Novel Human Computer Interaction Principles for Cardiac Feedback using Google Glass and Android Wear

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***Abstract*—This work presents a system for unobtrusive cardiac feedback in daily life. It addresses the whole pipeline from data acquisition over data processing to data visualization including wearable integration. ECG signals are recorded with a novel ECG sensor supporting *Bluetooth Low Energy*, which is able to transmit raw ECG data as well as estimated heart rate. ECG signals are processed in real-time on a mobile device to automatically classify the user's heart beats. A novel application for *Android*-based mobile devices was developed for data visualization. It offers several modes for cardiac feedback, from measuring the current heart rate to continuously monitoring the user's heart status. It also allows to store acquired data in an internal database as well as in the *Google Fit* platform. Further, the application provides extensions for wearables like *Google Glass* and smartwatches running on *Android Wear*. Hardware performance evaluation was performed by comparing the course of heart rate between the novel ECG sensor and a commercial ECG sensor. The mean absolute error between the two sensors was 4.83 bpm with a standard deviation of 4.46 bpm, and a Pearson correlation of 0.922. A qualitative evaluation was performed for the Android application with special emphasis on the daily usability and the wearable integration. When the *Google Glass* was integrated, the subjects rated the application as 2.8/5 (0 = Bad, 5 = Excellent), whereas when the application was integrated with a smartwatch the rating increased to 4.2/5.**

***Keywords*-Body Sensor Networks; Electrocardiography; Wearable Computing; Android Application; Human Computer Interaction**

I. Introduction

Changes in the demographic structure are characterized by lower reproduction rates, higher life expectancy, and a decrease in mortality [1], leading to an increase of chronic diseases. Therefore, a need to continuously monitor the individual's cardiac functions throughout the day for preventing fatal disorders becomes increasingly important.

Because the influence of the environment on the measurement of patients' physiology (commonly manifested as the *"white coat syndrome"* [2]) is not negligible, mobile devices like smartphones or tables are an ideal platform, given their integration into daily life.

Wearable healthcare technology is a promising way to improving the quality of life for chronic disease patients and elderly people as well as healthy individuals. These solutions allow an ubiquitous and pervasive monitoring of vital signs in the patients' daily environment without any restrictions in activity or modification in behavior, during physical activity or at rest.

Several research groups presented mobile applications for ECG recording. Oresko et al. [3], Yen et al. [4], and Makki et al. [5] proposed ECG analysis for detecting cardiac abnormalities, whereas Valchinov et al. [6] and Richer et al. [7] used ECG analysis for sports and fitness assessment. Gradl et al. [8] presented an application for Android-based mobile devices with an algorithm for real-time ECG monitoring and automated arrhythmia detection. These approaches mainly focused on the algorithm development, and did not provide a solution for daily life conditions. There is definitely a need for developing a user-friendly application that does not distract the user during its everyday activities. Nowadays, it is possible to display information about the user's vital signs as well as interacting between wearable and mobile phone at the same time.

The purpose of this paper is to develop a solution that incorporates novel human computer interaction principles with cardiac feedback that is usable in daily life situations. This work presents a novel low-power data acquisition ECG hardware using Bluetooth Low Energy. The main contribution however is the implementation of an application called *DailyHeart* for Android-based mobile devices with special focus on human computer daily life usability and wearable integration.

II. Methods

A. Data Acquisition

The sensor module presented here measures the user's ECG, which is sampled with a 12-bit resolution using the integrated ADC of a TI MSP430-FR5969 microcontroller (Texas Instruments, Dallas, TX, USA), whose clock frequency was dropped to 1 MHz due to energy saving aspects.

The sensor system was configured to measure the user's ECG, but it can moreover be configured for measuring physiological signals like EMG or respiratory rate [9].

