Medical Engineering and Physics 37 (2015) 1146–1151

Contents lists available at ScienceDirect

Medical Engineering and Physics

journal homepage: www.elsevier.com/locate/medengphy

Estimation of heart rate variability using a compact radiofrequency motion sensor

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ARTICLE INFO

Article history:
Received 10 January 2015
Revised 4 September 2015
Accepted 19 September 2015

Keywords:
Pocketable sensor
Contactless
Heart rate variability
Coefficient of variation of R–R intervals

ABSTRACT

Physiological indices that reflect autonomic nervous activity are considered useful for monitoring peoples' health on a daily basis. A number of such indices are derived from heart rate variability, which is obtained by a radiofrequency (RF) motion sensor without making physical contact with the user's body. However, the bulkiness of RF motion sensors used in previous studies makes them unsuitable for home use. In this study, a new method to measure heart rate variability using a compact RF motion sensor that is sufficiently small to fit in a user's shirt pocket is proposed. To extract a heart rate related component from the sensor signal, an algorithm that optimizes a digital filter based on the power spectral density of the signal is proposed. The signals of the RF motion sensor were measured for 29 subjects during the resting state and their heart rate variability was estimated from the measured signals using the proposed method and a conventional method. A correlation coefficient between true heart rate and heart rate estimated from the proposed method was 0.69. Further, the experimental results showed the viability of the RF sensor for monitoring autonomic nervous activity. However, some improvements such as controlling the direction of sensing were necessary for stable measurement.

1. Introduction

Rapid increases in social security budgets caused by aging of the population and the high costs of sophisticated medical technology are significant problems in many developed countries. To improve this situation, measures that help people exert greater control over healthcare and prevent diseases before they occur are needed. Blood pressure monitors and weight or body fat scales are good devices to manage people's health. However, sustained monitoring is needed to assess health conditions, and the information obtained from these devices is insufficient to protect against a number of diseases.

Monitoring autonomic nervous activity (ANA) may be useful for healthcare given the results of some previous studies that have reported on the association between abnormal ANA and diseases [1–4]. ANA can be estimated on the basis of heart rate variability (HRV) [5–9], i.e., beat-to-beat changes in heart rate (HR). To estimate ANA with a high degree of accuracy, HRV must be measured several times in a day because ANA shows diurnal variation [10]. However, stress often affects the measurement of physiological data. Indeed, there are people with so-called "white coat hypertension", whose blood pressure measured in medical settings tends to be higher than usual [11,12]. This suggests the need to prevent such people from being conscious of the measurements, in order to evaluate their ANA accurately.

Some approaches to measure HRV on a routine basis have been suggested in previous studies. For example, HRV can be measured on the basis of a photoplethysmogram obtained with a camera and a LED light built into a mobile or smart phone [13–15]. This allows people to obtain and record their ANA frequently by using devices they carry around with them for most hours of the day. However, this method requires users to touch the camera to obtain measurements. Contact-free detection of heartbeats is possible by using a video camera [16–19] or a radiofrequency (RF) motion sensor [20–29]. A video camera is a useful tool to measure HRV in a noncontact manner; however, an unobtrusive measurement is difficult because the camera must be set to take an image of user's exposed region such as a face. In contrast, an RF motion sensor is possible to be used in a pocket. The skin surface on the chest moves slightly in synchronization with heartbeats. Thus, the frequency of an electromagnetic wave radiated from the RF motion sensor changes upon reflection at the skin

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http://dx.doi.org/10.1016/j.medengphy.2015.09.008
1350-4533/

