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Mental stress detection using bioradar respiratory signals

José Raúl Machado Fernández [a,*], Lesya Anishchenko [b]

[a] Havana Technological University "José Antonio Echeverría" (CUJAE), Havana, Cuba
[b] Bauman Moscow State Technical University (BMSTU), Moscow, Russia

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ABSTRACT

Stress detection techniques seek to provide an accurate assessment of mental health. This paper presents a new stress detection technique based on signals taken by a bioradar. The main advantage of this approach is its non-invasive nature since it uses a non-contact concealed mechanism that does not require the direct interaction between the person and the measuring device. In addition to being one of the first solutions based exclusively on respiratory signals, the novelty of the research also lies in the use of Recurrence Quantification Analysis (RQA) features on respiratory recordings. The RQA features, traditionally applied for heart rate measurements, allowed reaching a precision of 94,4% after the leave-one-subject-out-cross-validation using a multi-layer perceptron.

1. Introduction

Mental stress is one of the fundamental problems of today's society. The high workloads and the variability of modern life, among other factors, disturb people's mental health, causing different effects. Previous studies have reported mental stress as one of the major contributing factors leading to various diseases such as depression [1], stroke [2], sleep disorders [3], heart attack and cardiac arrest [4,5].

Although there are numerous techniques for the treatment and prophylaxis of this condition, most assume that an expert examiner, the patient or people close to him, detect symptoms of stress. However, sometimes individuals who are under stress show no signs of their condition, or exhibit signs which are hard to notice.

Stress detection techniques are helpful tools in such situations since they facilitate the monitoring of stress levels. These methods are generally based on the processing of physiological signals such as: blood pressure [6], heart rate [6], heart rate variability (HRV) [7], skin conductance [8,9], level of cortisol [10,11], pupil diameter [12] and facial gestures [13], among others. The objective of these methods is to detect stress with a high level of accuracy, causing a minimum of discomfort to the patient.

This paper introduces a new method for the detection of mental stress using only respiratory patterns taken by a bioradar, avoiding the introduction of more complicated vital signs. One of the main advantages of the approach is its non-invasive nature, since the signals are taken by a non-contact method that establishes no direct physical interaction between the individual and the measuring device. Non-contact methods have experienced a growing interest by the scientific community thanks to the high acceptance of patients [14].

Even when samples were taken by a fixed laboratory equipment, there are modern implementations of the technology in small size devices [15,16]. In addition, the processed signals contained variations in the mean level and exhibited marked differences in the breathing rate from one subject to another, which supports the idea that the solution may be applicable in real environments.

Also, it should be noted that, until present work, heartbeat signal analysis had been mainly used for detecting mental stress by means of Doppler radar. For example, in [17] it was shown that the mean heartbeat frequency could be used to estimate exami-neesí reaction to mental stress. However, the accurate detection of heartbeat patterns using bioradars may be quite challenging, if not an impossible task, for subjects with body mass index greater than 25, whereas respiratory patterns can be reliably detected. This makes the proposed method applicable to a wider range of users.

2. Materials and methods

Bioradars provide the opportunity to detect persons remotely even behind opaque obstacles [18]. The proposed method is based on radar signal modulation by oscillatory movements of human limbs and internal organs. Electromagnetic wave reflected from human body contains specific biometric modulation, which is not present when interacting with motionless objects. The main cause

* Corresponding author.
E-mail addresses: josemf@electrica.cujae.edu.cu (J.R. Machado Fernández), anishchenko@rslab.ru (L. Anishchenko).

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of such signal changes for a person at steady state are contractions of heart and vessels, and reciprocal movements of chest wall and abdomen areas caused by respiratory muscles performance. Patient's physical activity, together with medical and psychological states, regulates the values and variation of these fluctuations.

2.1. Data-base and device

One minute sequences were used for the detection of the stress state, with data recorded in 2014 and 2017 by students of the Bauman Moscow State Technical University. A total of 43 subjects (26 males and 17 females) in the age group between 18 and 22 years participated in the study. All subjects gave confirmed consent for their voluntary participation in the research. A detailed explanation was given to them about the procedure prior to the start of the experiments.

During the trial, a subject sat in front of the bioradar at the distance of 1 m from the antennas. The test consisted of two measuring stages: one for the steady state and other for the mental stress state. During the first stage, the examinee was asked to relax and breathe normally. To imitate stress at the second stage, the standard mental load test was used, asking the subject to solve a simple mathematical problem. For each experimental stage, the trial lasted at least one minute.

