e-Vital: A Wrist-Worn Wearable Sensor Device for Measuring Vital Parameters

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***Abstract*—In today's world, connected wearable sensors became a delicate part of the imperative daily analysis and assessment to identify the urgency of the state of health. Recent advances in sensor designs and analysis techniques enable us to uniquely distinguish noninvasive wearable sensor technology with an exclusive integration to the body surfaces. In this regard, we have developed a low-cost wrist-worn wearable device called E-Vital that can monitor health conditions closely so that patient follow-up can access information directly and in a practical way. We aimed to design the system as a comprehensive and compact monitoring scheme by measuring physiological health parameters in long-term usage. In addition to the measurement of physiological signals such as an electrocardiogram (ECG), Galvanic Skin Response (GSR) and body temperature, it is possible to instantly display and store this health data with the E-Vital mobile application. Bluetooth technology is used to provide instant wireless data communication between the sensor device and the mobile application. Additionally, an SD card module attached to the sensor to prevent data loss against possible connection problems as a local buffer. The measurement performance of the proposed sensor device for capturing the electrophysiological signals, such as an ECG is compared with ECG obtained by a conventional gold standard data. The results indicate that the wearable sensor has an acceptable signal-to-noise ratio (SNR). Both the sensor device and mobile system have successfully been in terms of signal quality, continuous data transportation, and data storing performance during on-body trials.**

***Index Terms*—e-health, healthcare, biosensor, telemetry, health monitoring, wearable systems**

I. Introduction

The latest advancements in science and technology have accelerated the development of small devices with enhanced functionality through wireless connectivity. Devices are getting smaller day by day, at the same time, they become more widespread in use and portability. The use of these devices has taken place in many sectors from health to entertainment. In particular, a rapid increase has taken place in the global healthcare sector. Shrinking devices enable continuous monitoring of physiological parameters. This is possible by the efficient and effective transmission and storage of the data.

Wearable systems usage distribution is reflected to increase by 61 percent from 2014 to 2016 [1], with a 5.1 billion dollar profit. It is expected to have growth with 17% [2] every year by reaching 12 billion devices by 2021. In addition to this growth, problems are also growing simultaneously. Overall problems of the existing wearable sensor devices comprise high price, poor autonomy, poor user experience, user-required feedback, inexperienced functional applications, and the power capacity [3]. Given that these are common problems that continue to plague the development process.

One of the well-known examples of these problematic systems is the lack of functionality like the Smart Vest [4] does not support mobile monitoring, it is only accessible on computers and this making harder to follow the data at any time. Another study called the Smart Shirt [5] don't have any data loss prevention plan. The monitoring process can be only accessible on a computer which is violating the user experience. The poor user experience, poor autonomy and user-required feedback problems like mentioned above are the primary problems of the system. The system that is developed by Kapu et.al [6] cannot perform a flexible measurement. The user should always sit in front of the PIR sensor for measurement. Because of the lack of mobility, it is not practical for daily and regular use. The designing smart wearable to measure health parameters [7] deficient about the user-required feedback because it has heart rate data, but it suffers from the visualization of signals. Also, there is no backup plan to prevent connection failures. There are some similar studies [5], [8], that designed a smart wearable for monitoring of physiological signals.

Wearable sensor population increase dramatically used for physiological measuring stress,cardiovascular disease [9], fatigue [8], and lots of other activities such as sport [10]. Smartphones are in everyone's pocket now and everybody carries with by their side. In this manner monitoring on a mobile phone has become a necessity for everyone, therefore, within the scope of this project, a wrist-worn wearable device is developed that includes continuous collection and evaluation of multiple physiological signals for monitoring of vital sign, real-time activity, and emotional state.

Remote healthcare monitoring empowers people to stay at home rather than getting in costly healthcare facilities, such as hospitals or nursing homes. From this perspective, we aimed to provide an efficient and cost-effective alternative to on-site clinical monitoring systems. A wrist-worn design was realized for continuous long-term monitoring, which can be performed without interfering with the users' everyday activities and without restricting mobility by integrating several sensors as

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ECG, GSR, temperature, and accelerometer. In addition to wearable sensor, an Android-based mobile app was developed to enable data communication and provide user interfaces for various health reports.

