

ECG Motion Artefact Reduction Improvements of a Chest-based Wireless Patient Monitoring System

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Abstract

An evaluation of motion artefact for a newly CE approved wireless bodyworn monitoring device is presented. This evaluation has shown that the system under test has greatly reduced motion artefact with comparison to an FDA-approved leaded system. Analysis of physiological data, such as quality of ECG signal, accuracy of recording of heart rate, temperature and ECG R-R interval has shown the system to offer high fidelity recordings and a robust service during a range of basic movements.

Presented results have shown that the average difference in heart rate between the prototype and the reference device was 3.8bpm with standard deviation of 12.4bpm. Temperature analysis indicated the average difference between the prototype and the reference device was 5.66°C, with standard deviation of 0.44°C. R-R interval analysis highlighted mean interval difference as 78.96ms with standard deviation of 123.1ms. In general, the user activity of bending had highest errors due to the considerable torso movement.

1. Introduction

Advances in medicine during the late 20th and beginning of the 21st century have rapidly developed a plethora of ways to increase life expectancy. While great advances have been achieved, its success presents a new set of problems. The aging population is a well defined and discussed issue that is facing global healthcare systems [1] and the timely implementation of smart devices and electronic patient monitors to facilitate high-quality cost-effective connected healthcare is now considered essential. Such technologies afford patients earlier discharge, doctors increased flexibility and reduces hospital resource utilisation [2].

Due to current trends in Smartphones, wireless social networking, wireless web technology, Wi-Fi cafes and other such applications, patients expect such advances to permeate throughout every area of their lives, not least in the complex technology designed to monitor them whilst in a modern hospital. Thus they expect not to be bed-bound by restrictive cabling. Such technology exists to free patients from their bedside monitors through use of wireless technology [3]-[5].

However, the issue of measuring high-quality physiological signals is still of utmost importance. Basic physical movement inherent in ambulatory ECG patient monitoring can induce noise (motion artefact) into the system. Many patient monitors are designed to detect arrhythmias and raise alarms, however, motion artefact can generate false positives and false negatives and may serve to unnecessarily consume nursing time, ultimately effecting patient management and clinical outcomes.

Motion artefact in an ECG recording is typically low frequency interference overlapping spectrally with that of the ECG signal [6]. It is generated when the wearer of the electrode system makes physical movements, causing the electrode's metallic/electrolytic interface parameters to be altered and also causing changes to the skin's impedance characteristics due to stretching.

Design has been undertaken to address the issue of motion artefact in ambulatory patient monitors. Indeed, this solution has been successfully implemented in a commercial device for hospital and home monitoring. This work is significant and timely as it highlights current progress in addressing key technical issues for successful implementation of smart cardiac monitors and ensures the emerging generation of ambulatory patient monitors continue to deliver the same standards of recording as their bedside static counterparts. This paper reports on a practical evaluation of motion artefact for a prototyped wireless body-worn monitoring device using multiple adult test subjects. Section II describes the measurement systems

utilised, the environment and the test procedure. Section III reports on the experimental results, and section IV highlights conclusions.

2. Measurement system

The prototype system under evaluation was the recently CE approved Vitalsens VS100 patient monitor from Intelesens Ltd. (a University of Ulster spin-out company), who have developed a range of innovative electrodes and vital signs monitoring systems [7].

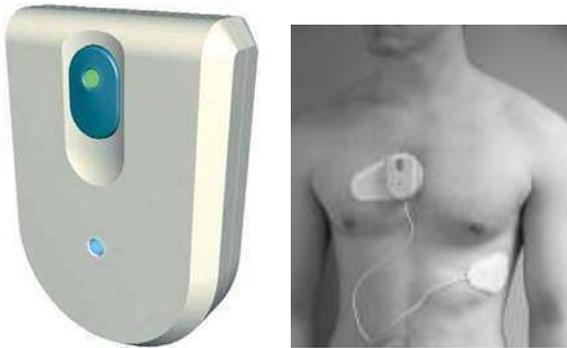


Figure 1: Vitalsens prototype device and sensor

The system combined disposable electrodes, with a reusable, miniaturized clip-on body-worn device for non-invasive vital signs monitoring (fig. 1).

