For several years the authors also share the view of the CF-AIMBE in what concerns the importance of assisting injured and the chronically ill.

Bearing in mind that demographics and costs lead to periods of internment in hospitals increasingly shorter, it is crucial to develop solutions that allow treatment and monitoring of health both in ambulatory and at home, either of the patient’s family or in nursing homes. This is particularly pertinent when elderly are at stake.

2.1 Unobtrusive, pervasive sensing

Equipment aimed at acquiring pertinent information of the physiological status of a person in non-hospital environments, namely during daily activity, must be as unobtrusive and pervasive as possible. Nowadays there are several solutions achieving these goals at different levels. Particularly, it is worth referencing here solutions and systems based on instrumented clothing (e-textiles) [5-7] because of the potential they bring to non-intrusive acquisition of physiological signals. The authors have been working and proposing unobtrusive and pervasive (ubiquitous) solutions [8-13] namely based on the use of non-conductivity electrodes [14,15] and ballistocardiography sensing [16-19], where the sensing part is embedded in wheelchairs and crutches [20].

3. Sensing with Microwave Doppler Radar

Sensing using the Doppler Effect is particularly suited for unobtrusive sensing. Ultrasonic medical imaging uses signals of 2 MHz and higher with power densities generally less than 1 W/cm^2. Ultrasound waves tend to reflect almost totally (up to 99% [21]) wherever air meets biological tissue. For this reason ultrasonic sensing requires not only contact of the source and receiver with the skin, but also that no air bubbles are in their interfaces. Sensing requires a probe, a gel that conducts well sound waves and an operator to handle the probe. Ultrasound sensing is thus not an alternative for pervasive sensing of physiological signals, particularly if the purpose is no contact between sensor and the person to monitor. Electromagnetic waves do not have the problem of ultrasound mentioned in the previous paragraph; they penetrate well non-metallic objects and thus the human body, which means that the source and receiver may be placed at some distance from the examinee.

Since de 1970s that it is known that microwave Doppler radar can be used for cardiovascular and respiratory measurements [22-23]. From then on, and until the 1990s, radar technology was slowly introduced in medical applications [24]. With the beginning of the current millennium, and due particularly to technological advances in ultra wide band (UWB) radio, radar technology has been increasingly used both for medical imaging and for heart rate and pulmonary motion monitoring [24-26].

Continuous wave (CW) Doppler radars are very sensitive devices in detecting movement, such as time varying physiological phenomena. But the electromagnetic wave reflected for instance by the chest and heart of a person, contains information namely about person's movement, respiration and blood circulation. To separate them, range information is necessary, which can be achieved using modulated signals such as pulsed signals or frequency modulated (FM) signals [27-31]. UWB radar is exactly based on pulsed signals and several medical applications have already been reported [32] namely for heart rate, respiration rate (RR), and heart movements recording [33,34]. Nevertheless, there is much to be done to take fully advantage of UWB radar for other medical applications, which may include apnoea, allergy, and asthma monitoring, without forgetting the potential negative effects of electromagnetic fields on humans.

In the framework of the work related to the implementation of pervasive, non-intrusive solutions for continuous monitoring vital signs of elderly, the authors have been studying the use of FM-CW radar through the implementation of devices and systems based on off-the-shelf components [35-38] namely as components of health monitoring systems installed in chairs, wheelchairs, and crutches.

3.1 FM-CW Doppler radar

In FM-CW Doppler radar the emitted signal is a constant amplitude sinewave (carrier) whose frequency is modulated by a triangular or sawtooth signal (modulating signal). The received signal is the sum of the signals resulting from reflections when the emitted signal faces a zone of characteristic impedance transition (that we will call an "obstacle"). The frequency of the received signal contains thus information of the position of the reflecting zones and also of their velocity if their positions relative to the emitted signal source are changing. Processing the received signal should then allow obtaining that information. Figure 2 shows an example of a sawtooth modulating signal when the emitted signal suffers a single reflection by an obstacle moving away from the emitted signal source.

