Biomed Tech 2012; 57 (Suppl. 1) © 2012 by Walter de Gruyter · Berlin · Boston. DOI 10.1515/bmt-2012-4342

# Evaluation of QRS detection algorithm implemented for mobile applications based on ECG data acquired from sensorized garments

Daniel Tantinger[1], Sven Feilner[2], Daniel Schmitz[2], Christian Weigand[2], Christian Hofmann[2], Matthias Struck[2]
[1]Fraunhofer Institute for Integrated Circuits IIS, Erlangen, Germany, daniel.tantinger@iis.fraunhofer.de
[1]Fraunhofer Institute for Integrated Circuits IIS, Erlangen, Germany

## Abstract

People can greatly benefit from mobile technologies that continuously monitor their vital signs, in medicine as well as in home environments and sports. In order to meet the requirements of mobile systems the algorithms have to be robust, reliable, take the limited resources into account and overcome the drawback of motion artefacts. This paper presents the evaluation of an algorithm for QRS detection based on ECG signals from a sensorized garment.

The system saves the ECG data, measured via two textile electrodes sewed into the shirt, on a microSD card using the EDF+-format. The raw data is processed on a desktop PC using a modified state-of-the-art algorithm. QRS complexes and R-peaks of electrocardiographic signals are detected using the technique of zero crossings. Hereby, main focus has to be placed on the proper specification of the band pass filter, which is the basis for high accuracy. For the evaluation a well-defined test protocol has been specified. Six activities respectively postures were defined: Sitting, standing, walking, running, cycling and rowing. Each activity was performed by 10 test persons for a fixed time interval.

Various parameters, where the temporal location of the R-peak is of importance, can be derived from the recorded ECG raw data, such as heart rate, heart rate variability or ECG classification. This method is robust and provides high accuracy even in case of noisy signals. Motion artefacts could be compensated on a high level. The performed study illustrates that even validated state-of-the-art R-peak detection algorithms have to be adapted and optimized for the mobile and daily usage. Due to its computational efficiency it is suitable for mobile applications in real-time.

## 1 Introduction

Continuous acquisition of vital parameters supports medical use cases and safety monitoring for people with the need of medical care. Additionally, sportive use cases such as mobile professional sports analysis or personal performance monitoring are to mention [1,2]. A consistent acquisition, especially of the cardiac function, is essential and enables both, the physician as well as the user to perform a basic evaluation of the person's health and fitness status, respectively.

Portable medical devices for telecare and home monitoring acquire the data almost without interference of their freedom of movement even during the user's daily life.

Apart from the medical use case it is being reported more frequently of athletes collapsing on the field without any warning [3,4]. The possibility of monitoring important vital parameters even during training units or football matches could provide valuable knowledge and thus prevent those accidents [5]. It is precisely for this reason that continuous monitoring of vital parameters has to be prevailed in (semi-) professional sports over longer periods. In particular, wearable systems [6] provide a more comfortable way for long-term measurements like during a football game or even at a 24-h ECG.

These clear benefits of the use of mobile and portable systems set significant requirements to the algorithm for detecting the user's ECG data. Not only the variety of movements itself, but more the resulting artefacts caused by muscle contraction during movements of the upper arm, require a robust algorithm. For the evaluation of the test data a modified algorithm, which uses zero crossing counts to detect QRS complexes in electrocardiographic signals [7], was used. It promises a high detection performance and at the same time saves computational power and resources, which is beneficial for the implementation on portable devices.

In this paper the evaluation of a modified algorithm during the performance of daily activities with an applied portable and wearable system – FitnessSHIRT – is presented.

## 2 Methods

### 2.1 FitnessSHIRT

The FitnessSHIRT (see Figure 1), developed by the Fraunhofer Institute for Integrated Circuits IIS in Erlangen, Germany, is a garment with integrated sensors which realizes a system for mobile vital parameter tracking where the focus is set on cardiac activity and respiration.

Figure 2 shows the basic principle of the main module which is placed between the shoulder blades. The system is divided into three elementary segments:

- Sensors (electrodes and respiration bands)
- Signal acquisition and signal processing
- Data storage and data transmission

The measurement of a single-channel ECG is enabled by two textile electrodes sewed into a tight fitting shirt on both sides of the thorax (see Figure 1, yellow ellipse).