As the procedure aimed exclusively at collecting data for steady and stress states, the difficulty of the mathematical problem was not altered nor were changed any other conditions. So, no information was gathered for identifying different stress levels in this first approach to the problem.

Not all records were found to have sufficient quality for further analysis. For some subjects, valid recordings were stored only for one of the two valid states (steady or stress). For others, two minutes were stored, which allowed to produce two separate samples from one recording. The final set contained 108 samples of one minute (54 for steady and 54 for stress), taken from 43 different subjects.

Information about the studied subjects is given in Table 1. In addition, the characteristics of the recording device, the multifrequency Doppler radar BioRASCAN-4 designed at Bauman Moscow State Technical University, are shown in Table 2.

Table 1
Information about the studied subjects.

Male: Female	26 : 17
Age (Years)	$19,9 \pm 0,7 (18-21)$
Body Mass Index (kg/m^2)	$22,1 \pm 3,5 (16,8-32,0)$
Breathing Rate (breath per minute)	$19,08 \pm 5,87 (8-36,85)$

Table 2
Characteristics of BioRASCAN 4.

Number of frequencies	16
Operating frequency range (GHz)	3,6–4,0
Modulation type	stepped frequency
maximum radiated power density (μW/cm^2)	1,36
Dynamic range (dB)	60
Analogue bandwidth (Hz)	0,01–10

2.2. Pre-processing

Pre-processing is a pre-requisite for the extraction of effective features. The samples taken by the bioradar were filtered by using a band-pass filter that removed base-line and preserved the fundamental respiratory information. Low-pass cut-off frequency and high-pass cut-off frequency were 0,001 Hz and 0,7 Hz respectively. Then, a zscore normalization was applied, which consist in dividing each sample by the standard deviation of the set with the purpose of forcing the standard deviation to 1. Finally, the available datasets were downsampled to a normalized sampling frequency of 0,1 Hz.

Time and RQA (Recurrence Quantification Analysis) features were extracted from the normalized data, while the frequency features were computed from the raw data to preserve frequency components. Fig. 1 shows how the breathing signal looks before and after pre-processing.

Analysis of experimental bioradar signals revealed that the level of the heartbeat signal was too low for accurate heart rate measurement. Therefore, the processing focused exclusively on respiratory signals. Hypothetically, bioradar devices should record all physical movement through the Doppler effect but movement of the thorax

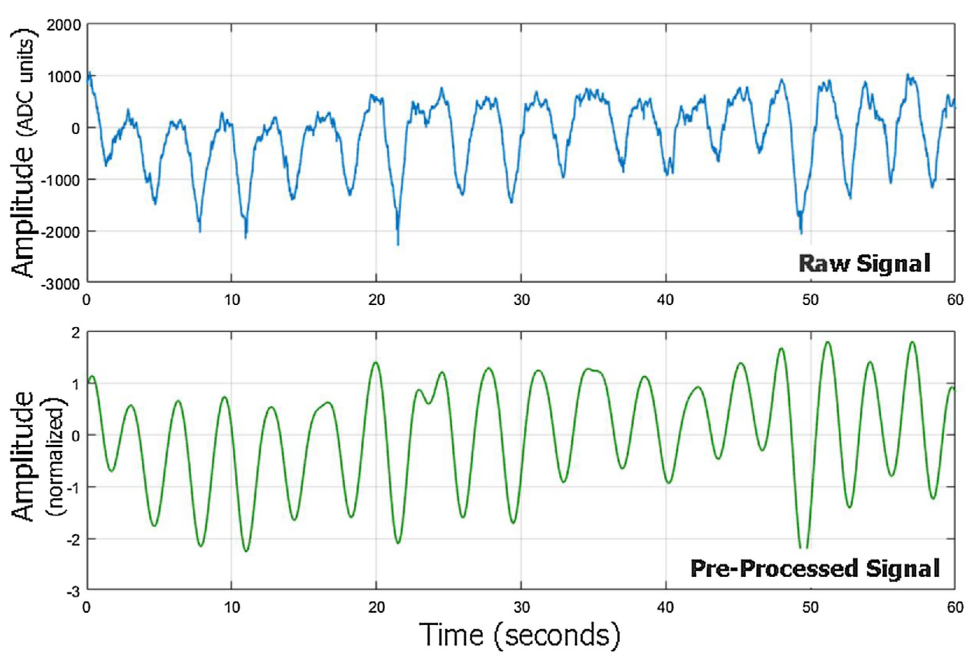

Fig. 1. Differences between raw and pre-processed signals.