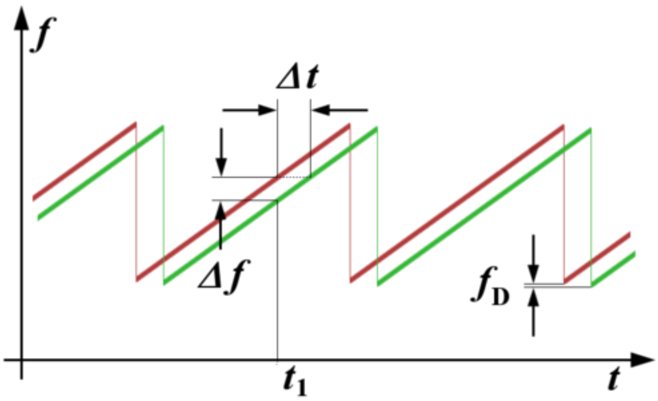


Figure 2. Sawtooth modulating signal of an FM-CW radar (red) and frequency demodulation of the received signal (green). Δt is a measure of the distance between emitter and obstacle and f_D a measure of the velocity at which the obstacle is moving away from the emitter.

When using FM-CW Doppler radar for health monitoring the situation is very different from the one depicted in Figure 2 because there are several sources of reflections, the received signal is a complex one, and thus identification of all reflecting sources is extremely different and only possible using signal processing techniques. The example present in the next section evidences this statement.

Figure 3 shows the simplified block diagram of a transceiver for FM-CW Doppler radar. In the simple case of Figure 2, the output of the mixer – intermediate frequency signal – allows determination of the distance between source and obstacle (range) and obstacle velocity.

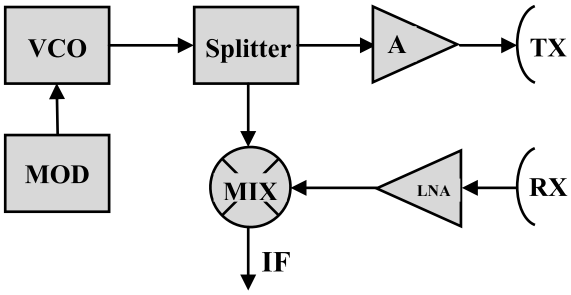


Figure 3. Block diagram of FM-CW radar transceiver: VCO – voltage controlled oscillator; MOD - modulator; A – amplifier; LNA – low noise amplifier; MIX – mixer; LPF – low pass filter; TX – transmitting antenna; RX – receiving antenna. IF – intermediate frequency signal.

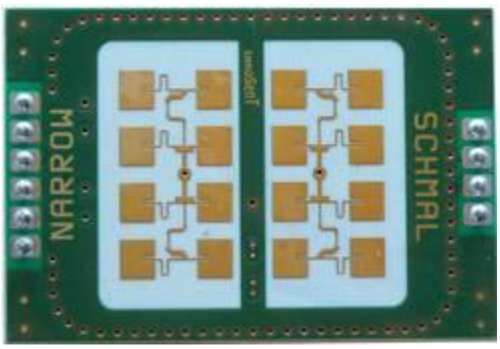
The space resolution Δd of FM-CW radar – minimum distance that can be measured - depends only on the bandwidth (BW) of the modulating signal and not on the base frequency of the carrier,

$$\Delta d = \frac{c}{2BW} \quad (2)$$

To detect and measure for instance chest movement due to respiration, which can be as low as 1mm, the modulating signal BW must be of 150 GHz! This value would require carriers of much higher frequency! This means that physiological parameters to obtain using radar must be based on velocity measurement and not on range detection.

4. Radar vital signals monitor (RVSM)

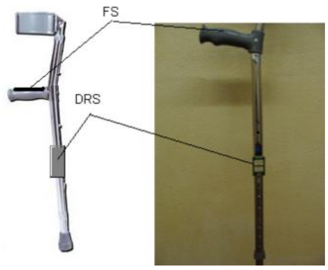
Heart rate and respiration rate are two basic vital signals and its monitoring represents the first step in health care. Figure 4 shows a commercial off-the-shelf (COTS) FMCW/FSK transceiver developed for automotive applications that the authors have been using namely for heart and respiration rate measurement. The transceiver VCO centre frequency is 24 GHz, the low limit of one of the industrial, scientific and medical (ISM) radio bands [39-40].



