UWB Platform for Vital Signs Detection and Monitoring

Ivana Čuljak, Hrvoje Mihaldinec, Zrinka Kovačić, Mario Cifrek, and Hrvoje Džapo

Abstract

In this paper a non-invasive method for vital signs detection and monitoring employing ultrawide bandwidth (UWB) technology is proposed. The idea behind the proposed approach is to use UWB technology to measure the variations in RF communication channel characteristics to detect vital signs. The feasibility of the proposed approach was experimentally tested with custom developed software and hardware platform, based on Decawave DW1000 M module. The platform was specifically designed and optimized to enable data acquisition of physical parameters with high sampling rate. The experiment consisted of placing UWB transmitter and receiver units in predetermined positions on the anterior and posterior thoracic wall where the transmitter generates an ultra-short UWB pulse with a minimum bandwidth of 500 MHz. From the channel impulse response (CIR) of the UWB channel measured at the UWB receiver the information about the heart muscle contraction is extracted. The heart muscle contraction detection algorithm exploits on the fact that the heart movements are periodic and therefore suitable for detection in frequency domain. The algorithm for feature extraction processes the sampled signal frequency spectrum, in order to estimate the heart rate. The obtained results showed the validity of the proposed approach and the performance of the proposed method was evaluated in comparison with commercial ECG device.

Keywords

Ultrawide bandwidth (UWB) • Vital signs monitoring
Heart rate detection • Biomedical instrumentation

1 Introduction

Early detection of the cardiac abnormalities can provide timely patient's diagnosis and as such could prevent further progression of the potential pathogenesis condition. UWB communication is based on sending very short pulses (duration from 100 ps to 1 ns) which occupy the minimum bandwidth of 500 MHz [1]. The Federal Communications Commission (FCC) specifies spectral and power limitation of the UWB technology in medical applications [2]. Features of ultrawideband (UWB) communication systems provide its application in numerous research fields, including monitoring and detecting human physiological parameters [3]. One of the first studies in the detection of human breathing and heartbeat through the wall by radar was proposed in [4] by Bugaev et al. After that there were also some further studies [5, 6] on the same topic. Related studies [7–9] proposed similar measuring technique but with different approaches in the implementation of feature extracting algorithm. In [7] four methods were proposed for detection of simulated heart rate using ultrawideband signals (based on variance, Fast Fourier Transformation (FFT), Wavelet and on Power Spectrum Density (PSD)). An algorithm for heart and respiration rate with UWB radar based on detection of movement energy in a specified band of frequency using wavelet and filter banks that contain other motion is proposed in [8]. Researchers proposed the harmonic path (HAPA) algorithm for vital signs monitoring based on UWB [9].

The existing approaches to the HR detection by means of UWB signals are based on a radar working principle where the electromagnetic energy propagated towards and through the body and it is reflected back from the tissue interfaces due to different relative dielectric constants of the organs [10]. In this paper we propose a different approach where a transversal method of measuring the changes in characteristics of the electromagnetic wave propagation path due to heart muscle activity are detected. We use the solution based on the commercially available UWB chip and module [11]. We employ similar algorithms for features extraction based

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L. Lhotska et al. (eds.), *World Congress on Medical Physics and Biomedical Engineering 2018*,
IFMBE Proceedings 68/3, https://doi.org/10.1007/978-981-10-9023-3_7

on variance and FFT, as described in [7]. The measurement method and algorithm are elaborated in Sect. 2. The preliminary experimental results of the proposed measurement method are presented in Sect. 3.