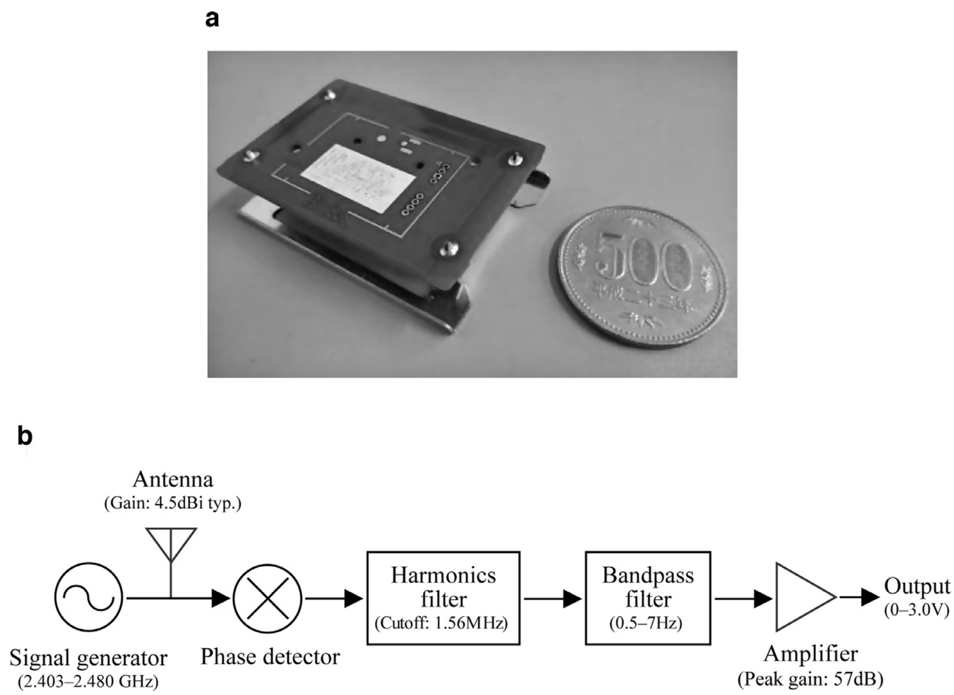

Fig. 1. (a) Appearance and (b) internal design of compact RF motion sensor.

Table 1
Basic performance characteristics of compact RF motion sensor.

Antenna	Radio frequency	2.403–2.480 GHz
	Radiated power	0 dBm (1 mW)
	Impedance	50 Ω (typ.)
	Gain	4.4 dBi (max.)
	Polarization	Linear
	VSWR	<2
Data communication	Modulation	GFSK
	TX mode	Burst mode
	TX interval	385 μs (duty 70%)
	Air data rate	1 Mbps
	Protocol (original)	Cyclic code of 89 bits data packet, including preamble, ID, and payload
Power supply	Voltage	5 V
	Current	15 mA
Size	Length	$40 \times 60 \times 14$ mm^3
	Weight	14 g

surface because of the Doppler Effect; HR is then obtained by detecting a peak in the power spectrum of the signal that reflects the change in frequency of the reflected wave. In previous studies, RF motion sensors were not intended to be embedded in mobile devices, and were thus located remotely from the subjects. In addition, most previous studies focused on estimating the mean HR rather than the HRV.

The aim of the present study is to develop a new system for monitoring HRV using a compact RF motion sensor (hereinafter called the RF sensor). The RF sensor is sufficiently small to fit in the chest pocket of a user's shirt or jacket, thus this sensor is not needed to be set up at a point distant from the user. Chest movements caused by breathing and irregular body motions affect the signal measured by the RF sensor and decrease the accuracy of HRV estimation. For this problem, a new detection algorithm is proposed on the basis of the short-term Fourier transform (STFT) to obtain a periodic component synchronous with heartbeats from the RF sensor signal. The developed system enables users to measure their HRV automatically and check their health condition on a daily basis by simply keeping the RF sensor in their chest pockets.

2. Methods

2.1. Compact RF motion sensor

The RF sensor used in this study is a preproduction prototype. Fig. 1 shows the appearance and internal design of the RF sensor. And Table 1 shows basic performance characteristics of the sensor. This sensor is compact ($40 \times 60 \times 14$ mm^3) and light (14 g), and obtains greater directivity by attaching an aluminum board on one side. A chest movement signal measured with the RF sensor is wirelessly transmitted to a data recording unit; therefore, the sensor can be set in a narrow space, such as a chest pocket, without a cable connection.

2.2. Heart rate estimation

In principle, an output signal from the RF sensor can be expressed by the following equation:

$$V_{out}(t) = V_{DC} + V_r \cos\left(\frac{4\pi}{\lambda} \cdot D(t)\right) \tag{1}$$