ECG data was transmitted to the mobile device by a TI CC2541 system-on-chip (SoC), which is an integrated

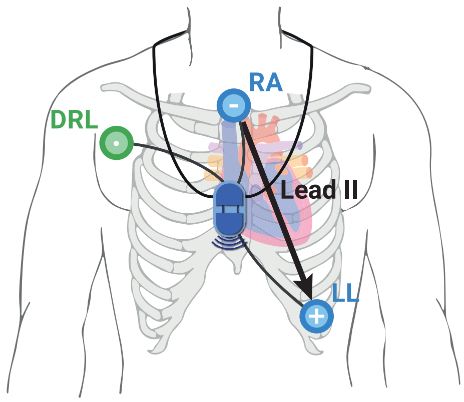

Figure 1. **Lead positioning of the BLE-ECG Stamp.** Schematic drawing of the sensor placement and the lead positioning; ***RA**: Right Arm, **LL**: Left Leg, **DRL**: Driven Right Leg*

solution for *Bluetooth Low Energy* (also referred as *BLE*, or *Bluetooth LE*) applications, combining a high power Bluetooth antenna with an improved 8051 microcontroller.

The Bluetooth Low Energy Application of the sensor system named *BLE-ECG Stamp* provides two different Bluetooth Services for transferring data to a mobile device: an *EcgService* and a *HeartrateService*. The EcgService streams the sampled ECG signal directly. In order to reduce the power consumption of the CC2541 SoC, the raw values are wrapped into packages with a size of 10 samples before transmission. By performing a heart rate calculation on the sensor side and only transmitting the current heart rate for the HeartrateService, the data rate (and thus the power consumption) is significantly reduced. The HeartrateService implements the *Heart Rate Profile (HRP)* as proposed by the Bluetooth SIG, and hence provides compatibility for other applications supporting this Profile [10]. Here, the EcgService was used since the entire ECG signal was needed for subsequent heart beat classification.

The sensor recorded a 1-channel-ECG at a sampling frequency of 256 Hz with 3 electrodes that were placed according to Lead II of Einthoven's triangle [11]. The negative electrode was placed on the sternum and the positive was placed on the left costal arch (Figure 1). The third electrode was placed on the right breast and used for the driven right leg circuit, which is often added to physiological signal amplifiers in order to eliminate electromagnetic interference [12].

B. Data Processing

The algorithm used for data processing was proposed by Gradl et al. [8]. It is able to perform a real-time detection of QRS complexes in an ECG signal, followed by an automated classification of normal and abnormal heart beats. The pipeline is visualized in Figure 2 and consists of four stages: QRS Detection, Template Formation, Feature Extraction, and Beat Classification.

QRS Detection The raw ECG signal was processed with a pipeline of digital filters proposed by Pan & Tompkins [13]. It consists of a cascaded Bandpass filter, a five-point derivative filter, a squaring operation, and a moving window integrator. QRS complexes were then isolated from the algorithm output.

Template Formation In order to allow an automatic classification of heart beats, a feature computation using two QRS complex templates which were automatically found in the ECG signal and adapted over time was implemented [8].

Feature Extraction The features for the heart beat classification were extracted from 400 ms windows centered on every isolated R peak [8]: The difference in absolute area and the maximal Pearson correlation between the templates and the current beat as well as the the width of the QRS complex, and the R-R interval between the last two QRS complexes.

Beat Classification The isolated heart beats were classified according to the decision tree proposed by Gradl et al. [8], distinguishing between abnormalities in *waveform* and abnormalities in *rhythm/pace*.

C. Data Visualization

The data acquired by the *BLE-ECG Stamp* was transmitted to the proposed application for Android-based mobile devices called *DailyHeart*. Android (Google Inc., Mountain View, CA, USA) was used because of its open source characteristics, the portability of code since the programming language is Java, and because it is the most widely spread mobile operating system up today [14] with a market share of 83.1 %. Furthermore, the BLE APIs of Android provide support for *Bluetooth LE* since software version 4.3 (API

