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Measurements Performance of a Bioradar for Human Respiration Monitoring

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Abstract

Breathing pattern monitoring of humans is very important especially during long isolation in space missions. In particular, several factors can induce some breathing anomalies during the sleep, which may cause apnea episodes; an early diagnosis of such episodes is crucial for the application of an efficient therapy.

Continuous wave bioradars operating in the microwave frequency range are effective contactless tools for monitoring the respiratory activity. These active systems emit a low power electromagnetic wave at a single frequency, which is reflected by the human chest. Based on the phase difference between the incident and reflected signals, it is possible to estimate and monitor the respiratory rate.

In this paper, a metrological characterization of the bioradar methodology is presented. To this end, bioradar results are compared with the ground truth data recorded by a spirometer, which is a standard medical device that measures the air volume inhaled and exhaled by the subject.

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Keywords: Bioradar; breathing monitoring; remote sensing.

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1. Introduction

Bioradars for contactless detection of vital parameters are important in several applicative areas such as security, medical diagnostics, and space medicine [1,7]. Their primary function is the remote (contactless) detection of breathing

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activity based on the phase modulation of the radar signal caused by the expansion and contraction of human chest [1,2]. The detection of vital signs in crisis situations is fundamental to save lives [4]. Recently, non-contact microwave based transceivers have been also proposed as diagnostic tools in the biomedical field [5,7].

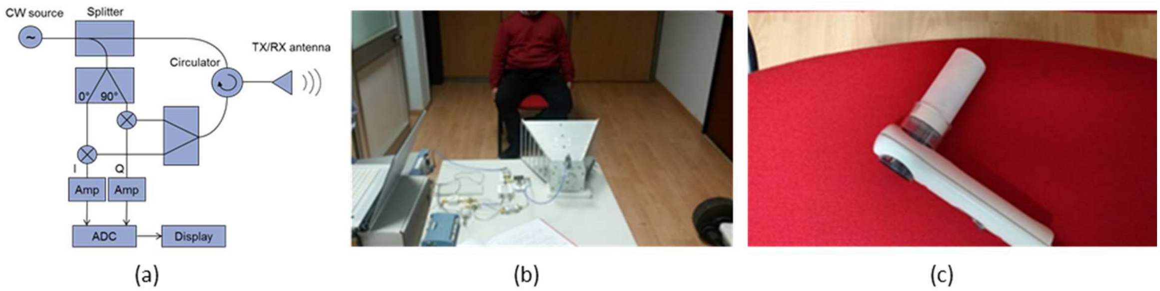
The goal of this work is to assess the metrological performance of a bioradar for breathing rate estimation in a free-space scenario. To this end, a standard medical device for air volume measurements is used as a benchmark for comparison purposes.

2. Apparatus and method

The bioradar considered in this investigation is a continuous-wave radar with quadrature receiver (see Fig. 1a for the radar architecture), which has been developed at IREA-CNR by using commercial off-the-shelf RF components. The system has approximate size of 284×184×252 mm and operates at discrete frequencies in the range from 1.8 to 3 GHz. As shown in Fig. 1a, the signal emitted by the RF source is partially radiated and partly used to generate two reference signals with ninety degrees phase offset, which are exploited to down convert the reflected signal at baseband. The outputs of the mixers are the in-phase (I) and quadrature (Q) components of signal reflected by the subject. The baseband I and Q signals are after amplified and digitized for subsequent data processing. The system adopts a single antenna (horn with 10dB gain) thanks to the use of a circulator that decouples the transmit and receive channels. The system is equipped with a graphical interface allowing the data acquisition and processing.

Different demodulation schemes have been proposed to exploit the information carried by I and Q signals [1]. In this work, for sake of simplicity, we select one between the I or Q signal on the basis of the highest peak-to-peak variation in order to achieve a satisfactory sensitivity. After a band-pass filtering, the breathing rate is estimated from the Fourier spectrum of the radar signal.

The measurement set-up considered for this study is illustrated in Fig. 1b. During the experiments, the subject sits in front of the radar breathing normally and, simultaneously to bioradar operation, a spirometer (Fig. 1c) records the volume of air inhaled and exhaled by the subject thanks to a digital turbine flowmeter. Therefore, the parameter measured by spirometer is the magnitude of airflow, which has a periodic behavior due to the inhalation and exhalation phases. A spectral analysis of the spirometer signal allows to estimate the reference breathing rate.



(a) (b) (c)

Fig. 1 (a) Radar system architecture. (b) Measurement set-up. (c) Spirometer.

3. Measurements Results

During the tests, an adult male subject (50 years old, weight 75 kg) was sitting in front of the radar at a stand-off distance of 1.5 m. Three different operating frequencies (2.1, 2.4, 2.6 GHz) were selected to assess the metrological performance of the radar system. In particular, ten independent measurements were carried out at each frequency. For each measurement, the bioradar and the spirometer recorded data simultaneously over a time window of 30 s.

An excellent agreement is observed in Fig. 2 when comparing the bioradar and spirometer signals. The breathing rates obtained for each frequency and trial are summarized in Table. 1. These data highlight a good match confirming the bioradar capability to detect the respiratory rate with good accuracy. This claim is supported also by the curves of the relative percentage error of breathing rate plotted in Figs. 3a-c. The average error for the three frequencies was equal to 3%, 3.8%, and 5%, respectively.

