# DESIGN OF ECG SYSTEM FOR REMOTE DATA COLLECTION

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***Abstract***

*The article introduces the remote ECG data collecting system. The system consists of a one-lead ECG device connectable via USB to a smartphone, an Android application, a server, and a web application. The ECG device is designed as a USB dongle with small dimensions and uses On-the-Go (OTG) powering technique. These features classify the developed device as wearables. The measured ECG data are stored in the smartphone's internal memory and transmitted to the remote biobank server at predefined time intervals for archiving and subsequent processing. The functionality of Android and the web application are also described in the article. Both applications have a user-friendly graphical user interface. The proposed system was tested in two scenarios: ECG measured on the patient simulator and living subject. The measured raw ECG signals are suitable for basic diagnostics of cardiac health and confirmed the correct function of the proposed system.*

***Keywords***

*Android, biobank, electrocardiography, smartphone*

## Introduction

An aging society is currently one of the problems emerging on a global scale. The demographics of the global human population from the last decades have revealed that the fraction of individuals older than 60 years increased from 9.2% in 1990 to 11.7% in 2013. It is expected to reach 21.1% (2 billion) by 2050 [1]. In light of this trend, it is reasonable to assume that conventional healthcare, as defined by a hospital-centric model, will be unable to meet future demands. Therefore, home healthcare or telemedicine has emerged as a promising approach for measuring our health status regularly and systematically outside the hospital settings. According to the World Health Organization, cardiovascular diseases (CVDs) present the leading cause of mortality worldwide. CVDs contributed to 31% of deaths worldwide in 2016 [2]. In high-income countries, the total number of ischemic heart diseases has gone down between 2000 and 2019 by 16% [3]. Nonetheless, ischemic heart disease remains the top cause of death regardless of the country's income group. Individuals with cardiovascular disease, including those at increased risk of getting it (due to the existence of one or more risk factors such as hypertension, diabetes, tobacco usage, harmful alcohol use, unhealthy diet and obesity, physical inactivity, or chronic disease), need early diagnosis and management.

The electrocardiogram (ECG) is the most common diagnostic modality of CVDs. The ECG can detect almost any heart abnormality at the initial stage of the emerging disease and represents an essential tool for assessing the cardiovascular system [4]. The twelve-electrode ECG is considered the gold standard in clinical practice. However, CVD symptoms are usually uncertain or intermittent in the early stage. Therefore, it is preferable to monitor a person's heart activity at any time or place when the symptoms occur. Additionally, most deaths caused by CVD are premature and could be prevented by changes in lifestyle. While instruments can be used to predetermine the heart condition, most people cannot afford to purchase one or lack the knowledge to interpret the results [5–8]. Over the last decade, a significant increase in mobile phone users allows for decreasing costs and increasing ease of use rapidly, such as recording the ECG outside the clinical settings through an external ECG sensor component [9]. Moreover, the mobile phone applications particularly designed to monitor cardiovascular risk revealed benefits in modifying individuals' behavior to improve cardiovascular health [10]. Due to the complex interplay between predisposing genetic factors, lifestyle, environmental, and cardiovascular risk factors involved in CVDs, digital biobanks were established in high-income countries [11]. Long-term collection of those multivariate data within the biobank could exhibit CVDs mortality predictors more deeply.

In this paper, we propose a complex remote ECG data collecting system using a smartphone application involving an external ECG device. The essential aspect of a purposely designed smartphone application is that



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it should be as user-friendly and straightforward as possible for the elderly. The design of an external ECG sensor is based on an analog front-end ensuring the efficient reliability and small cost and form factor as possible. A series of experiments to evaluate the data acquisition reliability were conducted using both the patient simulator and the living subject.

## Materials and methods

The concept of a remote ECG data collecting system is depicted in Fig. 1. The system consists of an ECG dongle and smartphone with Android OS, a remote server with a database system acting as a biobank or cloud, and a web application running in the web browser on the client PC.

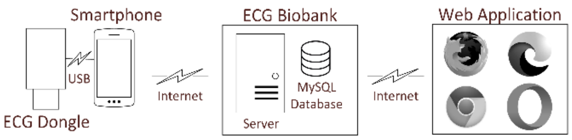


*Fig. 1: The overall concept of the remote ECG collecting system including the client (ECG dongle and smartphone), server-side (ECG biobank), and web application.*

The server uses a free and open-source Apache web server and MySQL database. This article aims mainly at the hardware design of the ECG dongle connectable to the smartphone. The other parts of a complex ECG collecting system, such as Android and web applications, are briefly described in the following subsections.

