BBE 150 1–11
ARTICLE IN PRESS
BIOCYBERNETICS AND BIOMEDICAL ENGINEERING XXX (2016) XXX–XXX

Available online at www.sciencedirect.com
ScienceDirect
journal homepage: www.elsevier.com/locate/bbe

Original Research Article

Analysis of the parameters of respiration patterns extracted from thermal image sequences

Jacek Rumiński

Gdansk University of Technology, Narutowicza 11/12, 80-233 Gdansk, Poland

ARTICLE INFO

Article history:
Received 19 March 2016
Received in revised form
19 July 2016
Accepted 28 July 2016
Available online xxx

Keywords:
Respiration rate
Respiration patterns
Image processing
Thermal imaging

ABSTRACT

Remote estimation of vital signs is an important and active area of research. The goal of this work was to analyze the feasibility of estimating respiration parameters from video sequences of faces recorded using a mobile thermal camera. Different estimators were analyzed and experimentally verified. It was demonstrated that the respiration rate, periodicity of respiration, and presence and length of apnea periods could be reliably estimated from signals recorded using a portable thermal camera. The size of the camera and efficiency of the methods allow the implementation of this method in smart glasses.

1. Introduction

The three main vital signs often monitored by healthcare professionals are body temperature, heart rate, and respiration rate. Respiratory rate (RR) is defined as the number of breaths per minute. A typical goal of respiratory rate measurement is to evaluate whether the respirations are normal, too fast (tachypnea), too slow (bradypnea), or nonexistent (apnea). Apnea is defined by the cessation of respiratory airflow and is especially dangerous during sleep. The length of time necessary to qualify a true apneic event (i.e., considered clinically significant in sleep apnea syndromes) is measured in seconds [1], e.g., >10 s for central sleep apnea syndrome [2]. The threshold values for sleep apnea syndromes are defined as a result of cumulative clinical experience and are different for adults (e.g., >9 s [3] or >10 s [2]) and children (>19 s [1]). In this paper, the term ''apnea'' is used in wide sense, i.e., as a ''cessation of respiration airflow''.

Respiratory rate is an important physiological parameter that is indicative of potential health risks. For example, a RR value greater than 27 bpm is an important predictor of cardiac arrest [4] and is also used in prediction of pneumonia [5] or lower respiratory tract infection [6]. It has also been shown that respiratory rate is more discriminatory between stable and unstable patients than pulse rate [4]. In [7], the authors specified many recommendations for measurement of RR in hospitals and in admission to intensive care units, including ''the respiratory rate should be measured and documented accurately in all hospital patients at least once a day, and should always be documented when other vital signs are measured''. In basic epidemiology, the WHO guidelines recommend that pneumonia case detection can be based on clinical signs alone, primarily respiratory rate [8].

E-mail address: jacek.ruminski@pg.gda.pl.
http://dx.doi.org/10.1016/j.bbe.2016.07.006
0208-5216/

Please cite this article in press as: Rumiński J. Analysis of the parameters of respiration patterns extracted from thermal image sequences. Biocybern Biomed Eng (2016), http://dx.doi.org/10.1016/j.bbe.2016.07.006

In clinical observations, the respiratory rate is often determined by counting the number of times that the chest rises or falls per minute [9]. More quantitative methods use inductive plethysmographs or thoracic impedance systems [10], oxygen masks [11], bioacoustic sensors [12], accelerometers or gyroscope sensors [13], among others.

Respiration-related parameters are typically analyzed in sleep studies. For example, the American Academy of Sleep Medicine (AASM) recommends, ‘‘Sleep apnea must first be diagnosed at a sleep center or lab during an overnight sleep study, or 'polysomnogram'’' [14]. The International Classification of Sleep Disorders [15] underlines that ‘‘Polysomnographic monitoring of obstructive sleep apnea syndrome should consist of monitoring of sleep by electroencephalography, electrooculography, electromyography, airflow, and respiratory muscle effort, and should also include measures of electrocardiographic rhythm and blood oxygen saturation’’. Other parameters are also measured to analyze respiration-related context, e.g., body position, snore acoustic signals, etc. [16,17].

