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M.H. BOREIKO, M.M. BUDNYK

DEVELOPMENT OF THE REMOTE HEART HEALTH MONITORING SYSTEM

The requirements to the telemedicine system for recording, processing, and reporting of electrocardiography signals are considered. The architecture and software and hardware implementation of such a system are proposed. A telemedicine system intended for remote monitoring of patients was developed. The system records, processes, and stores ECG signals and heart rate variability of patients and provides visual reporting via a user-friendly web interface. Nowadays the system is being tested in the Finnish company Cardiolyse.

Keywords: *telemedicine, client-server, medical devices, electrocardiography, cybersecurity, heart rate variability*

Introduction. The most common cause of death worldwide is cardiovascular disease (CVD). This problem is especially relevant for Ukraine, where CVD accounts for more than 68 % of all deaths. At the same time, in terms of population mortality rate (15.3 ‰), Ukraine is ahead of all European countries, entering the top ten countries with the highest mortality rates in Europe [1].

Since the COVID-19 pandemic started, things are getting even worse. Hospitals are overloaded and focused on the treatment of Covid patients, however, patients with other diseases remain underdiagnosed and receive less attention.

One of the most useful diagnostic tools for CVD is electrocardiography (ECG). Nowadays a lot of portable ECG devices are available on the market, which makes ECG accessible for each patient directly from home. That is why remote monitoring of patients with CVD is a very useful and important solution, which can save lives, time, and money.

There is some existing solution on the market, for example, AliveCor [2], which offer portable finger-lead ECG device, and mobile application for data transmission to the Cloud. But the security of such solutions is still in doubt. Processing, transmission, and transferring of medical data, such as ECG, is strongly regulated in most countries. For example, in European Union, there are new General Data Protection Regulation (GDPR) [3] and Medical Device Regulation (MDR) [4], which set up the highest requirement for any medical software security.

So, the goal of this work is to develop a cloud-based software solution for remote monitoring of patients with CVD using a portable ECG device.

The main requirements to such software are:

Mobile App with patients and doctors mode;

Connection to portable ECG devices via Bluetooth;

Transmission of ECG data from the portable ECG device to cloud server;

Store ECG data and report in a secure environment

Processing of ECG should be scalable to work in a high-demanding environment;

Provide convenient access to the doctor and patient to the results of processing and raw data, present them in a convenient and understandable format.

1. Software architecture. The System consists of 3 main components:

1. Portable ECG device (third party vendor).
2. Mobile application for Android/iOS, which connects to ECG device via Bluetooth, and then transmits data to the backend ser-ver. It also shows an analysis report to the patient or doctor.
3. Cloud server, which store, process, analyze and control the ECG data. It acts as a back-end server for mobile app and web apps.
4. Web application, which is intended for patient management and reviewing of ECG reports by a doctor.