### Hardware design of ECG device

The ECG device is designed for direct connection to a smartphone or computer via a USB port. The device takes the form of a USB stick/dongle, and that is why we call it an ECG dongle. The essential requirement for the ECG dongle was the lowest possible hardware complexity which results in the small size of the device. The first prototype of the ECG dongle was already presented in [12]. In this article, the new and enhanced ECG dongle is presented. The block diagram of the ECG dongle electronic design is shown in Fig. 2.

A USB port powers the ECG dongle. In the case of powering by smartphone, it must support USB On-the-Go (OTG) functionality, which allows the smartphone to act as a host and provide power for connected devices. The provided OTG voltage is typically 5 V. This voltage level is regulated to 3.3 V by a low-dropout (LDO) regulator. The voltage of 3.3 V is used for powering electronic circuits, as depicted in Fig. 2. The ATmega328P by Microchip is used as a microcontroller unit (MCU). It is an 8-bit MCU from the AVR family with a low power consumption which is desirable for battery-powered devices. The ATmega328P operates at an internal 8 MHz clock. The primary function of the MCU is acquiring ECG data from the analog front-end via Serial Peripheral Interface (SPI) and then sending them to a smartphone or PC via Universal Asynchronous Receiver-Transmitter (UART) interface.

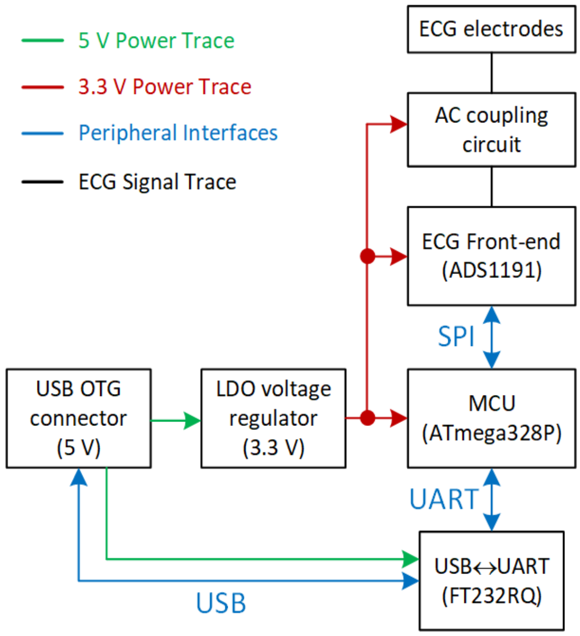


*Fig. 2: Block diagram of ECG dongle electronic design.*

The ADS1191 from Texas Instruments is used as an analog front-end. It contains one input channel of a 16-bit delta-sigma analog-to-digital converter with a built-in programmable gain amplifier, internal reference, built-in Driven-Right-Leg (DRL) amplifier, lead-off detection, and on-board oscillator. It operates at data rates up to 8 kSPS. The default sampling rate is set to 500 SPS, and the differential gain is set to 6. The sampling rate or signal gain can be adjusted from an application running on a smartphone or PC. The built-in DRL amplifier is activated, and the DRL electrode is placed on the patient body to reject common-mode noise (mainly 50 Hz from electricity).

In the previous version of the ECG dongle [12], the ECG electrodes were connected directly to the ADS1191 inputs. As a result, the measured ECG signal sometimes overreached the input range of the ADS1191 because the DC offset was fluctuating and not filtered out. An AC coupling circuit can effectively reduce this problem. We used the AC coupling solution based on the circuit presented in [13], which is appropriate for ECG devices with a third (DRL) electrode. The implementation of the AC coupling circuit is shown in Fig. 3. The capacitance of the C1 and C2 capacitors is 100nF, and the resistance of all resistors is 4.7 MΩ. This combination forms a high pass



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filter with a cut-off frequency of 0.34 Hz. The voltage followers (buffers) isolate the AC coupling circuit from the input circuits of the ADS1191.

