Combining the Information of Unconstrained Electrocardiography and Ballistography in the Detection of Night-Time Heart Rate and Respiration Rate

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ABSTRACT

An unobtrusive bed integrated system for monitoring physiological parameters during sleep is presented and evaluated. The system uses textile electrodes attached to a bed sheet for measuring multiple channels of electrocardiogram. The channels are also combined in order to form several additional ECG leads. One lead at a time is selected for beat-to-beat-interval detection. The system also includes force sensors located under a bed post for detecting respiration and movements. The movement information is also used to assist in heart rate detection and combining the ECG derived respiration information with respiration information derived from force sensors, is investigated. The authors tested the system with ten subjects in one hour recordings and achieved an average of 95.9% detection coverage and 99 percentile absolute error of 3.47 ms for the BB-interval signal. The relative mean absolute error of the detected respiration cycle lengths was 2.1%.

Keywords: Bed Integrated Electrocardiogram (ECG/EKG), Heart Rate, Night-Time Monitoring, Respiration Rate, Unobtrusive Physiological Measurement

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INTRODUCTION AND RELATED WORK

Automatic monitoring of night-time physiological information, especially the heart rate, the respiration rate and the movements can be used in various applications. Examples include the screening of medical disorders like sleep apnoea (Ayas et al., 2003; Roche et al., 1999) and monitoring of sleeping quality (Bulckaert et al., 2010) or psychophysiological stress (Hall et al., 2004). Polysomnography is currently used as the standard method for collecting reliable and multiparametric data from a sleeping person. Its biggest drawback is the high cost, which is the result of the requirement of specialized medical personnel and dedicated examination facilities. As a result, all the potential sleep disorder patients cannot be examined and the monitoring is usually done during one night only. The discomfort caused by wearing the measurement equipment may also affect the sleep and skew the results.

Wrist actigraphy is another examination technique increasingly used for sleep analysis. It can be used in a variety of sleep studies including longitudinal monitoring of night-time sleep patterns and circadian rhythm in the natural sleeping environment of the patient (Martin & Hakim, 2011). As the name implies, wrist actigraphy monitors patient’s activity through a wrist-worn device using accelerometers or other motion sensors. The benefit is that the device is relatively unobtrusive and the data can therefore be collected for extended periods of time. On the other hand, the device only offers one modality of information, activity, which limits its usability and the achievable accuracy.

In recent years, researchers have started to investigate technologies that combine the positive features of the aforementioned monitoring methods. This means technologies that are unobtrusive like the wrist actigraphy, but would still be able to provide more detailed physiological information about the state of the person being monitored. Heart rate (HR) and respiration rate (RR) or respiration cycle length (RCL) are other interesting parameters besides the activity. These technologies can also be realized so that they do not require any effort from the user, which enables the collection of longitudinal data and consequently a more comprehensive view of the person’s sleeping behavior being formed. In the future, these kinds of monitoring systems can also be integrated as a part of a wider eHealth system to provide nocturnal physiological information for supporting the decision making.

Ballistography (BG), which means the measurement of the mechanical signal produced by the heart beat or pulsatile blood movement and breathing is able to provide all the desired physiological parameters; HR, RR, and activity (movements). Recent studies that have focused on the night-time HR detection based on the ballistocardiographic (BCG) signal have reported average HR errors between 0.34% (Kortelainen et al., 2010) and 1.79% (Brüser et al., 2011). We obtained an average error of 0.45% in an earlier yet unpublished study by using force sensors under all four bed posts. Also the detection coverage of the HR is important for reliable sleep analysis. Long continuous beat-to-beat-interval (BBI) series enable a more reliable calculation of heart rate variability (HRV) parameters, which are commonly used in sleep staging and sleep quality evaluation. We achieved approximately 91% average recognition coverage with the ballistographic method in unsupervised recordings while Kortelainen et al. (2010) reported 88% coverage. Brüser et al. (2011) reported 95% coverage but they had instructed the test subjects to stay still during the measurements.

Even though the fairly good accuracy and high recognition coverage of the BBI data can be achieved with ballistographic sensors, it still may not be the optimal method for gathering the heart rate information. We achieved 95% recognition coverage and an average of 0.27 beats per minute (bpm) or 4.48 ms root-mean-square error with a system that measures contact ECG using textile electrodes sewn on a bed sheet (Peltokangas et al., 2012). Other studies have reported detection coverages between 82% and 93% with large textile electrodes that
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