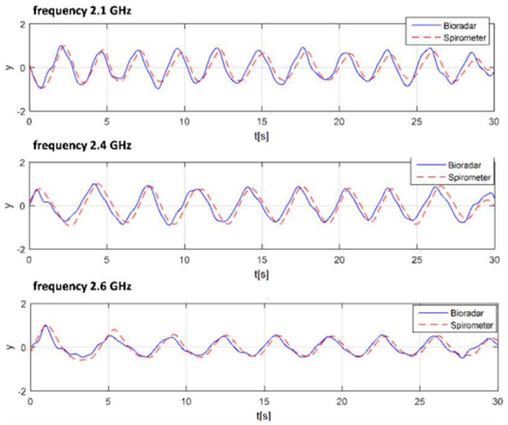
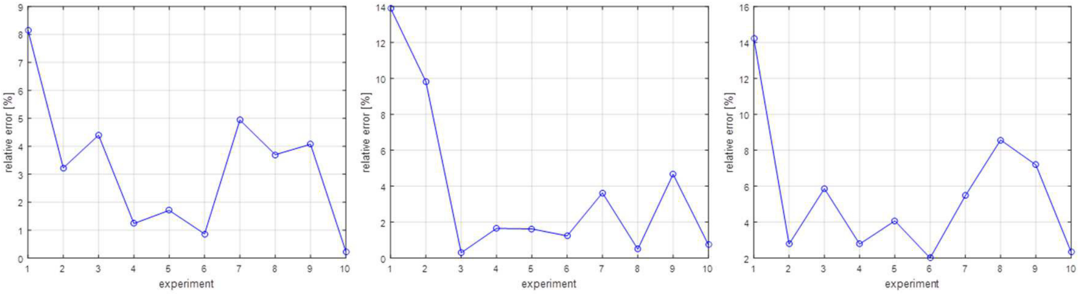


Fig. 2 Comparison of bioradar and spirometer signals at 2.1, 2.4, 2.6 GHz for a single experimental test.

Table 1 Comparison between breathing rates recorded by bioradar and spirometer

Test	2.1 GHz		2.4 GHz		2.6 GHz	
	Bioradar[Hz]	Spirometer[Hz]	Bioradar[Hz]	Spirometer[Hz]	Bioradar[Hz]	Spirometer[Hz]
1	0.322	0.350	0.327	0.287	0.301	0.350
2	0.365	0.383	0.299	0.331	0.325	0.334
3	0.332	0.347	0.340	0.341	0.275	0.293
4	0.331	0.335	0.310	0.315	0.302	0.292
5	0.306	0.301	0.324	0.329	0.251	0.261
6	0.348	0.350	0.325	0.329	0.279	0.274
7	0.349	0.333	0.317	0.328	0.275	0.292
8	0.272	0.262	0.320	0.319	0.250	0.273
9	0.251	0.262	0.338	0.323	0.252	0.272
10	0.349	0.348	0.312	0.314	0.273	0.280



(a) (b) (c)

Fig. 3 The relative percentage error of breathing rate at three frequencies. (a) 2.1 GHz, (b) 2.4 GHz, (c) 2.6 GHz.

4. Uncertainty of measurement process

The measurement standard uncertainty was computed as the sum of two contributions [8]: the first one u_A estimated by performing the statistical analysis of the set of performed measurements; the second one u_B is based on scientific judgment using all of the relevant information available about the measurement. Finally, the extended uncertainty was calculated as the double of the composed uncertainty, i.e.

$$U_\mathrm{e} = 2 \cdot \sqrt{u_A^2 + u_B^2} \tag{1}$$

The first contribution u_A is evaluated by means of the arithmetic mean

$$u(\bar{x}_i) = \frac{s_i}{\sqrt{n_i}} \tag{2}$$

where s_i is the experimental standard deviation

$$s_i = \sqrt{\frac{\sum_{q=1}^{n_i}(x_{iq} - \bar{x}_i)^2}{(n_i - 1)}} \tag{3}$$

By assuming *n* statistically independent observations (*n* > 1); x_{iq} is the measured value, $\overline{x_i}$ the average value of the measured value.

The second contribution u_B can be evaluated under some assumption. An interval [x_{imin}, x_{imax}] is considered where the uncertainty has the same value in each points. In this way, it is possible to assume an uniform probability distribution inside the interval of width x_{imax} - x_{imin}. equal to:

$$u(\overline{x_i}) = \frac{x_{imax} - x_{imin}}{2 \cdot \sqrt{3}} \tag{4}$$

The estimated values for the extended uncertainty are reported in Table 2 together with the average breathing rates.

Table 2 Measurement results with uncertainty value

Bioradar frequency used	2.1 GHz	2.4 GHz	2.6 GHz
Measured value ± uncertainty	(0.320±0.06) Hz	(0.321±0.02) Hz	(0.270±0.04) Hz

5. Conclusions

This work has presented a comparison between two measurement techniques: electromagnetic bioradar, innovative technique, and the spirometer, standard medical technique. Both techniques allow to monitor the human breathing, which may suffer from disturbance especially in the nocturne phase during long isolation as the space mission. An interesting result has been obtained by the comparison between the uncertainties of bioradar and spirometer. It has been found that, in the worst case, the uncertainties are less than or equal to 20 percent of the reading value. Since both uncertainties have the same order of magnitude, of course this result is due to the measured variable for physiological reasons. A notable uncertainty reduction is achieved at higher operating frequencies of the radar. Indeed, at higher frequencies, it is possible to evaluate with a greater accuracy the chests movements and consequently the breathing pattern.

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