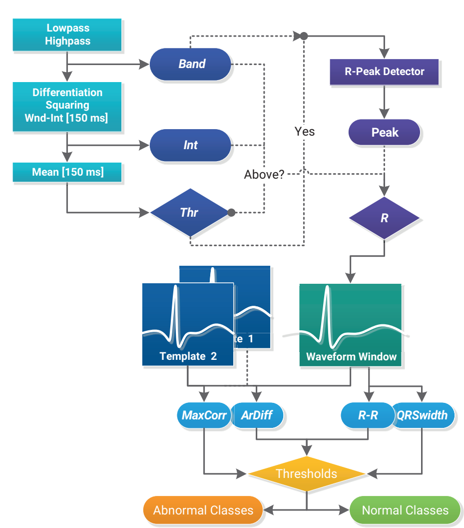

Figure 2. **Algorithm pipeline.** Overview of the pipeline that is used for QRS detection and heart beat classification (modified with permission from [8])

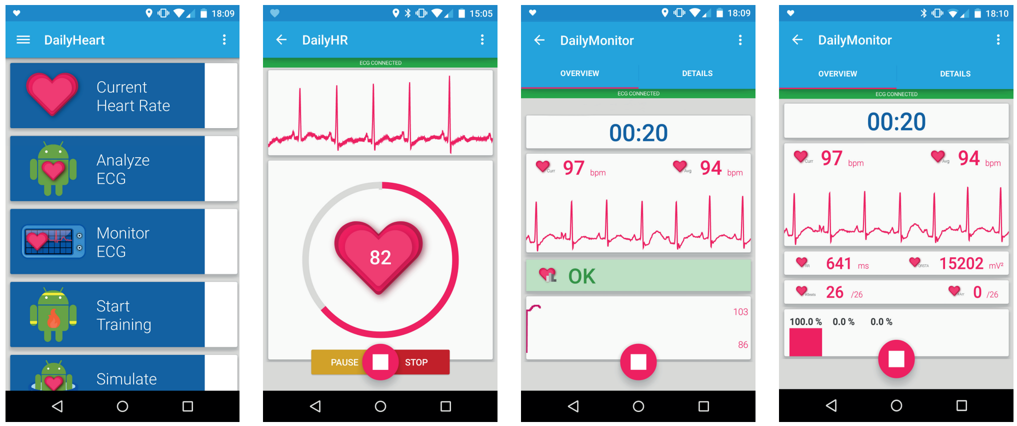

Figure 3. **User interface of *DailyHeart*.** Different screens of the application. *From left to right:* Main menu for selecting the recording mode; Activity to measure the user's current heart rate; Activity consisting of two tabs to monitor the user's ECG.

level 18). The *DailyHeart* application was implemented using the *Android SDK 5.0* (API level 21), which was released with Android 5.0 *Lollipop* in November of 2014. It introduced a completely new design language called *material design* that is characterized by Google as bold, colorful, and responsive, providing a new and intuitive user experience [15].

The application consists of several components: a **BLE Service** for data delivery, a **User Interface** for informing the user and receiving input, a **Data Storage** unit for saving the recording results, and a **Wearable Extension** for *Google Glass* and *Android Wear*-based smartwatches.

BLE Service This component is implemented as an Android background service. It provides ECG data for the processing unit and delivers the results to the user interface. The data can either be obtained via *live mode* or *simulation mode*. In live mode, the service establishes a connection to the *BLE-ECG Stamp* and receives the acquired data via Bluetooth LE, whereas in simulation mode, real-time sampling is simulated by reading data from the external storage. It is possible to simulate pre-recorded data from *DailyHeart*, or data from the *MIT-BIH Arrhythmia* databases [16]. Handlers are used to pass data to the service's signal processing unit and the user interface. By using a service, data delivery and processing runs independently from any foreground process, which allows the user to switch between applications without terminating the connection.

User Interface The application was designed following the material design guidelines in order to provide a clear, intuitive and appealing user interface for cardiac feedback. It features modes that were designed for different daily life situations (Figure 3 shows screen examples): a *CurrentHR* mode to perform a snapshot heart rate measurement, a *AnalyzeECG* mode to analyze the ECG over a period of time, and a *DailyMonitor* mode to continuously monitor the user's ECG. In addition, a *DailySimulate* mode was implemented for re-playing pre-recorded data. All activities plot the live ECG signal and display the current heart rate to the user. The *DailyMonitor* mode provides also the average heart rate, the course of heart rate since the beginning of recording, as well as further features obtained from the ECG processing. At the end of the measurement, a summary of the acquired data is shown as well as buttons to restart the measurement or save the results to the internal database and/or *Google Fit*. The history screen accesses the database and lists all entries.