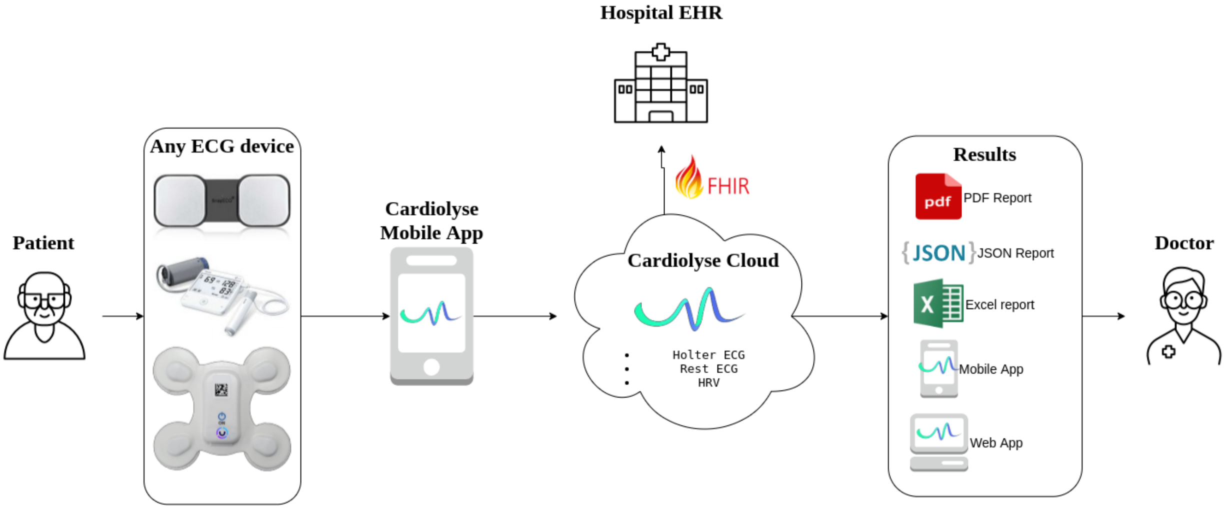


FIGURE 1. General solution architecture of developed system

2. Mobile App Details. Mobile App is based on React Native Framework [5]. React Native is a JavaScript framework for writing real, natively rendering mobile applications for iOS and Android. It’s based on React, Facebook’s JavaScript library for building user interfaces, but instead of targeting the browser, it targets mobile platforms. In other words: web developers can now write mobile applications that look and feel truly “native,” all from the comfort of a JavaScript library that we already know and love. Plus, because most of the code you write can be shared between platforms, React Native makes it easy to simultaneously develop for both Android and iOS.

The main features of the Mobile App:

- Record ECG using Bluetooth connected device;
- Transmit ECG to the Cloud;
- Show ECG reports;
- Manage list of patients in doctor mode;
- View history of ECG readings and trends.

3. ECG recorders. As development of a hardware part of the solution is not the goal of this paper, we used portable ECG devices which are already available on the market.

One of this devices is portable finger-lead ECG manufactured by Solvaig 06000.1 [6] (see Figure 4).

The ECG Recorder model 06000.1 is a portable electronic device with autonomous power supply, designed for the ECG registration in 1 bipolar or 6 monopolar leads, with Bluetooth communication module.

Our mobile app implemented Bluetooth communication protocol provided by Solvaig, so all ECG data came from the device are transmitted to the mobile app in real time.

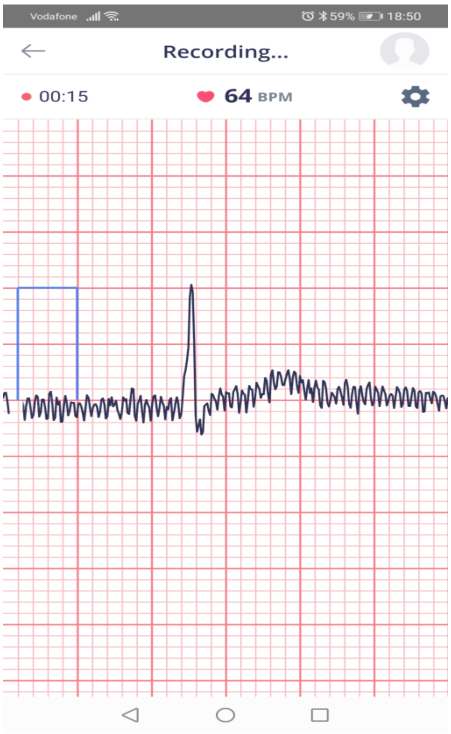
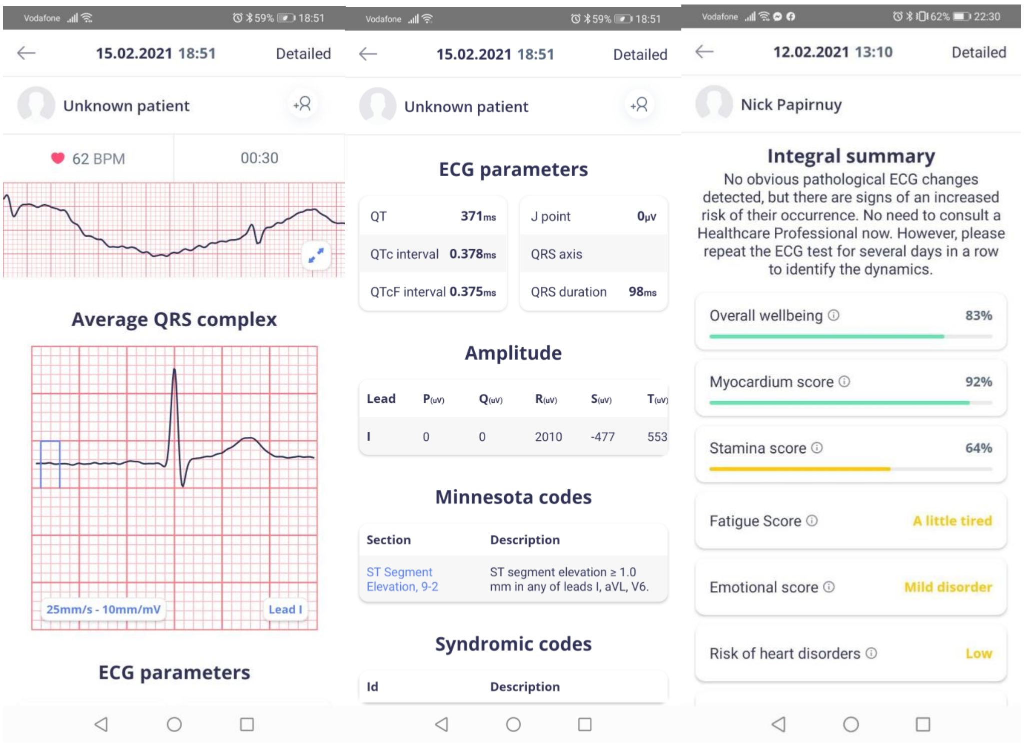