Motion artefact reduction is addressed using a number of strategies. These include novel sensor design [8], minimal ECG lead design, complex front-end filtering and powerful microcontroller processing algorithms, all combining to reduce motion artefact for high quality vital sign collection.

2.1. Experimental set-up

To evaluate the Vitalsens prototype device a number of tests were devised to trial the system for typical user movements commonly experienced during clinical operation. The range of basic movements undertaken were specifically standing, sitting, walking, squatting, bending, climbing stairs; all conducted under controlled and repeatable conditions. The tests were selected to best investigate the quality of data collection from the cardiac device. Data recorded included skin temperature, heart rate, ECG waveforms and R-R analysis.

Stationary tests were performed for a user standing stationary with arms at the sides. Seated tests were executed for the subjects sitting upright in an armless chair with the feet flat on the floor and hands placed on the lap. Walking tests were completed for the user walking with natural movements at a speed of 0.5m/s. Squatting tests were conducted for a user starting from the stationary standing position and squatting directly down by bending at the knees, whilst holding onto a chair to ensure a controlled descent and ascent. Bending tests were undertaken for a user bending forward from the waist and picking up a small object from the floor using controlled movements. Tests for walking up and down stairs were implemented for a user descending and ascending a flight of stairs (which confirm to building regulation BS585, part 1989) at a natural speed of approximately 60 stairs per minute. All tests were repeated numerous times for each test conducted and for each test subject to ensure statistical significance. Subjects were selected to ensure a range of physical sizes, weights and heights, with a mean weight of 87 Kg and height of 1.74 m.

For performance comparison, an FDA approved non-wireless system was employed and sensor leads were restricted using an elastic cuff on the waist to minimise their movement. This device was a 12-lead ECG system from Midmark (Brentwood IQ-ECG) which records ECG waveforms and heart rate. Temperature was additionally recorded using the temperature probe from an FDA approved vital signs device (Welch Allyn Vital Signs Monitor 300 Series). Both systems were worn concurrently, ensuring results were directly comparable.

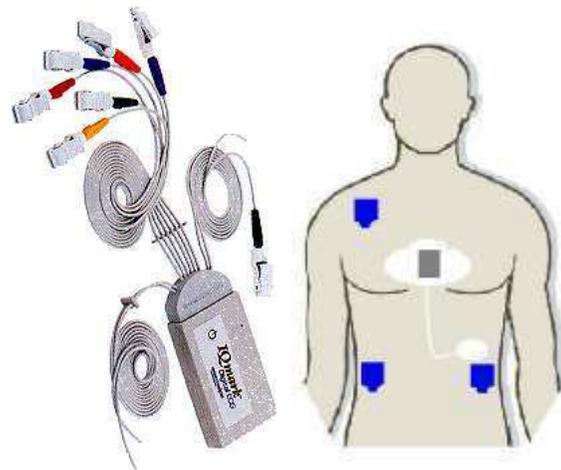


Figure 2: Midmark 12-lead ECG system

Figure 3: Placement of both systems (shaded electrodes refer to placement of FDA leaded system).

3. Results

The measurements were recorded as specified as per the above protocol. Results indicate that the Vitalsens prototype system has greatly reduced motion artefact compared to the reference system. In addition, heart rate and R-R intervals were of higher quality due to clearer ECG waveforms.

Average difference in heart rate between the Vitalsens prototype and the reference device was 3.8bpm with standard deviation of 12.4bpm (fig. 4). This indicates similar measurements made from both systems, with the heart rate error values coming from the reference device due to noisy spikes in the waveforms being mistaken for an R pulse (and hence a higher than true heart rate) or due to loss of processable ECG data due to large signal degradation, particularly in the case of large movements such as squatting or bending over.

For temperature analysis (fig. 5), the average difference between the Vitalsens prototype and the reference device was 5.66°C, with standard deviation of 0.44°C. Averaging over the six movement activities, it was discovered that the range of temperatures and the difference between temperatures measured from both systems displayed only minor fluctuations. As each test followed the last, the activity of exercise increased skin temp while core temp remains similar throughout. Due to the design of the ECG patch for the Vitalsens prototype, a microclimate is created around the skin temperature sensor. Indeed, skin temperature results from this device have been shown to offer good correlation with core body temperature [9].