Parameter	Symbol	Min.	Typ.	Max.	Units
transmit frequencies	f		24.000 - 24.250		GHz
varactor tuning voltage	V_{tune}	0.5		10	V
tuning slope			40		MHz/V
temperature drift (frequency)	Δf		-1		MHz/°C
output power (EIRP)	P_{out}		15		dBm
IF-output	offset	1.0	2.2	4.0	V
IF-amplifier	bandwidth		DC - 50k		Hz
	gain		20		dB
full beam width @ -3dB	horizontal		45		°
	vertical		38		°
side-lobe suppression	horizontal		13		dB
	vertical		13		dB
supply voltage	V_{cc}	4.75	5.0	5.25	V
supply current	I_{cc}		35	50	mA
operating temperature	T_{OP}	-20		+60	°C

Figure 4. InnoSenT IVS-162 FMCW/FSK transceiver and its main specifications. The golden squares constitute the transmitting and receiving antenna.

The transceiver permits FM or FSK modulation; therefore measurement of distance as well as recognition of stationary objects is possible, depending on modulation. The receiving path includes IQ mixing - stereo (dual channel) operation -, which allows for direction of motion identification. The transceiver includes an IF pre-amplifier whose bandwidth is limited to 50 kHz for lowest noise performance. The transceiver dimensions (40x30x19 mm) and power requirements (5V/50mA) allow ubiquitous installation (e.g. crutches and walkers, Figure 5, for motion detection [38]).



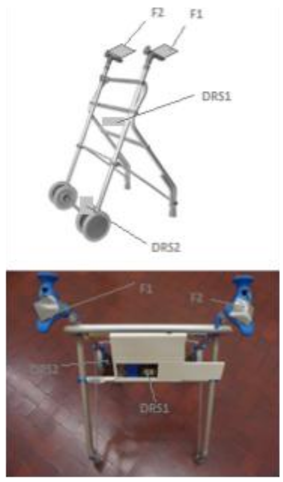


Figure 5. Smart crutch (top) and smart walker (right) (DRS, DRS1, DRS2 - Doppler radar sensors; FS, F1, F2 - piezoresistive force sensors).

Figure 6 shows the overall block diagram of the circuitry that implements the hardware component of a heart and respiration rate monitor based on InnoSenT IVS-162 transceiver developed by the authors [12].

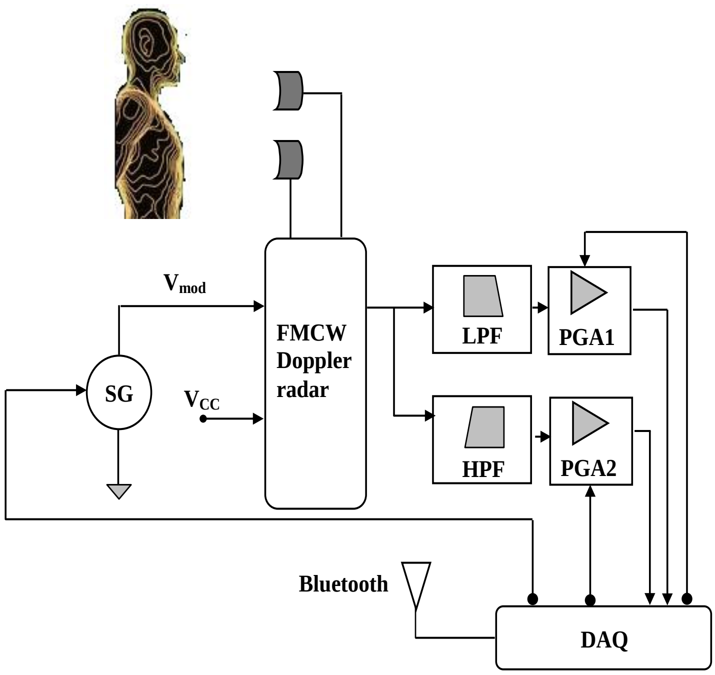


Figure 6. Heart rate and respiration rate non-intrusive measurement based on InnoSenT IVS-162 FM-CW Doppler radar transceiver: SG – signal generator; V_{mod} – modulating signal; V_{CC} – supply voltage; LPF – low pass filter; HPF – high pass filter; PGA1, PGA2 – programmable gain amplifiers; DAQ – data acquisition module.