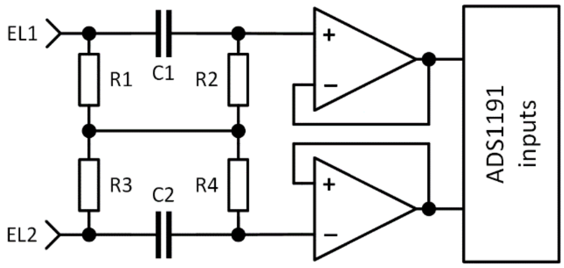


*Fig. 3: AC coupling circuit for DC offset reduction.*

The used MCU does not contain a USB interface; that is why a USB to UART converter must be used. The FT232RQ by FTDI Chip is used as an interface converter in our solution. Although the converter is powered from a 5 V voltage source, the converter includes an internal 3.3 V reference, which can power UART logic levels. The presence of an internal reference ensures the same voltage levels between the MCU and converter. The USB interface is also used to update the MCU firmware.

The prototype of the ECG dongle is shown in Fig. 4. The ECG lead cables are connected to ECG dongle via a 2.5 mm stereo jack connector. The USB A connector used in the first prototype [12] is replaced by a USB-micro connector. This replacement reduces the outer dimensions of the dongle. The ECG dongle is connectable to the smartphone via USB-micro to USB-C or USB-micro to USB-micro cable, depending on the smartphone connector.

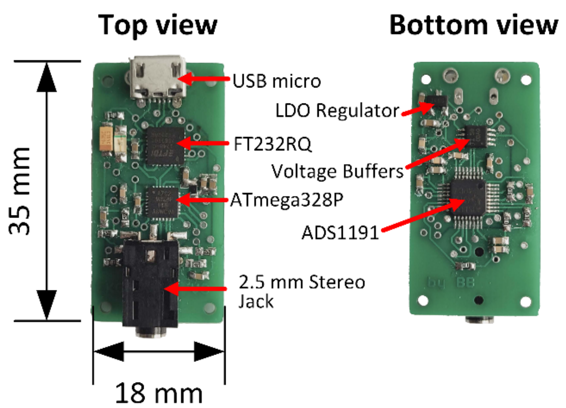


*Fig. 4: The ECG dongle prototype with main components from a top view (left) and bottom view (right).*

## Android application

We developed an application named EasyEKG dedicated to smartphones running Android OS. The minimal Android version is 4.1 (API Level 16). We used a proprietary Android D2xx library provided by FTDI Chip for communication with the FT232RQ device. The application's main functionality is acquiring ECG data, storing them on internal or external (SD card) memory, and sending the data over the internet to the server. The ECG data are stored in separate files created in predefined time intervals, e.g., every 10 minutes. Once the file is stored in memory and the internet connection is available, the file is sent to the ECG biobank (see Fig. 1). If the internet connection is not available, the unsent files are waiting in the queue, and they are sent to the server in the next successful attempt for file transmission. The application can be used by already registered users who are stored in the database or unregistered users who are allowed to view measured ECG online without the possibility of uploading files to the server.


*Fig. 5: The login screen of the developed Android application.*

The application starts with a login screen, where the user is asked to enter a username and password (Fig. 5). The entered data are sent to the server by HTTP post request while the confidential data are encrypted. After the user is verified, the patient ID is received as a server response, and the main activity is started with the layout shown in Fig. 6. When the ECG dongle is connected to the Android phone, the application automatically connects to a device. The device is disconnected automatically when the user ends the application. Once the ECG dongle is successfully connected, the version and name of the connected device are shown below the timer numbers (Fig. 6).

The ECG data acquisition is started by clicking on the Start button. When it starts, the timer starts and shows elapsed measurement time in the format: (hours:seconds). The ECG samples are stored in the phone or SD card memory. The file's name is unique because it is generated automatically according to the current timestamp. If the ECG logger option is selected by the toggle button (bottom left area in Fig. 6), the data are uploaded as a file to the server database at



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regular predefined time intervals. The file is sent by HTTP post request and processed by a PHP script on the server-side. The personal data about the patient (e.g., name, date of birth) are not included in the file, so the personal data are safe.

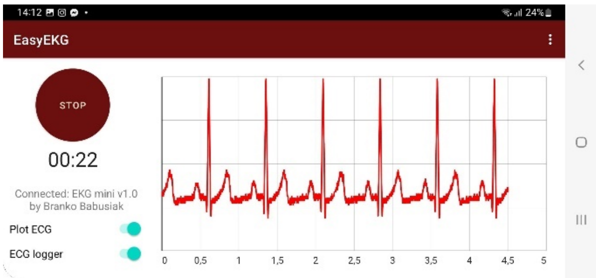


*Fig. 6: The preview of the main screen of the EasyEKG application.*

The file contains only ECG data, the patient ID, and the sampling rate of the ECG signal. According to the ID, the file is assigned to the particular patient on the server side. Afterward, the new record is added to the database containing a name and path to the received file, the sampling frequency, and the patient's ID referenced to the file. The measured ECG can be displayed in real-time after selecting this option by the Plot ECG toggle button located in the bottom left area of Fig. 6.