II. Proposed System: e-Vital

This section describes the details regarding the non-invasive wrist worn sensor device that have proposed for providing continuous physiological value monitoring. In this context, a Bluetooth integrated wearable sensor device called E-Vital is developed using a Arduino Nano microprocessor and several sensors such as GSR, ECG, body temperature, accelerometer and gyro. We also have preffered some additional equipment such as micro SD Card and lipo battery to complete the proposed design. Each component has been shown and explained in Figure 1.

Every component was unified and fitted into the wrist-worn device's hull. Also, an open-source mobile application (E-Vital mobile app) is developed to display and store sensor values in real-time. According to Android's statistics [11], 90% of the Android operating system phones are currently using Android 5.0 and above in the market. To increase the user range, project development was conducted by Android Studio IDE (Android 5.0 Lollipop) with Gradle technology to add libraries and make version adjustments to the application. This shows that many phones on the market are capable of running our application.

We provided a mechanism to store data in both the sensor device (stores approximately 1600 hours of data) and the phone memory. In this way even though the Bluetooth connection was interrupted, the back-up files always can be used to save the data alternatively. There is no need for the internet connection to visualize the data or display the real-time values of the mentioned system.

The integrated battery allows measurement for at least 24 hours and it can be charged in approximately 40 mins. After the start record button is pressed, the data is stored in the memory inside the wrist-worn device and at the same time continues to be recorded in the sensor device in case of a possible interruption. Once the connection has been re-established, the pre-measured data can be transferred to the phone in a complete and in an accurate manner. The environment can be seen in Figure 2a that illustrates a schematic representation of the sensor device.

The mobile application receives and decodes the raw signal data which is transmitted from the device via Bluetooth, then visualizes the measurements in the real-time, and start a record for every instance to save each signal individually. In addition to that, we have calculated heart rate (HR) from ECG signal via Peak Detection algorithm [12].

III. Experimental Results

Wearable sensors have to be convenient and easy to use for the customers. The proposed sensor device was designed to fit compatible into the wrist that can be seen in Figure 2b. The development tests of the developed system and its components has been evaluated in several steps. The first attempt was made to determine the sampling frequency and a reduction of the gold standard frequency which is considered as 1000 Hz, without disturbing the characteristics of the ECG signal. We have tried the following sampling frequencies; 1000 Hz, 500 Hz, 300 Hz, 200 Hz, 150 Hz, 120 Hz, and 100 Hz to gather proper ECG data. Simultaneously, the heart rates were measured with an external device and were compared with our results. We can all agree that the suggested /gold standard sample rate is 1000 Hz in the literature for ECG, but this consumes too much energy. After making some trials we experienced the results that can be tolerated around from 200 Hz. So, we have decided to reduce the sampling frequency to 200 Hz by results of these assessments. Following that, we have conducted several experiments to validate the signal quality such as monitoring of vital parameters, real-time activity, and emotional state has experimented.

A. *Monitoring of vital signs*

The first issue to be validated is defining a range for medical information during the experiment of the signal is to specify the clinic knowledge considering the monitoring activity. The simple and easy way to test the normality of the measured signal is using the information in the literature for sufficient evaluation. We have validated the heart rate, body temperature, and the electrical activity of the skin based on clinical information. In addition, medical knowledge, the effects of motion, the intrinsic variability of vital signs, and the uncertainties associated with human behavior should be considered during the experiments.

The test procedure was performed to consider the fatigue, the participant was asked to attend to resting test to monitor vital signs as a first experiment. During the experiment sensor device is attached to the left wrist. GSR glove is attached the first and second fingers of the left hands and ECG patches are attached to the chest. When measuring the skin resistance, temperature, and heart rate of the individual in a steady-state, the person to be tested remains in a resting state for 10 minutes and signals are gathered. At the end of this experiment, we observed that the heart rate was in a normal range (74 bpm) for a relaxed person, GSR value was about to 0.65 mv, and body temperature was 36.75°C. We proved that the device is working perfectly and sending signals without disturbance.

B. *Real-time activity monitoring*

To test the results of physical activity, we have collected data during walking and running. From our observations, we can perceive that the acquisition system is not affected too much from the movement during the measurements. We have seen from the results of monitoring of walking (Figure 3), it was concluded that the HR was increased to 87 bpm compared to the resting status. Average body temperature and GSR are increased 37.1°C, 1.46 mV respectively.