A signal generator (SG) module, which is controlled by the Bluetooth data acquisition module (DAQ), delivers a voltage V_{mod} that modulates the VCO of the transceiver. The heart rate and respiration rate can be obtained by measuring the velocities of heart movement and of the chest. Thus, the radar is operated at a constant frequency selected by a constant value of V_{mod} and only IF signal in-phase with the transmitted signal (I component) is used to obtain both heart and respiration rates. For that purpose, the I component of the IF signal is filtered using a set of two active filters: an LPF (0.3 Hz), to extract the very low frequency breathing signal, and an HPF (0.9 Hz) to isolate the higher frequency signal associated with cardiac activity. Two programmable gain amplifiers, PA1 and PA2 increase the dynamic range of the filters output to take advantage of the 16bit ADC of a data acquisition module, DAQ (BlueSetry from GridConnect).

Figure 7 shows the signals IF and HPF output signals obtained from a stationary person. As can be seen, further processing is required to extract heart and respiration rate. The output of the LPF and HPF are digitized, transmitted to a remote processing unit (e.g. PC) for the removal of an eventual DC component in the IF signal resulting from reflections on stationary objects and for digital filtering and detrending algorithms, based on digital wavelet transform, applied to the resulting data.

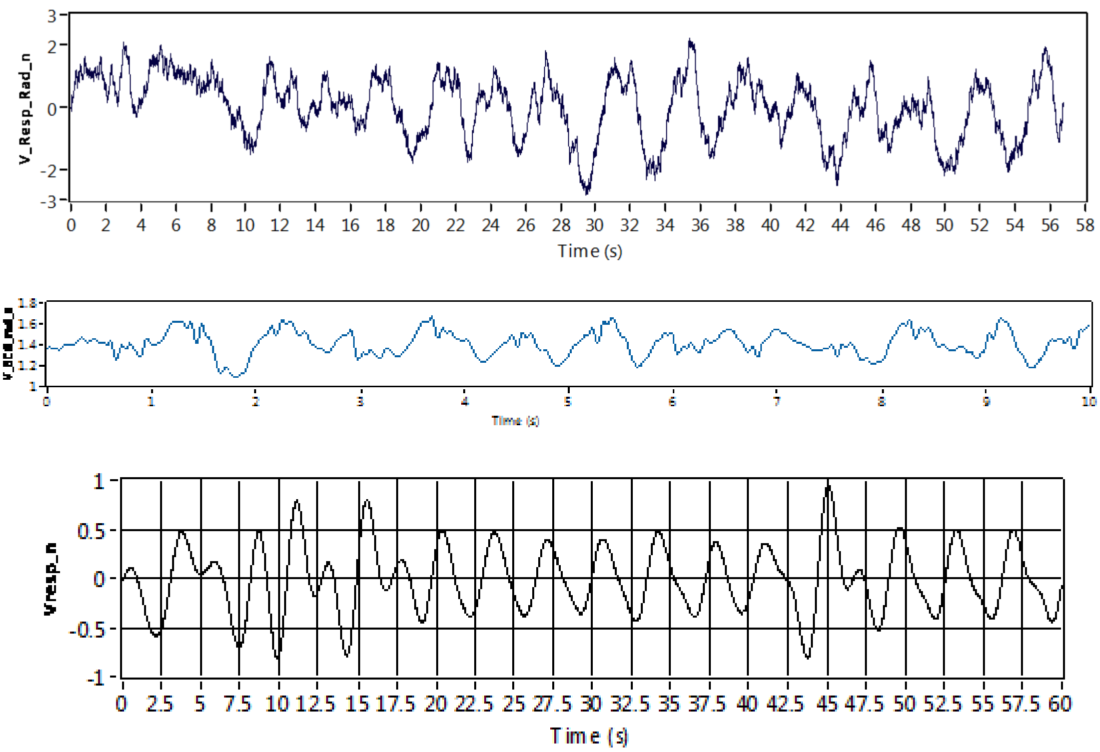


Figure 7. From top to bottom (arbitrary units): I-component of the Doppler radar IF signal taken from a stationary person; output of the HPF; output of the LPF.

The signals shown in Figure 8 were obtained with the same type of Doppler radar installed in a walker used by three different moving persons: one normal (normal gait), one suffering from myopathy (myopathic gait), and another from hemiparesis (hemiparetic gait). The signals are sufficiently different, but further tests and data processing are required to definitely claim the validity of the Doppler radar for people gait identification.