### Web application

The web application is running in the web browser on the client-side. The application is under development, so it currently has limited functionality. However, it allows to browse of patient records and display a selected ECG waveform (Fig. 7). The patient data and information about the ECG records are loaded from the MySQL database. The available patient records are listed in the table below the general information about the patient. The records with a duration of 10 minutes and two sampling rates (125 Hz a 500 Hz) are shown in the table. The mouse click on the View record button displays the selected ECG record below the table. The web application uses the AJAX technique for comfortable browsing ECG waveform without refreshing the web page, thanks to retrieving the signal data from a server asynchronously (in the background).

The application is intended for a doctor or other expert who will be able to add a description of the record via the web page. We are currently working on additional functions such as R peak detection, BPM calculation, Poincare plot, and HRV analysis, which will be implemented in the next version of the web application.

The ECG dongle and Android application were tested using the assembly shown in Fig. 8. The ECG dongle is connected to the smartphone using USB-micro to USB-C cable, the smartphone is operating Android 11 (API 30), and a typical one-lead ECG cable set is used.

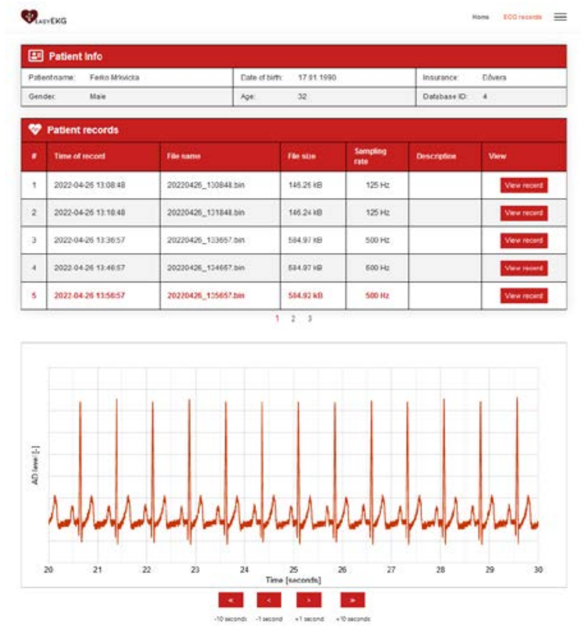


*Fig. 7: Preview of the web application for browsing ECG records. The ten seconds of ECG record no. 5 is displayed. The ECG signal is measured from the patient simulator.*

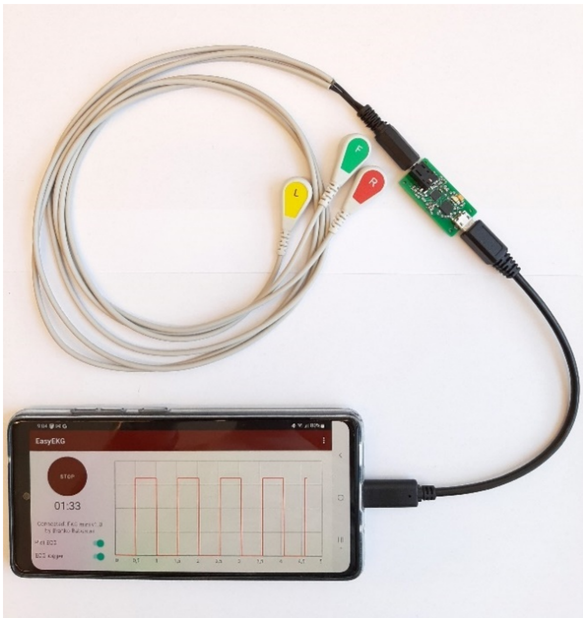

*Fig. 8: Measuring assembly for ECG acquisition.*

The functionality of the measuring system depicted in Fig. 8 was tested in two scenarios. In the first testing scenario, the lead set was connected to the patient simulator ProSim 2 by Fluke (Fig. 9A). The ECG signal with 1 mV peak-to-peak voltage and 80 BPM is generated at the simulator output. In the second scenario, the ECG electrodes are placed on the forearms of a living subject (Fig. 9B). The third green



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electrode represents the DRL electrode which can be placed on any part of the body surface. Both presented connections correspond to the I. Einthoven lead.