Furthermore, the thoracic respiration is measured by making use of the resistive method. This is achieved by two flexible bands integrated into the fabric at the lower costal arch (see Figure 1, green line). Both, ECG and respiration data, are acquired with a sampling rate of 256 Hz.

**Figure 1** Applied FitnessSHIRT with integrated sensors (ECG – yellow, Respiration band – green)

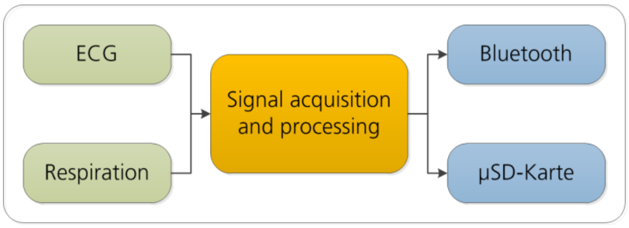


**Figure 2** FitnessSHIRT system conceptions

The sensors are connected to the main module, which ensures a long-time data acquisition on a microSD card for a more detailed data analysis using the EDF+-format for data storage [8]. In addition, with the aid of an integrated Bluetooth module the raw data can be transmitted to a portable device (smartphone or tablet) or a PC to display the raw data (e.g. ECG-curve) in real-time.
Hence, a textile for reliable continuous vital signs monitoring using ECG and respiration was developed. Even after several washes the signal quality of the textile sensor elements was within a valid range, so a reliable operation and feasible measurements for the evaluation of the presented algorithm (see chapter 2.2) can be assured.

## 2.2 Algorithm

Köhler et al. developed a technique for detection of QRS complexes in electrocardiographic signals that is based on a feature obtained by counting the number of zero crossings per segment. This method provides high detection accuracy, as it is largely independent of sudden changes in the amplitude level of the ECG signal and is robust against noise and pathological signal morphologies. At the same time, due to its simplicity, this approach provides a computationally efficient solution [7].

For this feasibility study the algorithm was adapted to work best with the signals from the FitnessSHIRT. First, the band pass filter was used to increase the signal to noise ratio. In our implementation a linear phase FIR filter of 71st order with the cut-off frequencies of 18 Hz and 35 Hz was used. The next steps were implemented as proposed by Köhler et al., whereas the following parameters were chosen:

| | |
|---|---|
| $\lambda_D = 0.995$ | …forgetting factor for determination of the signal magnitude |
| $\lambda_K = 0.9$ | …forgetting factor for the auto regressive low pass filter |
| $c = 4$ | …constant gain |

For processing the feature signal, which provide information about the zero crossing count, a simple threshold (TH = 0.85; determined empirically), instead of the adaptive threshold, is used in order to define and localize the events. When the feature signal falls below the threshold an event is detected. This threshold is a trade-off either to detect the R-peaks and keep the events as small as possible. This enables the use of the rising edge of the event signal to determine the position of the R-peak.
In addition, a plausibility check is used to ensure that the RR-interval, and subsequently the heart rate, is in a physiological range.
The signal is shifted to compensate the delay due to the band pass filtering. In Figure 3 the initial ECG signal and the detection results can be seen.

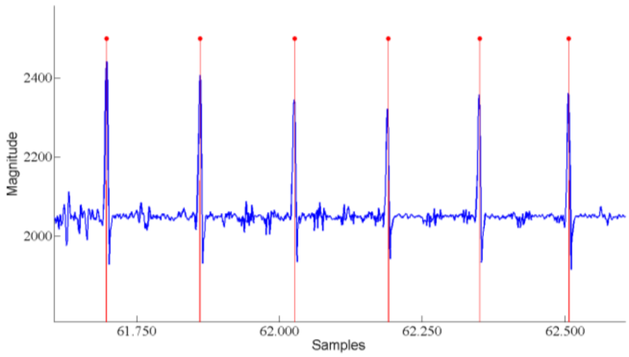


**Figure 3** ECG signal from the FitnessSHIRT (blue) and the results of the R-peak detection (red)

## 2.3 Test protocol

In order to evaluate the algorithm the following test protocol was specified:

