Continuous Vital Monitoring and Automated Alert Message Generation for Motorbike Riders

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Abstract

We present an integrated sensor system for continuous monitoring of motorcyclists, which aims to benefit from the growing acceptance for wearable electronics, but goes beyond the most common life-style applications by trying to improve the user's safety. Our system features a textile front end (garment, e.g. shirt) with integrated ECG electrodes and respiration sensor as well as electronics for data acquisition, signal conditioning and onboard processing. ECG and respiration signals are processed not only to give the user feedback on his health status, but are further analyzed to detect fatigue and trigger a driver warning and thus avoid critical situations. In addition inertial sensors are used to detect accidents and trigger an emergency call, compliant to the eCall standard, if necessary. In case of an accidents health data can be online provided to first responders, before they reach the accident site. This paper includes a short description of the overall system, discusses methods to adapt the vital sign monitoring to our application and evaluates signal quality with of the acquired ECG signal.

Our results indicate, that our system allows reliable heart rate measurements even on long motorbike rides.

1. Introduction

Within the past decade, textile integrated wearable electronics have evolved from raw concepts to sophisticated wide spread products with growing acceptance. Especially a high demand for self-quantifying electronics within the sports sector has pushed on development of integration techniques and intelligent materials. This progress led to more and more both comfortable and reliable systems for continuous textile integrated vital sign monitoring.

Multiple sensor systems for driver monitoring have been introduced in the past. Most of them however address car drivers rather than motorcyclist and use sensors integrated to the car itself in order to determine the driver's health data [1-3]. Clearly, monitoring of motorcyclists by sensors within the motorcycle itself is challenging due to the fact that there is very little contact between the machine and the rider. In addition, motorcyclists usually wear thick protective clothes, which make direct skin contact, for example between hands and handlebars, impossible. Even if capacitive electrodes were used, the driver could not be expected to always keep his hands in the correct position for reliable ECG acquisition. In case of an accident, the rider usually gets separated from the bike, which would render sensors attached to the bike completely ineffective. Therefore our system includes wearables, which can acquire data directly from the user. Even after accidents, the wearables stay attached to the rider and continue gathering health related data.

2. System Description

2.1. System Overview

To improve safety by redundancy, our system utilizes two signal sources for health data acquisition and accident detection. One set of sensors, developed by CETEM (CETEM Technological Centre - Yecla, Spain) is integrated to the helmet, including ECG, EEG and inertial sensors. Another set of sensors is subject to the research of Fraunhofer IIS and was integrated within the rider's garment including ECG, respiration and inertial sensors.

Electronics are connected to the sensors of helmet and garment, including analog front ends, a processing unit to perform signal acquisition and online data processing, as well as wireless communication operating at the power-saving Bluetooth Low Energy (BLE) standard. Processed health data is continuously transmitted to a smartphone, where it is visualized and stored. Using a specifically developed app, motorcyclists can record their vital data to view curve runs of heart rate and respiration rate as well as a map of the ride, recorded using the smartphone's GPS.

Using heart rate variability (HRV) processing additional signal parameters are derived with the aim to detect fatigue of the rider. If the user's health data exceeds certain thresholds, the smartphone app is notified via Bluetooth. The app afterwards establishes a Bluetooth link to a headset within the helmet, in order to suggest a break.

Figure 1. System overview: Electronics in helmet and garment are connected via Bluetooth. App can be notified by electronics to trigger eCall compliant emergency message.

2.2. Textile Front End

As textile front end we use a modified common sports shirt, which can be worn underneath the motorcycle jacket. Two ECG electrodes are sewed to the inner of the shirt and connected via textile cables to the electronics. A major challenge when measuring ECG over multiple hours is to remain good signal quality over the whole measurement. Electrodes of common chest straps used for sports applications usually have to be moisturized before the measurement. These systems however profit from the users transpiration which keeps the electrodes wet during sport. When recording ECG during a motorcycle ride, constant moisturizing by transpiration is not given. For that reason we were searching for electrodes, which keep good skin contact over multiple hours, without the need of repeated moisturizing. As electrode material we chose conductive silicone. In contrary to textile electrodes, liquid between skin and silicon cannot evaporate. Thus, when initially wet, our electrodes allow reliable ECG measurement during long motorbike rides.

Respiration measurement is performed using an inductive sensor integrated within the sensor shirt. This sensor can be seen as a one-loop coil, encircling the user's thorax. When the user inhales, radius of the coil is enlarged changing its inductance. At exhalation the radius decreases which causes the opposite change.

The garment electronic is enclosed by a housing which can be attached to the textile front end. When detaching the electronics, the sensor shirt can be washed using a washing machine.