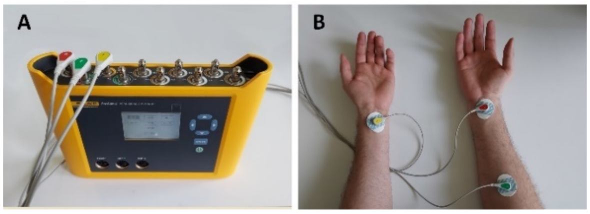


*Fig. 9: Two scenarios used for testing measuring system functionality. ECG lead set connected to the patient simulator (A) and the electrodes placed on the forearms (B).*

## Results

The raw signal segments with a length of ten seconds loaded from the file stored on the server are shown in Fig. 10 and Fig. 11. The sampling rate of 500 Hz was used during the signal acquisition. The living subject signal contains noise that can be suppressed by appropriate de-noising techniques, such as wavelet filtering [14].

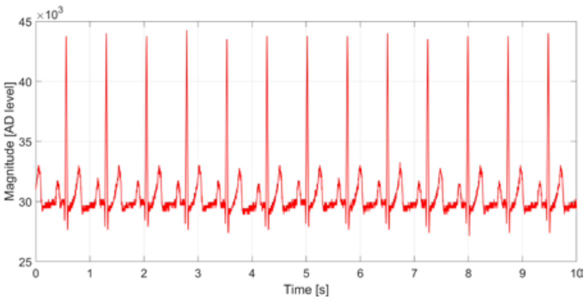


*Fig. 10: The first 10 seconds of the raw ECG signal measured from the patient simulator.*

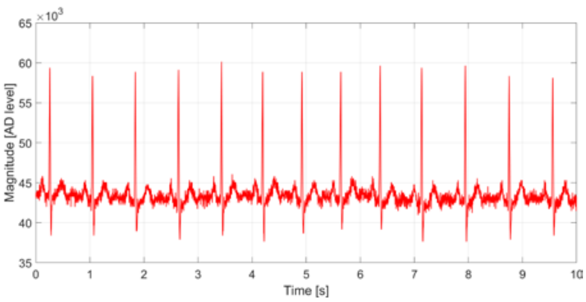


*Fig. 11: The first 10 seconds of the raw ECG signal measured from the living subject.*

## Discussion

In this article, the remote ECG data collecting system was presented. The unique ECG device was developed as part of this system. The device connects to the smartphone via a USB connector and takes energy from the smartphone, thanks to OTG functionality. The lack of a battery allows for small dimensions and low weight of the developed device. Thanks to these properties, the developed device can be classified as a wearable device and used for long-term measurements. Furthermore, because of the missing battery (no need to charge the battery), the device is permanently ready to measure anytime when the patient notices heart problems and needs to measure ECG immediately (short-term measurement).

The Android application named EasyEKG was developed to collect and display ECG data measured from the subject. Besides storing ECG data in the smartphone memory, the data are sent to a remote server at regular adjustable time intervals for further analysis. This feature is appropriate for long-term (Holter-type) ECG measurements. In the case of short-term measurement of ECG, it is possible to send ECG records to the server right after measurement by selecting this option from the application menu. The Android application has a simple and user-friendly graphical interface. The application starts automatically after the ECG dongle is connected to the smartphone.

The web interface was also presented in this paper. The web application is intended to be used by doctors or specialists who view patient records, add a description to records and make a diagnosis of heart disease. The web interface is intuitive, and no advanced computer skills are required. The application is still under development, so just the browsing of ECG signals is available via the web application. The results of ECG analysis, such as R peak detection, BPM calculation, and HRV analysis, will be added to the further version of the web application.

The functionality of the proposed system was verified in two scenarios: ECG measured on the patient simulator and living subject. The measured raw ECG signals in Fig. 10 and Fig. 11 showed good signal quality. Furthermore, the segments and intervals of the ECG curve can be clearly identified, so the signal is suitable for further analysis.

## Conclusion

This article presented the hardware design of an ECG device connectable to the smartphone. The developed ECG dongle is an essential part of a complex system for collecting ECG data and storing them in the remote server (biobank). The biobank with many ECG records is a prerequisite for conducting various cohort studies. The developed ECG dongle is an affordable solution for data collection, which needs only a regular smartphone with Android OS. The proposed solution is appropriate for short-term and long-term ECG



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monitoring. Our further work is focused on the further development of the biobank web interface, including ECG records management, data analysis, and data security.

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