Consistent with this result, during the second activity which is running, HR was increased to 101 bpm and other variables was ascend too. We also have followed the acceleration and position values that obtained using the 3-axis accelerometer.

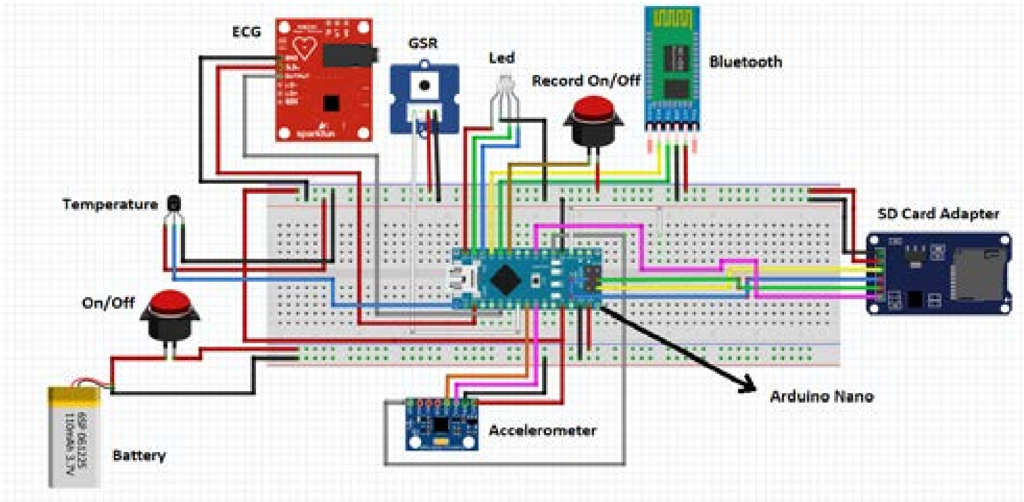
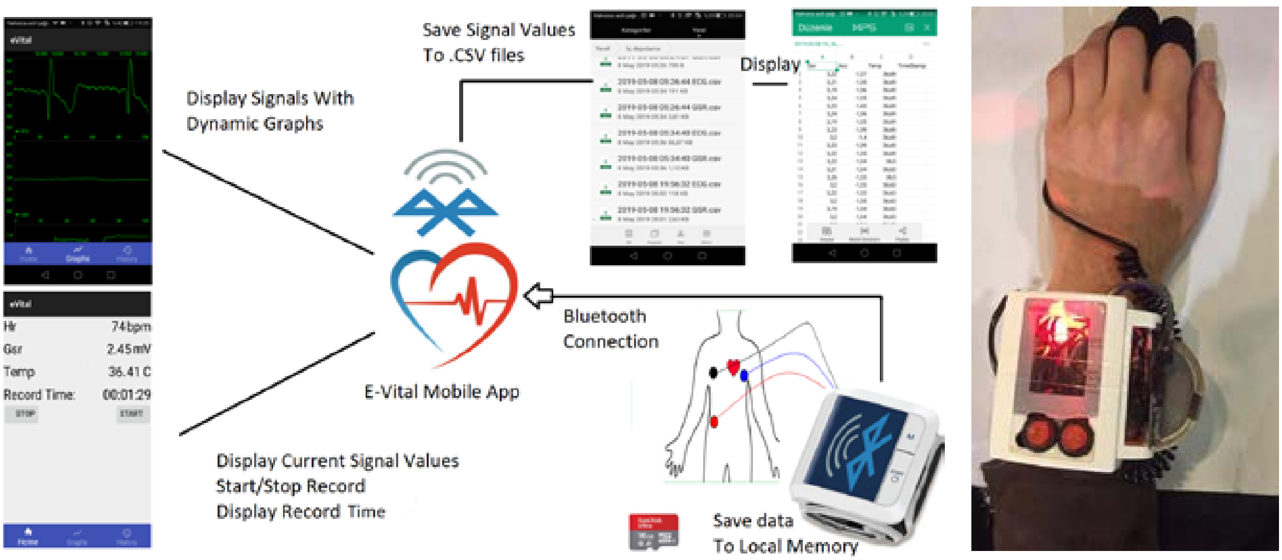


Fig. 1: Components of the proposed sensor device.