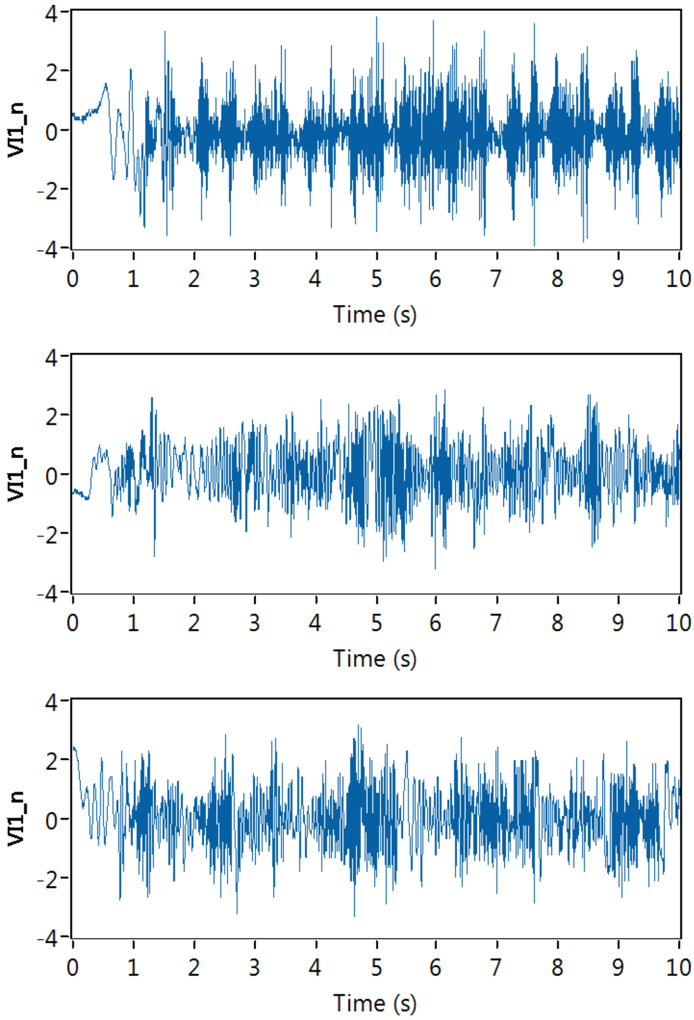


Figure 8. Gait sensed by a Doppler radar embedded in a walker (Vtune – 6 Vpp, f = 10kHz, triangular). From top to bottom (arbitrary units): regular gait; myopathic gait; hemiparetic gait.

5. Conclusion

Pervasive (ubiquitous) healthcare is a research field of increasing importance. Technological progress in areas such as materials, electronics, sensors, telecommunications, computer systems and signal processing have allowed the development of interesting and promising devices and systems appropriate to health care in non-hospital environment. Microwave Doppler radar is a fairly well establish technology, but its use for medical applications is still at a research stage, namely in what UWB radar is concerned. To the best of our knowledge, no device or system is currently in a market stage.

The heart and respiration rates are two vital signals fairly accessible to microwave radar usage. The 24GHz microwave CW (continuous wave) Doppler radar based monitor described in this paper is an example of what is possible nowadays. The results obtained validate the proposed solution, but only when measurements are made on stationary people. We look forward to demonstrating the efficiency of the monitor in environments where several people are in motion recurring to the possibility of frequency modulating the transmitted signal, which is possible with the transceiver used, and additional data processing. The authors will also go on researching the use of microwave Doppler radars in the monitoring of other physiological signals and persons activity and gait identification.