1. Test of measuring unit (FitnessSHIRT)
2. Explanation of test protocol to the test person including daily activities
3. Explanation of exercise devices (treadmill, bicycle and rowing machine ergometers)
4. Application of measurement unit on test person

Biomed Tech 2012; 57 (Suppl. 1) © 2012 by Walter de Gruyter · Berlin · Boston. DOI 10.1515/bmt-2012-4342

5. Performance of daily activities by test person
6. Offline analysis of acquired data with MATLAB

Each daily activity was performed over a period of 2 minutes, containing:

- Sitting on an office chair
- Walking (at a speed of 2 km/h on a treadmill)
- Jogging (at a speed of 8 km/h on a treadmill)
- Cycling (at a resistance of 150 Watt on a bicycle ergometer)
- Rowing (rowing machine ergometer)

The participants, as a group consisting of n = 10 male test persons, had a mean age of 29.1 years (Standard deviation: σ = 3.7 years), a mean body mass of 81.4 kg (σ = 7.0 kg) and an average height of 182.9 cm (σ = 5.0 cm). Each subject has to perform the exercises while wearing the FitnessSHIRT with conductive gel on the electrodes in order to increase the signal to noise ratio of the ECG signals.
The raw data was transmitted to a desktop PC by Bluetooth for offline evaluation using MATLAB.

# 3 Results

The proposed algorithm was applied to the complete data set of the test trial mentioned in chapter 2.3. As a performance measure the values gained from the binomial classification (see Table 1) are used to compute the sensitivity (true positive rate, TPR) and the precision (positive prediction value, PPV), whereby TP denotes the number of true positives, FN the number of false negatives and FP the number of false positives (see Equation 1 and 2) [9,7].

**Table 1** General binomial classification matrix

| | | actual value | |
|---|---|---|---|
| | | R-peak | no R-peak |
| test result | R-peak | TP | FP |
| | no R-peak | FN | TN |

$$TPR = \frac{TP}{(TP+FN)}$$ **Equation 1**

$$PPV = \frac{TP}{(TP+FP)}$$ **Equation 2**

Table 2 shows the results of the algorithm grouped by activity. The largest number of false positive detections can be seen in the activities with the highest amount of motion artefacts, i.e. running and rowing, whereas all R-peaks were detected correctly while sitting.

**Table 2** Results of QRS detection grouped by activities

| Activity | TP | FP | FN | TPR (%) | PPV (%) |
|---|---|---|---|---|---|
| Resting | 1464 | 0 | 0 | 100.00 | 100.00 |
| Walking | 1871 | 33 | 1 | 99.95 | 98.27 |
| Running | 2702 | 46 | 5 | 99.82 | 98.33 |
| Cycling | 2645 | 3 | 1 | 99.96 | 99.89 |
| Rowing | 2607 | 59 | 0 | 100.00 | 97.79 |
| **Total:** | **11289** | **141** | **7** | **99.94** | **98.77** |

The algorithm results grouped by test persons can be seen in Table 3. Due to extremely high artefacts during the running activity, caused by motion and noise, the signals from test person 8 delivered the largest number of false positive detections. Also detection results from test person 10 where influenced by artefacts, which, in this case, where caused by the muscle contractions during the rowing activity. On the contrary, for all the other test persons the algorithm achieved a high detection rate.
Overall a sensitivity of 99.94% (7 FNs) and a positive prediction value of 98.77% (141 FPs) could be achieved with this system – signals recorded from the FitnessSHIRT and processed by the proposed algorithm.

**Table 3** Results of QRS detection grouped by test persons

| Test person | TP | FP | FN | TPR (%) | PPV (%) |
|---|---|---|---|---|---|
| 1 | 850 | 6 | 0 | 100.00 | 99.30 |
| 2 | 1207 | 4 | 0 | 100.00 | 99.67 |
| 3 | 1087 | 4 | 0 | 100.00 | 99.63 |
| 4 | 1162 | 15 | 0 | 100.00 | 98.73 |
| 5 | 1085 | 2 | 0 | 100.00 | 99.82 |
| 6 | 1011 | 0 | 0 | 100.00 | 100.00 |
| 7 | 1395 | 8 | 4 | 99.71 | 99.43 |
| 8 | 1351 | 67 | 2 | 99.85 | 95.28 |
| 9 | 1099 | 4 | 1 | 99.91 | 99.64 |
| 10 | 1042 | 31 | 0 | 100.00 | 97.11 |
| **Total:** | **11289** | **141** | **7** | **99.94** | **98.77** |