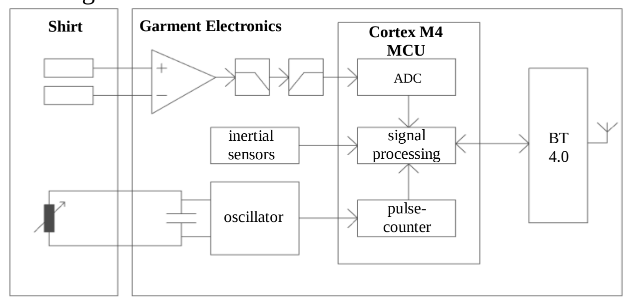

Figure 2. Garment electronics, system overview

2.3. Garment Electronic

For acquisition and processing of health data our electronics utilize an ARM Cortex-M4 based microcontroller. Due to its improved digital signal processing capabilities, this microcontroller type has proven as a good solution for applications which use complex algorithms but have high demands for long battery runtime [4].

ECG measurement is performed at a sampling rate of 256 Hz. Our system allows determination of heart rates between 30 bpm and 250 bpm. In order to do reliable HRV, we use an upsampling-algorithm which increases temporal resolution of ECG signal to 1024 Hz. In order to do this without creating aliasing effects, we use a sharp band pass. The low pass of our filter reaches a suppression of -20 dB at 125 Hz. Thus the upsampled signal holds the same information as a signal sampled directly with 1024 Hz, but energy is saved due to longer sleep intervals of the microcontroller [5].

To measure respiration related chest movement in real-time, we implemented a low-power LC-oscillator, changing its frequency with the sensor's inductance. Frequency measurement is performed using the microcontroller's pulse counter. The sample rate of respiration signal is 16 Hz. Respiration rates between 7 min^{-1} and 60 min^{-1} can be determined.

Raw data from all signal sources are forwarded to the processing algorithms, which calculate additional parameters like heart and breath rate, or detect accidents. Health parameters or detected events are transferred using a Bluetooth 4.0 compliant radio module.

For safety reason our system is forced to achieve long battery run times. To enlarge operating time, the battery is charged using textile solar panels integrated in an optional safety vest. Two panels are connected in parallel, each with a maximum output of 1 W. If no solar charging is used our system is fully operational for more than 24 h (using a fully charged 300 mAh Li-Polymer battery).

3. ECG Measurements

Determination of health parameter is essential for our system due to its safety related functions. Falsely triggered driver warnings, or wrong information on the user's health status after an accident, would lead to a significant decrease in acceptance. In addition, calculated RR-intervals have to be reliable in order to perform HRV calculations. Even though it might not be possible to keep raw signals completely free from distortion, a high R-peak detection rate is essential. To evaluate our ECG signal quality, we identified three important requirements the system has to fulfill. From those requirements we derived different measurement set-ups.

1. Long Time Stability

Since our system is intended to be used on long motorcycle rides, it is essential to keep good skin contact, even after multiple hours of use. Therefore our first measurement is a long time recording over 5 hours. To quantify the quality of the acquired data, we do an optical examination, in order to detect and classify distortion on the signal. Distortions are separated in 3 different classes (see also Figure 3):

- Class 1: Signal saturation is reached, no analyzable signal, R-peak detection is not possible.
- Class 2: Signal saturation is not reached, but artifact amplitude is higher than amplitude of the foregoing R-peak. Might be misinterpreted as R-peak by algorithm.
- Class 3: Amplitude of distortion is lower than amplitude of foregoing R-peak. Misinterpretation is possible but unlikely.

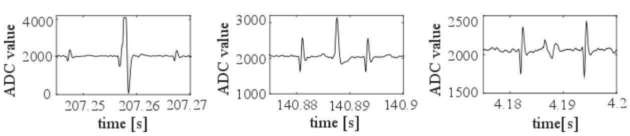

Figure 3. Examples for different distortion classes. From left to right: class 1 distortion; class 2 distortion; class 3 distortion.

2. Movement Related Artifact Stability

Since a motorbike rider is believed to mostly sit in a fixed position, we do not expect strong movement related artifacts compared to sports application. During sports high distortions can arise in particular when the user is walking or running, since each step leads to a force that moves the electrodes. To investigate the influence of high physical activity we acquired ECG data during a treadmill exercise. In order to evaluate quality of the measured signal, it is compared to data acquired in parallel using Ag/AgCl adhesive electrodes. To give a comparison on how well each signal is suited for heart rate determination, calculated RR-intervals for both data sets are compared. The measurement is performed using the following protocol:

a) 2 min standing
b) 2 min walking at 4 km/h
c) 2 min jogging at 8 km/h
d) 2 min running at 12 km/h
e) 2 min standing

3. Motorcycle Induced Artifact Stability

Even if the user itself was not moving during a motorcycle ride, distortions could be generated by vibration of the bike. A motorbike engine is believed to run at frequency higher than 2000 min^1 (33,3 Hz) which is close to the QRS-complex' signal parts [6]. ECG Signal is acquired during a motorbike ride. Detected RR-intervals are examined for anomalies in the curve runs.