6. References

[1] Doppler C 1842 Über das farbige Licht der Doppelsterne und einiger anderer Gestirne des Himmels *Proc. Royal Bohemian Society of Sciences* Part V **2** 465-482 Prague
[2] Zhang R, Zhang Y, Dong ZC, Jiang S, Zhang C, Chen LG, Zhang L, Liao Y, Aizpurua J, Luo Y, Yang JL, Hou JG 2013 Chemical mapping of a single molecule by plasmon-enhanced Raman scattering *Nature* **498**, 82–86
[3] College of Fellows, American Institute for Medical and Biological Engineering 2013 Medical and Biological Engineering in the Next 20 Years: The Promise and the Challenges *IEEE Trans. on Biomedical Eng.* **60** 7
[4] Hoerbst A, Ammenwerth E 2010 Electronic Health Records. A Systematic Review on Quality Requirements *Methods Inf. Med* **4** 1-17
[5] Zysset C, Kinkeldei T, Cherenack K, Tröster G 2010 Woven Electronic Textiles: An Enabling Technology for Health-care Monitoring in Clothing *Proc. UbiHealth 2010* Copenhagen Denmark
[6] Pereira TP, Carvalho H, Catarino AC, Postolache O, Girão PM 2013 Wearable Biopotential Measurement Using the TI ADS1198 Analog Front-End and Textile Electrodes *Proc. IEEE Int. Symp. Medical Measurements and Applications – MeMeA* **1** 1-6 Gatineau Canada
[7] Catarino A, Carvalho H, Dias MJ, Pereira T, Postolache O, Girão PS 2012 Continuous Health Monitoring Using E-Textile Integrated Biosensors 2012 *Proc. Int. Conf. Exp. Electrical and Power Engineering (EPE 2012)* Iasi Romania
[8] Ribeiro MR, Postolache O, Girão PS 2014 A Novel Smart Sensing Platform for Vital Signs and Motor Activity Monitoring *Sensing Technology: Current Status and Future Trends I* Mason A, Mukhopadhyay SC, Jayasundera KP, Bhattacharyya N (Heidelberg: Springer)
[9] Postolache O, Girão PS and Postolache G 2013 Pervasive Sensing and M-Health: Vital Signs and Daily Activity Monitoring *Pervasive and Mobile Sensing and Computing for Healthcare - Technological and Social Issues* - Smart Sensors, Measurement and Instrumentation **2** Mukhopadhyay SC, Postolache OA 1–49 (Berlin Heidelberg: Springer-Verlag)
[10] Postolache O, Girão PS, Postolache G 2013 Comparative analysis of two systems for unobtrusive heart signal *Proc. Int. Conf. IEEE Engineering in Medicine and Biology Society – EMBC* **I** 1-4 Osaka Japan
[11] Postolache O, Girão PS, Ribeiro M, Guerra M, Pincho J, Santiago F, Pena A 2011 Enabling telecare assessment with pervasive sensing and Android OS smartphone *Proc. IEEE Int. Workshop Medical Measurements and Applications* 288-393 Bari Italy
[12] Postolache O, Girão PM, Pinheiro EC, Postolache G 2010 Unobtrusive and Non-invasive Sensing Solutions for on-line Physiological Parameters Monitoring *Wearable and Autonomous Biomedical Devices and Systems for Smart Environment* Lay-Ekuakille A, Mukhopadhyay SC (Berlin: Springer)
[13] Pinheiro EC, Postolache O, Girão PS 2010 A Survey on Unobtrusive Measurements of the Cardiovascular Function and their Practical Implementation in Wheelchairs *Sensors & Transducers Magazine* **9** 12 182-199
[14] Pinheiro EC, Postolache O, Girão PS 2013 Contactless Impedance Cardiography Using Embedded Sensors *Measurement Science Review* **9** 3 157-164
[15] Pinheiro EC, Postolache O, Girão PM 2012 A Practical Approach Concerning the Capacitive Acquisition of the Electrocardiogram in a Moving Wheelchair *Proc. IMEKO World Congress* **I** Busan, South Korea
[16] Pinheiro EC, Postolache O, Girão PS 2012 Study on ballistocardiogram acquisition in a moving wheelchair with embedded sensors *Metrology and Measurement Systems* **XIX** 4 739-750
[17] Postolache O, Girão PS, Postolache G 2011 Seismocardiogram and Ballistocardiogram Sensing *Int. J. Meas. Tech. Inst. Eng. (IJMTIE)* **1** 3 67-88