2 Measurement Method Description

2.1 Theoretical Background

The proposed method is based on the assumption that the heart motion is continuously changing the communication channel parameters and thus modulates the observed signal power on the receiver side; under the assumption that the transmitted signal power and mutual position of transmitter and receiver units do not change over the time. It has been shown that the signal propagation in a human body is significantly attenuated due to the muscle tissue layer variations in all frequency bands [12]. The UWB module [11] used as a basis for our custom-designed measurement system provides a real-time information about the channel impulse response (CIR), which is described in details in [13]. By measuring CIR we can detect variations in reflection and absorption rates at the receiving end for the uniformly transmitted signal. With continuous measurements in the observed time interval we should be able to detect the motion of the heart muscle and with its rate of change. To ensure the maximum signal absorption rate (SAR), the antenna was placed no less than 1 cm from the human body, as it was shown in [14]. Due to the significant difference of the dielectric properties of an inflated lung and deflated lung in the proposed method, to minimize this effect measurements were executed during the retained exhale phase.

2.2 System Description

The prototype hardware module shown in Fig. 2 is based on the Decawave DWM1000 M module [11]. The DW1000 chip [11] is IEEE 802.15.4-2011 compliant and provides high communication data rate (up to 6.8 Mbps), with optional simultaneous measurement of transmit and receive timestamps with a resolution of 15.6 ps. Furthermore, the chip provides large bank of memory that holds the accumulated channel impulse response (CIR) data. Data contains 992 or 1016 samples with complex values, a 16-bit real integer and a 16-bit imaginary integer for nominal pulse repetition frequency (PRF) of 16 or 64 MHz respectively [13]. The size of the printed circuit board (PCB) is 60 x 25 mm s shown in Fig. 1, which makes it suitable for on-body placement and measurements. Software stack is based on FreeRTOS operating system. The sampling rate of the system was set at 50 ms, where each sample represents the current CIR reading.

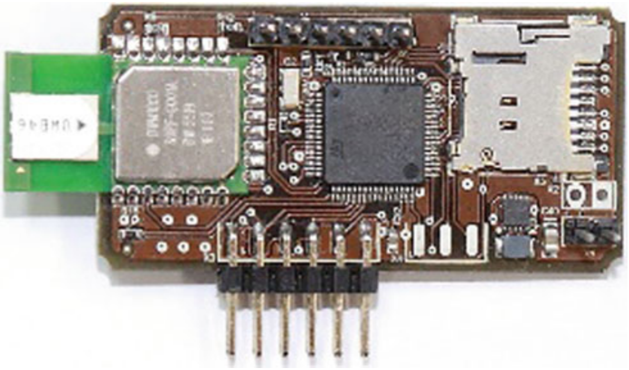


Fig. 1 Developed UWB platform based on Decawave DWM1000 M module

The ECG waveform was recorded simultaneously with the commercially available ECG device Shimmer3 [15], which provides a configurable digital front-end for 5-lead ECG measurements with sampling rate set at 512 Hz. ECG vector from the right arm (RA) position to the LA (left arm) position was measured on Lead I. To synchronize the measurements between our test system and ECG reference device, the trigger signal from module was used and directly connected to the ECG lead. The pin was triggered when the UWB module started the measurement and stopped at the end of the predetermined measurement window (Fig. 2).