For R-R analysis, the mean interval difference between the prototype device and FDA-approved device was 78.96ms (fig. 6) with a standard deviation of 123.1ms (fig. 7). In general, bending has highest errors due to considerable torso movement.

Figure 8 shows comparison of ECG waveforms from both devices for the user walking. Observation of the recording from the FDA leaded device highlights the base reference point of the R-wave is fluctuating from beat to beat with respect to the zero point on the y axis (mm/mV). In addition, the PR and ST segments of this device are very noisy, which would affect arrhythmia analysis and may generate false positives. This was found to be the case for all non-stationary movements during these tests. No such significant motion artefact was observed for the Vitalsens prototype device.

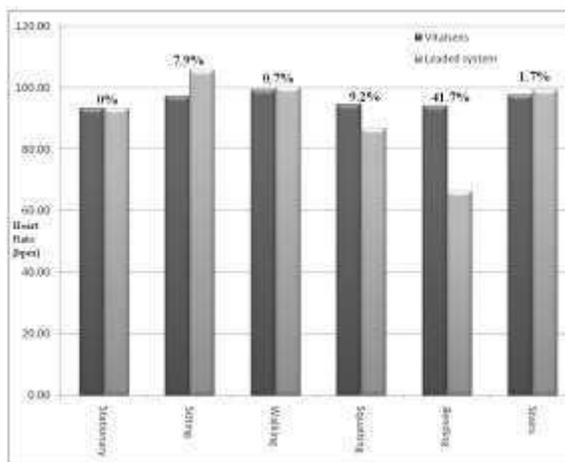


Figure 4: Comparative results for averaged heart rate (in beats per minute) recorded during basic physical activities.

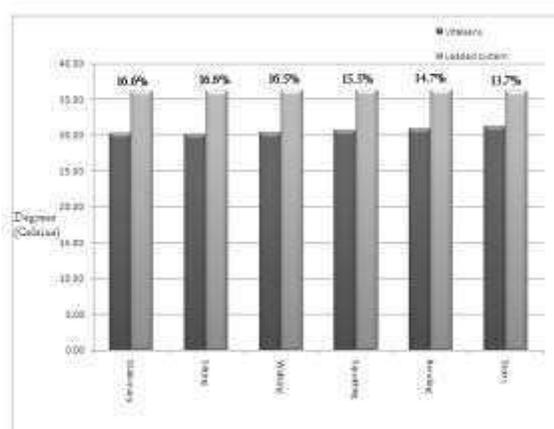


Figure 5: Comparative results for body temperature (skin and core respectively) (in deg. Celsius) for basic user activities.

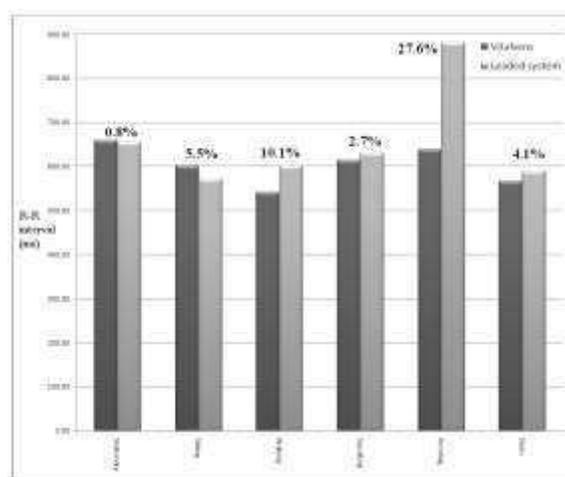


Figure 6: Comparative results for R-R interval values (in milliseconds) recorded during basic physical activities.