Data Storage The Android operating system is shipped with a *SQLite database* that allows to store results into the database for retrieving it again at a later time. The *DailyHeart* application uses this feature for local data storage and also provides support for *Google Fit*, a health-tracking platform where users can access their fitness and health data acquired and uploaded by different devices and applications.

Wearable Extension Android Wear is a modified version of the Android operating system for smartwatches and other wearables by integrating smartphone features with a watch form factor. Information on smartwatches running on Android Wear can be displayed either by extending regular Android system notifications for wearables, that are then synchronized between smartphone and wearable, or by creating custom applications for Android Wear that can communicate with the smartphone application. The extended notifications allow the user to fully control the application after it has been launched. They furthermore continuously update the screen with new information. In this work, a custom application for smartwatches was implemented in order to enable voice capabilities. This allows the user to start the application by saying the phrase *"Okay Google, start DailyHeart!"*, or to directly measure the current heart rate by saying *"Okay Google, what's my heart rate?"* or *"Okay Google, what's my bpm?"*.

Google Glass is a wearable device with an optical head-mounted display (OHMD), a camera, and several sensors like IMU, ambient light sensor, proximity sensor, and a GPS receiver [17]. It also includes chips for Wi-Fi and Bluetooth communication. Google Glass can be controlled by voice commands or by swipe-and-click gestures performed on a touchpad located at the right of the frame. By using the same extended notifications as for smartwatches, the *DailyHeart* application also provides support for Google Glass. The OHMD offers cardiac feedback by overlaying information directly into the user's field of view.

III. Evaluation

A. Sensor Evaluation

The *BLE-ECG Stamp* was evaluated to assure that the provided signal was accurate and reliable enough for subsequent data processing. Therefore, a *Shimmer* (Shimmer Inc., Dublin, Ireland) ECG sensor was used as gold standard hardware. This sensor system has already been used in earlier work [7], [8] providing a validated ground truth.

A study involving a physical exercise on a stationary bicycle was conducted with five healthy male subjects (age 22.2 ± 1.3 years (mean $\pm$ SD)). Their suitability was assured by means of the *Physical Activity Readiness Questionnaire* (PAR-Q) [18]. All subjects passed the PAR-Q and signed a written consent to perform the following protocol: two minutes of resting, two minutes of low-intensity cycling, one minute of heavy-intensity cycling, two minutes of low-intensity cycling, two minutes of resting. The study was approved by the ethics committee of the Friedrich-Alexander-Universitt of Erlangen-Nrnberg.

Both sensor systems were worn simultaneously with the same lead configuration. The ECG data was transmitted via Bluetooth and saved as CSV-formatted files, which were imported into the *DailyHeart* application using the *simulation mode*. The course of heart rate during the measurement was exported to MATLAB® (The Mathworks, Inc., Natick, MA, USA) for comparing the results.

B. App Evaluation

Five male and five female subjects (age 21.0 ± 1.7 years (mean $\pm$ SD)) participated in a study for evaluating the *DailyHeart* application with emphasis on daily life usability and wearable integration. All subjects were healthy and signed a written consent approved by the ethics committee of the Friedrich-Alexander-Universitt of Erlangen-Nrnberg. The participants were asked to wear the *BLE-ECG Stamp* with the default lead configuration and a *Nexus 5* mobile device (LG Electronics, Seoul, South Korea) running on Android 5.0.1 "Lollipop". They furthermore wore a *LG G Watch* (LG Electronics, Seoul, South Korea) running on Android Wear, and a *Google Glass* (Google Inc., Mountain View, CA, USA). The participants were then asked to test the features of the application and perform daily life activities for a duration of one hour (including a short run of one minute). To evaluate the functionality of the application, each subject answered a questionnaire[1].