FIGURE 2. Measurement screen of Mobile Application with recorder ECG signal



15.02.2021 18:51 Detailed

Unknown patient

62 BPM 00:30

Average QRS complex

25mm/s - 10mm/mV

Lead I

ECG parameters

15.02.2021 18:51 Detailed

Unknown patient

ECG parameters

QT	371ms	J point	0μv
QTc interval	0.378ms	QRS axis	
QTcF interval	0.375ms	QRS duration	98ms

Amplitude

Lead	P(uV)	Q(uV)	R(uV)	S(uV)	T(uV)
I	0	0	2010	-477	553

Minnesota codes

Section	Description
ST Segment Elevation, 9-2	ST segment elevation ≥ 1.0 mm in any of leads I, aVL, V6.

Syndromic codes

Id	Description

12.02.2021 13:10 Detailed

Nick Papirnuy

Integral summary

No obvious pathological ECG changes detected, but there are signs of an increased risk of their occurrence. No need to consult a Healthcare Professional now. However, please repeat the ECG test for several days in a row to identify the dynamics.

Overall wellbeing ⓘ	83%
Myocardium score ⓘ	92%
Stamina score ⓘ	64%
Fatigue Score ⓘ	A little tired
Emotional score ⓘ	Mild disorder
Risk of heart disorders ⓘ	Low

FIGURE 3. Visualization of diagnostic reports on smartphone screen

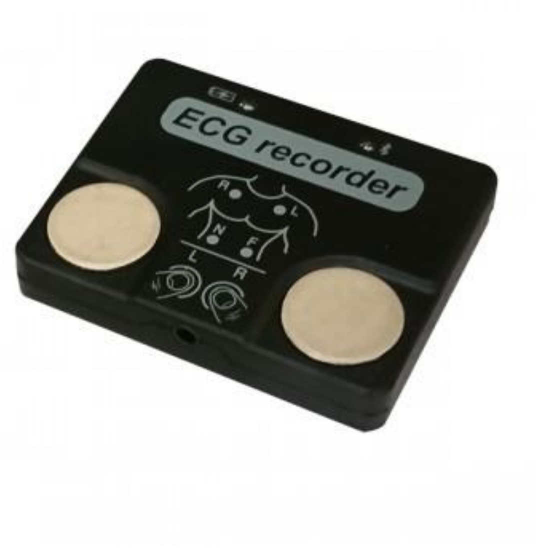


FIGURE 4. Portable ECG recorder Solvaig 06000.1

Another device integrated via Bluetooth is Bittium Faros Holter ECG recorder [7]
It has one or three ECG channels, and also has built-in 3D accelerometer. It offers continious ECG recording during up to 8 days on single battery charge.

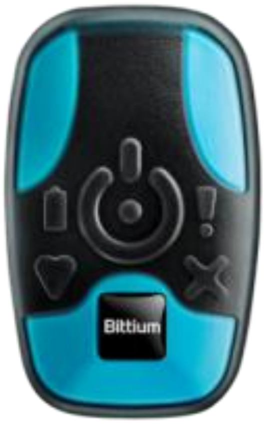


FIGURE 5. Portable Holter ECG recorder Bittium Faros 180

4. Cloud server details. The cloud server is the main component of the whole solution. The cloud platform implements the REST API [8] interface for interaction with the web and mobile apps. To write a web server, the Java programming language and the Spring framework [9] are used, which simplifies and accelerates the development of complex web services.