[18] Pinheiro EC, Postolache O, Girão PS 2010 Theory and Developments in an Unobtrusive Cardiovascular System Representation: Ballistocardiography *The Open Biomedical Engineering Journal* **4** 1 201-216
[19] Pinheiro EC, Postolache O, Girão PS 2009 Pulse Arrival Time and Ballistocardiogram Application to Blood Pressure Variability Estimation *Proc. IEEE International Workshop on Medical Measurements and Applications* **I** 132-136, Cetraro Italy
[20] Postolache O, Girão PS, Dias Pereira JM, Postolache G 2011 Smart Walker for Pervasive HealthCare *Proc. Int. Conf. Sensing Technology – ICST* **I** 1-5 Palmerston North, New Zealand
[21] Aldrich JE 2007 Basic physics of ultrasound imaging *Crit. Care Med.* **35** 5 S131-S137
[22] Lin JC 1975 Non-invasive microwave measurement of respiration *Proc. IEEE* **63** 1530
[23] Lin JC 1979 Microwave apexcardiography *IEEE Trans. MTT* **27** 618-620
[24] Øyvind Aardal and Jan Hammerstad 2010 Medical radar literature overview *Norwegian Defence Research Establishment (FFI) rapport 2010/00958*
[25] Xu Y, Lu YH, Zhang HX, Wang YQ 2007 An overview of ultra-wideband technique application for medial engineering *Proc. IEEE/ICME Int. Conf. Complex Med. Eng.* 408-411 Beijing PR China
[26] Staderini EM 2002 UWB radars in medicine *IEEE Aerosp. Elec. Syst. Mag.* **17** 1 13-18
[27] Pfanner F, Maier J, Allmendinger T, Flohr T and Kachelrieß M 2013 Monitoring internal organ motion with continuous wave radar in *CT Med. Phys.* **40** 9 091915
[28] Mostov K, Liptsen E and Boutchko R 2010 Medical applications of shortwave FM radar: Remote monitoring of cardiac and respiratory motion *Med. Phys.* **37** 1332-1338
[29] Mazlouman SJ, Tavakolin K, Mahanfar A and Kaminska B 2009 Contact-less Assessment of In-vivo Body Signals Using Microwave Doppler Radar *Biomedical Engineering* **13** 239-260 Mello CAB (InTech)
[30] Droitcour A, Lubecke VM, Lin J and Boric-Lubecke O 2007 A Microwave Radio for Doppler radar Sensing of Vital Signs *IEEE MTTS Int. Microwave Symp. Dig.* **1** 175-178 Phoenix AZ USA
[31] Guohua L, Jianqi W, Yu Y and Xijing J 2007 Study of the ballistocardiogram signal in life detection system based on radar *Proc. 29th IEEE EMBS Ann. Int. Conf.* 2191-2194 Lyon France
[32] Immoreev I and Ivashov S 2008 Remote Monitoring of Human Cardio-respiratory System Parameters by Radar and its Applications *Proc. Int. Conf. Ultrawideband and Ultrashort Imp. Sign.* 34-38 Sevastopol Ukraine
[33] Lazaro A, Girbau D and Villarino R 2010 Analysis of vital signs monitoring using an IR-UWB radar *Progress in Electromagnetics Research* **100** 265–284
[34] Bilich CG 2006 Bio-medical sensing using ultra wideband communications and radar technology: a feasibility study *Proc. Int. Perv. Health Conf. Work.* 1–9
[35] Postolache O, Girão PS, Dias Pereira JM, Postolache G 2011 FM-CW radar sensors for vital signs and motor activity monitoring *ICST Trans. on Ambient Systems* **11** 10-12 1-10
[36] Postolache O, Girão PS, Postolache G, Mendes J 2011 Cardio-Respiratory and Daily Activity Monitor Based on FMCW Doppler Radar Embedded in a Wheelchair *Proc. Int. Conf. IEEE Engineering in Medicine and Biology Society – EMBC* Boston USA
[37] Postolache O, Girão PS, Pinheiro EC, Madeira R, Dias Pereira JM, Mendes J, Postolache G, Moura C 2011 Multi-usage of Microwave Doppler Radar in Pervasive Healthcare Systems for Elderly *Proc. IEEE Int. Inst. Tech.Conf. - I2MTC* 30-34 Hangzhou PR China
[38] Postolache O, Girão PS, Madeira R, Postolache G 2010 Microwave FMCW Doppler radar implementation for in-house pervasive health care system *Proc. IEEE International Workshop on Medical Measurements and Applications* 47-52 Ottawa Canada
[39] Frequency ranges for global or regional harmonization of short-range devices 2011 *Recommendation ITU-R SM.1896*
[40] Limitation of radiation from industrial, scientific and medical (ISM) equipment Recommendation ITU-R SM.1056-1