# 4 Conclusion

The FitnessSHIRT, a sensorized garment which realizes a system for mobile vital parameter tracking with the focus on cardiac activity and respiration, is introduced. Furthermore, an approved algorithm for detecting QRS complexes, which was adapted to the specific use case, is presented.
The evaluation results achieved with the specific test setting showed that the system provides high detection rates for all activities, even with artefacts and noise. Especially,

the results from activities with high movement levels, e.g. running and rowing, showed that the system is also suitable for mobile applications.
The next step is to port the algorithm either to the firmware of the FitnessSHIRT module and/or onto a mobile device (e.g., tablet or smartphone), and evaluate the results in a long-term study with a larger test group.
Making use of mobile devices can enrich the use case within the field of telemedicine, accompanied with the needs of standardized communication [12], e.g. ISO/IEEE 11073-20601 (Continua).
Future work will also combine the FitnessSHIRT with an additional accelerometer in order to reduce the impact of motion artefacts [10]. Moreover, this accelerometer could be utilized to detect falls of the user, which is of great importance in a variety of Ambient Assisted Living (AAL) scenarios [11].

The authors would like to thank the test persons for their participation in the recording of measurement data of daily activities.

# 5 References

[1] Welk G., McFarland J.: “Physical Activity Assessments for Health-Related Research”, Human Kinetics Pub Inc, 2002

[2] Dellal A. et al.: “Heart-rate monitoring in soccer: interest and limits during competitive match-play and training - Practical application”, The Journal of Strength & Conditioning Research, ISSN: 1064-8011, 2012

[3] Copping J., Duffin C.: “Fabrice Muamba collapses at Tottenham v Bolton game”. Retrieved 24 June 2012 from http://www.telegraph.co.uk/sport/football/news/9150696/Fabrice-Muamba-collapses-at-Tottenham-v-Bolton-game.html, 2012

[4] Telegraph staff: “Livorno's Piermario Morosini dies after suffering heart attack during Serie B clash against Pescara.” Retrieved 24 June 2012 from http://www.telegraph.co.uk/sport/football/9204710/Livornos-Piermario-Morosini-dies-after-suffering-heart-attack-during-Serie-B-clash-against-Pescara.html, 2012

[5] Marti B. et al: “Plötzlicher Herztod beim Sport: sinnvolle Vorsorgeuntersuchungen und Präventionsmaßnahmen”, Schweizerische Zeitschrift für “Sportmedizin und Sporttraumatologie” 46 (2), pp 83-85, 1998

[6] Di Rienzo M. et al.: “MagIC System: a New Textile-Based wearable Device for Biological Signal Monitoruing. Applicability in Daily Life and Clinical Setting”, Engineering in Medicine and Biology Society, pp 7167-7169, 2005

[7] Kohler B.U., Orglmeister R.: “QRS Detection Using Zero Crossing Counts”, Progress in Biomedical Research, 8 (3), pp 138-145., 2003

[8] Kemp B., Olivan J.: “European data format 'plus' (EDF+), an EDF alike standard format for the exchange of physiological data.” Clinical Neurophysiology, 114, pp 1755-1761, 2003

[9] Afonso V.X et al.: “ECG beat detection using filter banks“, IEEE Trans Biomed Eng., 46, pp 192-202, 1999

[10] Krassnig G., Tantinger D., Hofmann C., Wittenberg T., Struck M.: “User-friendly System for Recognition of Activities with an Accelerometer”, 4th IEEE Int. Conf. on Pervasive Computing Technologies for Healthcare 'Pervasive Health 2010', pp 1-8, 2010

[11] Dinh C., Tantinger D., Struck M.: “Automatic Emergency Detection Using Commercial Accelerometers and Knowledge-Based Methods”, Computers in Cardiology 2009, pp 485-488, 2009

[12] Struck M., Pramatarov S., Weigand C.: “Method and system for standardized and platform independent medical data information persistence in telemedicine”, Computers in Cardiology 2008, pp 257 - 260, 2008