Table I
Results of the Sensor Evaluation. *MAE* = Mean Absolute Error, *SD* = Standard Deviation, *PC* = Pearson Correlation

	MAE (bpm)	SD (bpm)	PC
Subject 1	2.43	2.91	0.957
Subject 2	6.54	6.58	0.920
Subject 3	3.85	3.45	0.912
Subject 4	5.64	4.29	0.913
Subject 5	5.68	5.05	0.906
Mean	4.83	4.46	0.922

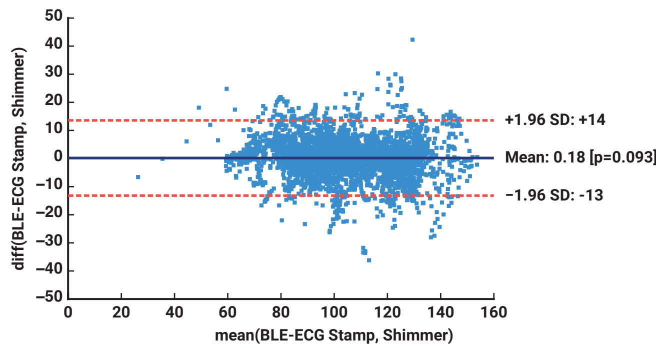

Figure 4. **Bland-Altman plot for the sensor evaluation [19].**

IV. Results

A. Sensor Evaluation

The results of the sensor evaluation for each subject are listed in Table I. The Bland-Altman plot in Figure 4 visualizes the relationship between both sensor systems [19]. The evaluation achieved a mean cross correlation coefficient of 0.922 with a mean absolute error of 4.83 bpm $\pm$ 4.46 bpm (MAE $\pm$ SD).

B. App Evaluation

The results of the app evaluation are visualized in Figure 5. Higher ratings as well as lower standard deviations were obtained for Android Wear compared to Google Glass throughout the entire evaluation. In addition, 30 % of the participants were afraid that Google might misuse the health data stored in *Google Fit*. Every participant would use the *DailyHeart* application in combination with a smartwatch for cardiac monitoring, but no one prefered the combination with Glass.

V. Discussion

A. Data Acquisition

In this work, the hardware components and the wireless communication were chosen to keep power consumption as

[1]The questionnaire can be accessed here: http://www5.cs.fau.de/fileadmin/groups/ds/dailyheart.pdf

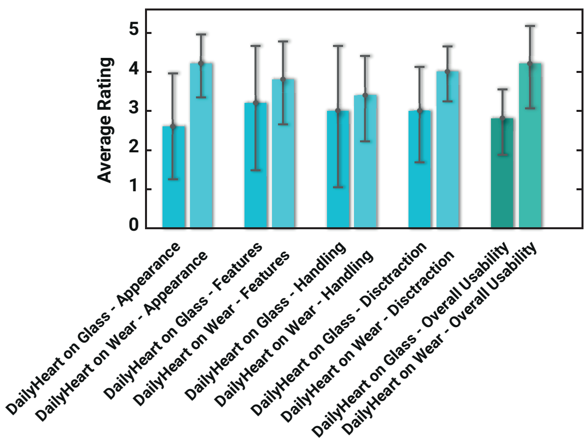

Figure 5. **Results of *DailyHeart* evaluation.** The bar chart presents the answers to the questionnaire that was filled out by the participants of the study, with 1 being the most negative answer and 5 the most positive answer.

low as possible, for providing a sensor system that enables a long-term monitoring without having to charge the device in between.

The study design for validating the correct functionality of the *BLE-ECG Stamp* was chosen to challenge the recording system by conducting a protocol that includes strong motion and muscle artifacts. The results show an error of 4.83 bpm $\pm$ 4.46 bpm (MAE $\pm$ SD) compared to the *Shimmer* sensor. The high Pearson correlation of 0.922 proved that the sensor provides a solid wearable solution for continuous cardiac monitoring.