4. Results

Figure 4 shows a plot of the acquired ECG raw data from 5 hours long time measurement, while Table 1 shows the counted distortions for each artifact class. Most observed artifacts are from class 2. Strong artifacts which lead to a complete loss of the ECG Signal were only observed three times during the whole measurement. Most sections are free from distortion.

The results from measurement 2 are presented in figure 5. Besides a small deviation between amplitude of both signals (adhesive electrodes lead to slightly lower amplitude) the acquired raw signals show no significant difference. Sharp peaks within the RR-interval curve run indicate missed (FN, false negative) or falsely detected (FP, false positive) R-peaks.

Table 2 images the evaluation of R-peak detection during treadmill exercise and motorcycle ride. R- peaks detected by the algorithm have been compared to manually annotated R-peaks in order to calculate true positive rate (TTR), which is calculated by:

$$TPR = TP \ / \ (TP + FN)$$

Figure 6 shows the ECG acquired during a motorcycle ride. As can be seen ECG is not overlain by distortion of the engine.

Table 1. Counted distortions in ECG raw signal during 5 h measurement

class of distortion	count
class 1	3
class 2	64
class 3	16
sum	83

5. Discussion

The aim of our work was to design a textile integrated system suitable for long time ECG and Respiration measurement. Since reliability of derived heart rate values is essential for safety related functions of our system, we evaluated signal quality of measured ECG signals.

Table 2. R-peak detection during treadmill exercise and motorcycle ride. TP: true positive; FP: false positive; FN: false negative; TPR: true positive rate; T: minimum tolerance for deviation between automatically and manually detected peak location to achieve best results

Measurement	Electrode	TP	FP	FN	TPR	T
Treadmill	Silicone	1357	3	7	0.995	3
Treadmill	Ag/AgCl	1347	13	16	0.988	5
Motorcycle	Silicone	340	0	3	0.991	7

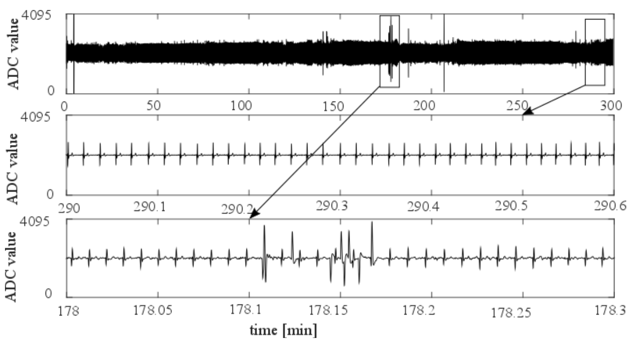

Figure 4. Long time ECG measurement. Starting from the top: Full ECG; non distorted area; distorted area

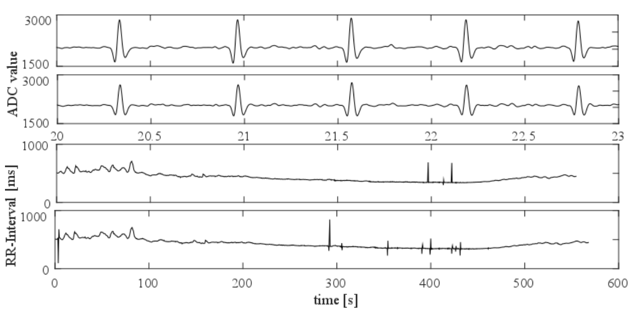

Figure 5. Results of treadmill exercise. Starting from the top: ECG (silicone electrodes); ECG (adhesive electrodes); RR-intervals (silicon electrodes); RR-intervals (adhesive Ag/AgCl electrodes)

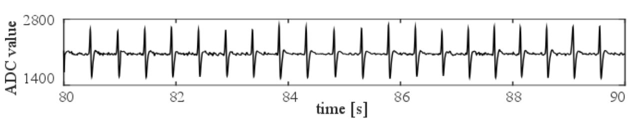

Figure 6. ECG acquired during a motorcycle ride

We identified long time stability, movement artifact stability and motorcycle induced artifact stability as particularly critical factors. To rate how the system meets our requirements, we took ECG raw data and did optical analysis as well as analysis of processed data (RR-intervals).

Silicone electrodes appear to be a well suited alternative to textile electrodes. Our textile front-end achieves good long term stability. Most parts of the measured long time ECG were completely free from distortion. In addition our system shows a tolerance to physical activity, which is comparable to adhesive Ag/AgCl electrodes. Our system seems to be unaffected by motorbike induced artifacts. Calculated RR-intervals show little aberrations even under high physical activity.

Although first results indicate that our system is well suited for the desired application, not enough data has been be acquired at this state. For further evaluation of our system, measurements with multiple subjects and multiple types of motorcycles (e.g. engine size) have to be performed.

6. Conclusion

Our results suggest that continuous heart rate monitoring for motorbike rider is possible with our proposed system.

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