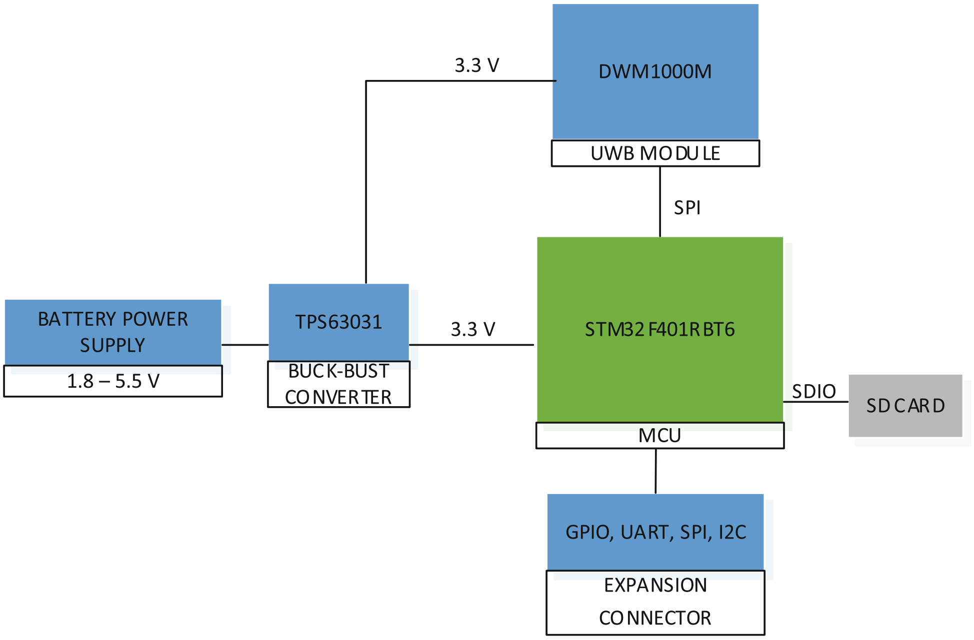
2.3 Experimental Setup

The UWB transmitter and receiver units were placed on the anterior and posterior thoracic wall of the test subject. Measurements were conducted on a 25-year-old female subject. To minimize non-related effects, the subject was asked to exhale and sit still for 10–30 s while readings were captured. The antenna placement is shown on Fig. 3. Chip antenna of DW1000 M module was placed no less than 1 cm from the skin. The experiments were executed with variable channel settings given in Table 1 to ensure the validity of the platform and the proposed algorithm. The CIR accumulator was sampled every 50 ms and logged on the SD card for offline processing.

2.4 Algorithm for Heart Rate Detection

In this study we applied a basic algorithm for heart motion estimation, like the method described in [7]. The first step was to remove background clutter by subtracting the average value of the CIR accumulator with the originally received CIR data. Then we applied the moving average filter to increase a dynamic effect of the heart motion. Finally, the

Fig. 2 Block diagram of the developed UWB module



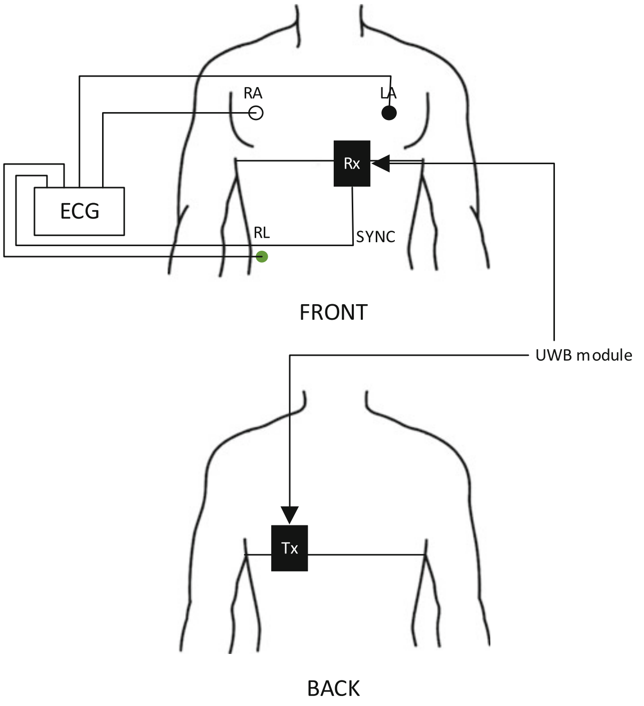


Fig. 3 The experimental setup for monitoring heart rate activity with UWB transmitter and receiver