However, the evaluation reveals a key problem for wearable ECG sensors: Motion and muscle artifacts result in a distorted ECG signal, which can be especially observed during heavy-intensity cycling periods. In comparison to the *BLE-ECG Stamp*, the *Shimmer* uses shorter leads, which is a reason for the lower noise level of the Shimmer signal. Therefore, shorter leads (and perhaps fixed to the body) should be used for the *BLE-ECG Stamp* as well, so that the sensor is more tightened to the body and hence more robust in the face of artifacts. Furthermore, a version with a digital ECG amplifier is part of future work, which may result in an improved signal quality.

B. Data Processing

The implemented algorithm provides high QRS detection rates, high sensitivity and a low number of false negatives, which is an important basis for adequate cardiac monitoring [8]. The algorithm ran in real-time on the testing mobile device but created high computational load which could be observed by a slight warming of the mobile phone. Given the flexibility of the app design, the data processing unit could easily be replaced, as long as it implements the interface of the application.

C. Data Visualization

The application layout of *DailyHeart* was reduced to only the essentials in order to provide clarity and to prevent unnecessary loss of time by getting used to the handling, which was the main purpose of introducing the material design. Future work could use more detailed queries that are compiled against the *SQLite database* implemented for this application, so that results can be filtered to specific record types or time intervals. Further, cardiac information could be combined with additional data from GPS and accelerometers for a *DailyTrain* mode specialized for various types of physical activity such as running or biking, that provides information about about location, speed, or energy expenditure. It would also be feasible to improve the clinical aspect of the application by incorporating heart rate variability analysis.

One key intention of this work was the incorporation of novel human computer interaction concepts like Google Glass and smartwatches with an application for cardiac feedback. Adding wearable-specific functionality to notifications and enabling voice capability are an important part of the wearable experience. It provides better user experience and allows the user to interact with the application quickly and hands-free. The original intention of Google Glass was to present a standalone wearable system since it has enough computational resources and sensor technology to work independently from a handheld device. However, excessive usage of Google Glass rapidly leads to overheating and significant battery loss. Therefore, it is not recommended to perform complex calculations on Glass, which makes a standalone version of *DailyHeart* for Google Glass not feasible.

The results of the app evaluation show that the mean usability rating for smartwatches (4.2) is higher than the Google Glass rating (2.8). The OHMD of Google Glass is placed in the least comfortable area of the human field of vision [20]. Due to that, staring at the display for a longer period of time is counterintuitive and causes discomfort in the eye muscles [20]. In contrast, wristwatches have been worn for a long time by a major part of the population and therefore are an integral part in daily life. Since Glass is an entirely new technology, smartwatches receive higher public acceptance and need lower habituation periods. Privacy concerns against Google Glass have been raised by various sources due to the possibility of videotaping people in public without their awareness and permission [21]. Concerns do not only exist due to the integrated camera of Google Glass, but also about the privacy policy of Google in general. 30 % of all study participants are afraid that their health data stored in Google Fit could be misused by third parties. The intention of the *Google Fit* integration into *DailyHeart* is to exclusively upload the user's heart rate when the user desires so – it is not intended for uploading all collected cardiac data to Google servers. With this aim, the internal database was implemented, but future work includes improving the overall security of the application.

VI. Conclusion

This work presents a novel wearable system that is capable of measuring the user's cardiac functions throughout the day, from a one-time heart rate measurement to a continuous ECG monitoring. The core features of the smartphone application were combined with the possibilities of wearable devices like Google Glass and smartwatches based on Android Wear. Additionally, novel human computer interaction principles were incorporated to increase the usability and provide a feasible solution for daily life usage. Each component was designed focusing on constraints that are encountered throughout daily usage for shaping an integrated system. Storing the acquired data in the internal database and the *Google Fit* platform allows a subsequent supervision for the user as well as for physicians. The results from the quantitative and qualitative evaluations show that the developed system for cardiac monitoring is usable for daily life. Future work includes an extension of *DailyHeart* in order to enhance the range of features.

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