Remote measurement of RR could be especially useful for medical screening (e.g., severe acute respiratory syndrome (SARS), pandemic influenza, etc.). Therefore, the use of near-infrared and thermal imaging was found to be a useful method for evaluation of chest respiration movements or nasal heat flow. In [18], the authors used an active-stereo depth-sensing system composed of a near-infrared (NIR) illuminator and a camera. After calculation of the depth map, the region of interest (ROI) containing the rib cage and the abdominal cavity was detected. Finally, from the processed set of frames, a temporal sequence of volumes was calculated that represented breathing signals, which could be further processed to calculate the respiration rate and patterns. The disadvantage of this method is that the patient must wear a tight elastic top during measurement.

Extraction of signals from a series of thermal images has been found valuable for specifying diagnostic parameters [19,20]. In [21,22], thermal imaging was used to estimate the human respiration rate from a sequence of facial images. The side view of the subject to the camera was used to visualize the breathing-jet dynamics. In [21], the CO_2 content of exhaled air was captured using a narrow band-pass filter in the CO_2 absorption band (4.3 μm). Experiments were performed on 9 subjects at distances ranging from 6–8 ft. Ground-truth measurements were obtained via a traditional contact device (an abdominal transducer).

The results showed a high correlation between the imaged breath rate and the ground-truth breath rate. The measurement methods presented in [23,24] used a thermal camera that was positioned collinear to the subject's face. The methodology was based on capture of the modulation of nasal tissue radiance during inhalation and exhalation of air. In [24], the authors described the method and lab validation with the participation of 20 healthy volunteers. In [23], the authors reported application of the method in a clinical study with the participation of healthy subjects and pathological subjects (suffering from sleep apnea). In the described studies, the respiration rate was typically estimated using statistical methods or analysis of dominant peaks in the frequency spectrum.

A similar method was proposed in [25] in which the temperature gradient distribution throughout the nasal cavity (temperature difference between the inspiration and expiration phases) was used to extract the respiration waveforms. The temperature difference is the product of radiative and convective heat transfer components during the breathing cycle. The authors estimated the values of respiration rate and compared the results with manually registered values from the reference bedside monitor. Validation performed on 5 subjects showed small differences between the estimated values and reference values (mean = 1.18 bpm, std. dev. =0.80). In [26], using a portable thermal camera, the authors presented a preliminary study focused on evaluation of respiration rate for subjects during silence or speech. The results showed highly accurate RR estimation with respect to reference measurements.

The measured thermo-physiological signal for respiration analysis represents the modulated nasal tissue radiance, and signal extraction requires location of the source of thermal changes in the area of nostrils or mouth. The related source points or a region of interest (ROI) can be specified manually or obtained using automatic detection (in a frame) and tracking (between frames). For example, in [27], the authors presented a particle filter tracker driven by a probabilistic template function, which is capable of adapting to abrupt positional and physiological changes. First, the user manually inputs the initial template (rectangular ROI) in the first frame (using the computer mouse). For the following frames, the method automatically performs the template updating process by first extracting stable and unstable seeds and subsequently computing the spatiotemporal fuzzy mask. The method was tested on a dataset consisting of 25 thermal sequences for various conditions (e.g., movements of subjects). The method demonstrated robustness and accuracy in thermal facial imaging. Other tracking methods have also been proposed (e.g., [28,29]).

A single thermo-physiological signal is usually constructed by calculating a mean temperature in the ROI of each video frame. Such a methodology is simple and effective but does not allow visualization and localization of subtle pathological patterns, as proposed in [30].

The miniaturization of thermal imaging sensors (e.g., TAMARISK cameras, Flir Lepton sensors) allows embedding of such sensors in mobile portable devices, e.g., in smart glasses. In recent years, many smart glasses have been proposed, including Google Glass, Epson Moverio BT-200, and so on, and many applications of smart glasses in healthcare have been presented. For example, Evena Medical reported the use of smart glasses to improve visualization of skin veins with IR illumination [31]. Under the eGlasses project (www.eglasses.eu), our group is developing a smart glasses platform that can use different sensors, including visible and thermal cameras [32,33]. The user of these dedicated smart glasses can identify a person (e.g., using graphical markers [34] or facial features [33]), attempt to estimate vital sign parameters (using a thermal camera, visual camera, etc.) and store the information in a healthcare information system. Therefore, it is important to analyze the reliability of the RR estimation for short image sequences recorded using a mobile thermal camera. Additionally, the goal of the work reported in this paper is to analyze the types of respiration patterns that can be accurately evaluated and described using such mobile

Please cite this article in press as: Rumiński J. Analysis of the parameters of respiration patterns extracted from thermal image sequences. Biocybern Biomed Eng (2016), http://dx.doi.org/10.1016/j.bbe.2016.07.006