Table 1 Parameters of the DWM1000 used in experiments

Channel	f_c (MHz)	BW (MHz)
2	3993.6	499.2
4	3993.6	1331.2
5	6489.6	499.2
7	6489.6	1081.6

total energy in time was calculated to show absorption due to the cardiac cycle. We expect that the maximum energy expressed at the end of the systole when heart is contracted, and the minimum value of the energy at the end of the diastole when the heart is full of the blood. Then we apply FFT on all calculated total energies in one measurement. In the frequency domain we estimate the HR and compare it with the commercial ECG device to validate our measurement setup. The R peaks were detected by means of Pan Tompkins algorithm [16]. The error rate is expressed in

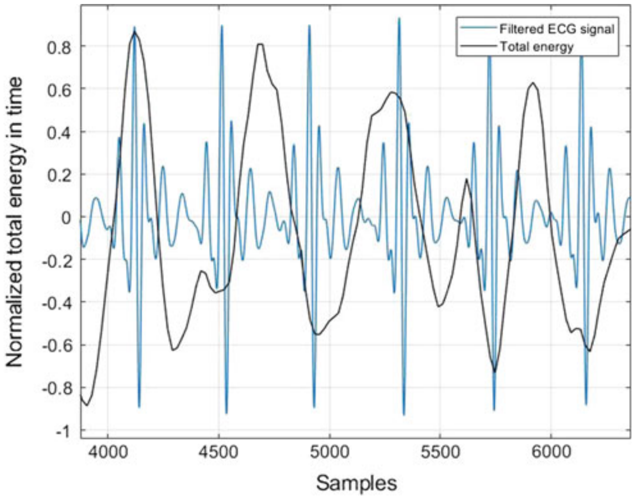


Fig. 4 Comparison of the normalized total energy in time $E(t)$ with the filtered ECG signal: for UWB parameters channel 4, PRF 64 MHz; BT 6.8 Mbps

Table 2 Heart rate error rate obtained by experiment

Meas. No.	Meas.duration (s)	UWB Parameters [11]	Ref. HR frequency [Hz]	Estimated HR frequency [Hz]	ER (%)
1	15.16	CH5, 16 MHz, 6.8 Mbps	1.31	1.25	4.99
2	13.49	CH7, 16 MHz, 6.8 Mbps	1.18	1.18	0.00
3	20.50	CH2, 16 MHz, 6.8 Mbps	1.21	1.26	4.00
4	25.08	CH4, 16 MHz, 6.8 Mbps	1.31	1.11	15.15

percentage as a difference in the HR frequency estimated by our device and the reference ECG system.

3 Results

We conducted several series of measurements following the measurement procedure described in the Sect. 2. In the Fig. 4 the $E(t)$, calculated from sampled CIR variations in time, is plotted along with simultaneous measurements acquired by means of reference ECG device.

The results shown in Fig. 4 show comparison of the normalized signal of the total energy in time E(t) with the filtered ECG signal for one case of UWB communication parameters. The results are very promising because one can visually notice very good agreement of the waveforms in terms of following the activity related to heart rate. Our results also exhibit good heart motion estimation for all tested UWB channels. The y-axis provides the normalized signal in reference to maximum values of the total energy in time. Additionally, error rates in HR detection were calculated presented in Table 2.

4 Conclusion

In this paper we proved that it is feasible to detect heart muscle motion and heart rate relatively accurately by using off-the-shelf UWB chips, employing the transversal method of measuring the changes in characteristics of EM wave propagation media due to the heart muscle activity. Previous studies have shown that it is possible to use a radar principle in conjunction with UWB technology to detect heart rate but such approach requires costly laboratory equipment. The proposed method is implemented in custom-designed prototype device which is suitable for low–power, low–profile, safe, contactless and inexpensive vital signs monitoring system solution, that can be tailored to achieve the high performance for various specific applications. The future research will focus on further investigation on the most useful parts of the information and efficient algorithms for extracting the information contained in the CIR accumulator.

Acknowledgements This research has been supported by the European Regional Development Fund under the grant KK.01.1.1.01.0009 (DATACROSS).

Conflict of Interest The authors declare that they have no conflict of interest.

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