(a) Diagrammatic representation of the proposed system

(b) The wrist worn wearable sensor device that is attached to the wrist

Fig. 2: Design overview of sensor device and related components.

C. Emotional state monitoring

The emotion can be gathered by observing plenty of individual expressions. For instance, the direct measure of a heart rate is different from the heart rate predicted by a camera. Or, even if direct measurement techniques are used, physiological responses vary in different events. The measurements of this experiment were conducted during the watching thriller movie and soccer game and outcomes are observed. First, we want them to watch a thriller movie to see the emotional change at the signals. We observed that some instant ups and downs in the GSR signal which represent the stimuli. GSR is used for monitoring psychological or physiological arousal.

Another measurements in Figure 4 are done while the subject watching a soccer game, you can see inside of the first circle how the signal is changed while the subject watching someone's scoring a goal. Inside of the second circle, we will see another signal change and this signal belongs to while the subject accidentally dropped his phone. Thus, we observed the signal changes while the subject gets nervous or excited. Average skin conductance response is measured as 1.25 mV.

Analyzing a transmitted signal may generate accurate results when we use variables that contain some rules relevant to the subject. The developed sensor device can be used to monitor in cardiac patients or cognitive evaluation of participants. In this case, we can not evaluate the participant by calculating the average values but also the effects of the signal characteristics should be considered during the decision-making process.

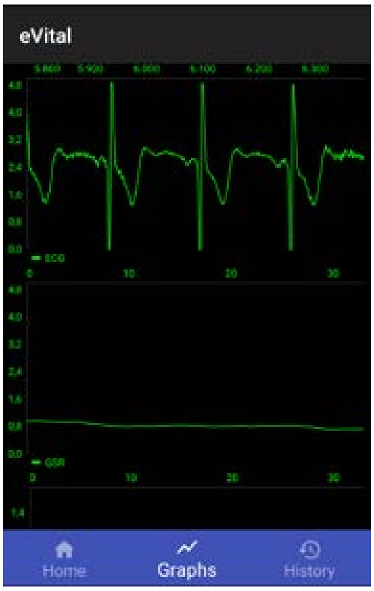


Fig. 3: Plots of physiological signals during walking.

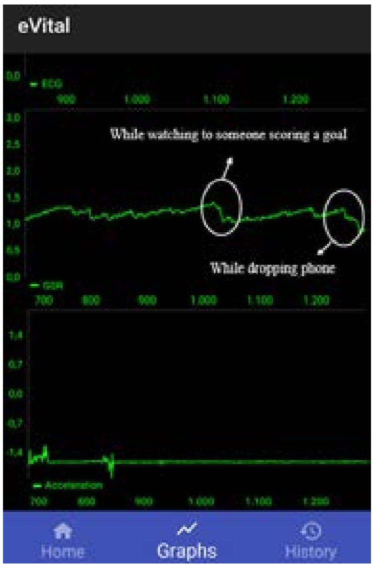


Fig. 4: GSR signal while watching soccer game.

We only focused on the validation of the device and the quality of the signal. Additionally, the data can be analyzed and used for determining both the cardiovascular status and emotional state of users.

IV. CONCLUSIONS

The main criterion of personal health monitoring is that it is always traceable and can be easily achieved due to the mobility of wearable sensor devices. In our proposed system, design requirements were focused on developing a functional system that can respond to vital changes during daily activity. The signals are monitored properly and accessible all the time and the battery life has been maximized for for longer use. All data stored in the memory of the sensor device and also stored in the phone memory in case of disconnections between phone and sensor device. Results of this project have not only implications on the technological domain but also medical sector trying to use continuous psychological data and history of the users in their decision process. We present a low-cost, compact wearable device to monitor users' daily routine. Besides, we considered possible data losses and added a feature to solve this issue by back-up files that allow us to store data in the SD card in the sensor device. As a conclusion, the developed wrist-worn wearable sensor device can able to measure the vital signs via a non-invasive approach and transfer the signal to a mobile device. Finally, we have validated the measured signal with the help of several experiments such as; monitoring of vital signs, activity, and emotional states.

In the future, this prototype can be minimized and made looking more aesthetically pleasing. The storing of the data is currently in local though can be transferred into a cloud environment. Another future dispersion of this study is; noise-reducing algorithms of the signal's can be performed via accelerometer and gyro sensors.

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