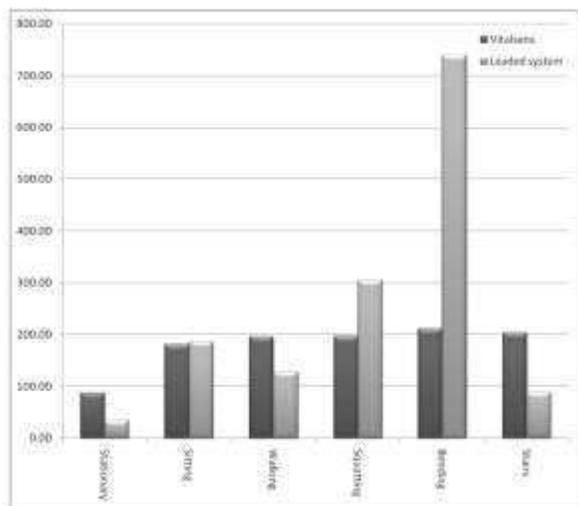


Figure 7: Comparative results for standard deviation of R-R interval values (in milliseconds) for basic physical activities.

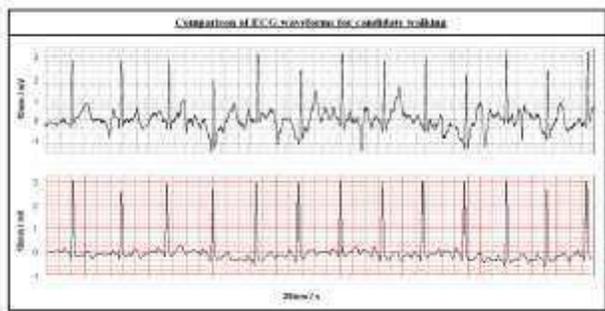


Figure 8: FDA led ECG (top graph) comparison with prototype system (bottom graph) for a candidate walking.

4. Conclusions

In this paper, results of comparative trials between a recently CE approved ambulatory patient monitor and a leaded FDA-approved ECG/vitalsigns monitor have been presented. It is concluded the quality of physiological data (ECG, heart rate, temperature and R-R interval) has shown the prototype system to offer high fidelity recordings during basic movement. Comparison with the FDA approved leaded system highlights better quality of recording within a clinical setting for typical user movement.

Overall, the data recorded highlights an average difference in heart rate between the prototype and the

reference device of 3.8bpm with a standard deviation in results of 12.4bpm, an average temperature difference between the prototype and the reference device of 5.66°C, with standard deviation of 0.44°C and mean R-R interval difference of 78.96ms with standard deviation of 123.1ms. In general, bending yielded the highest errors in all parameters and all test subjects (with the exception of temperature) due to the considerable torso movement involved in bending from the waist.

References

- [1] Taparugssanagorn A, Pomalaza-Raez C, Isola A, Tesi R, Hamalainen M, Iinatti J. UWB channel modeling for wireless body area networks in a hospital. *International Journal of Ultra Wideband Communications and Systems*. 2010;1:226-236.
- [2] Paksuniemi M, Sorvoja H, Alasaarela E, Myllylä R. Wireless sensor and data transmission needs and technologies for patient monitoring in the operating room and intensive care unit, *Proc. IEEE EMBC*. 2005;786:5182-5185.
- [3] Corventis AVIVO [Online] Available: <http://www.corventis.com/EU>
- [4] Catherwood PA, Scanlon WG. Off-body UWB channel characterisation within a hospital ward environment, *Int. J. Ultra Wideband Communications and Systems*, 2010; 1: 263- 272.
- [5] Conway GA, Cotton SL, Scanlon WG. Design and characterization of integrated antennas for compact wearable wireless devices, *USNC / URSI National Radio Science Meeting*, Ottawa, Canada, 2007.
- [6] Thakor NV, Zhu Y. Applications of adaptive filtering to ECG analysis: noise Cancellation and arrhythmia detection, *IEEE Trans. Biomedical Engineering*. 1991;38:785-794.
- [7] Intelesens Ltd [Online] Available: <http://www.intelesens.com>
- [8] McLaughlin JA, Anderson J, McAdams ET. Profiled biosignal electrode. Patent No. 930230 (Mar. 1993)
- [9] Harper R, et al. Evaluation of a CE approved ambulatory patient monitoring device in a general medical ward, *32nd Annual International Conf. of the IEEE EMBS*. 2010;32:94-97.

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