The main features of the Cloud server:

- Listen for incoming ECG data with RestAPI endpoint;
- Save data in a secured database;
- Automatically process ECG data to get the clinical interpretation;
- Generate analysis reports.

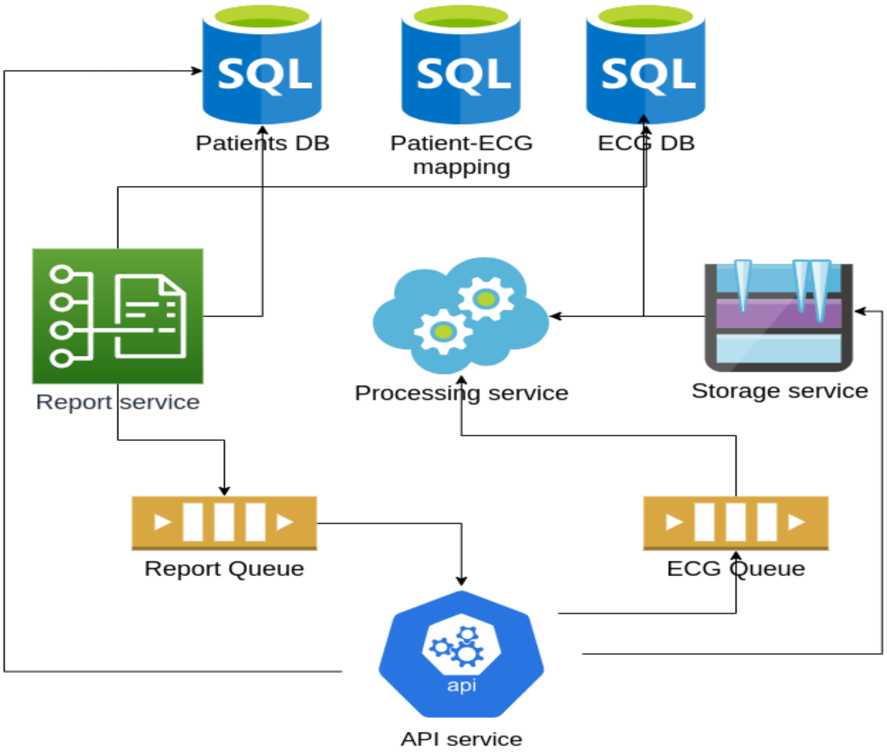


FIGURE 6. Cloud server arhitecture

Cloud is based on microservices architecture, where each service is responsible only for some small function.

- API service provides RestAPI for communication with Mobile and Web App.
- Proc service is intended for ECG processing. It is the most loaded service and it can be easily scaled.
- Storage service is intended for storing raw ECG data and ECG report in the secure Cloud storage.
- Report service is intended for the generation of different kinds of reports.

The data flow of ECG is following:

1. API receives raw ECG from the mobile app.
2. API pushes raw ECG to the ECG queue.
3. Proc listens to the queue, and when a new ECG comes, it starts to process it.
4. When processing is finished, Proc pushes the results to the Results queue.
5. Report service listens to the Results queue, and when a new result comes, it generates a corresponding PDF report.
6. Then, the mobile app can request an API service for a newly generated PDF report.

5. Deployment to the Cloud. Each server component (service, database, queue, etc…) is containerazed with Docker [10].

Docker is a set of platform as a service products that use OS-level virtualization to deliver software in packages called containers. Containers are isolated from one another and bundle their own software, libraries and configuration files, they can communicate with each other through well-defined channels.

Docker enables you to separate your applications from your infrastructure so you can deliver software quickly. With Docker, you can manage your infrastructure in the same ways you manage your applications.

Then, the whole solution was deployed to cloud hosting Microsoft Azure [11].

Microsoft Azure is a secure cloud services platform, offering compute power, database storage, content delivery and other functionality to help businesses scale and grow. In simple words AWS allows you to do the following things – running web and application servers in the cloud to host dynamic websites.

Cloud hosting makes applications and websites accessible using cloud resources. Unlike traditional hosting, solutions are not deployed on a single server. Instead, a network of connected virtual and physical cloud servers hosts the application or website, ensuring greater flexibility and scalability.

Key features:

Applications and solutions are deployed on a cloud network rather than an on-premises, single server.

Resources scale to user needs.

Organizations only pay for the resources they use.

Cloud hosting can support SQL (including MySQL) or NoSQL databases.

Solutions are automated and controlled using APIs, web portals, and mobile apps.

6. Web App details. The web app is intended for usage by doctors only, and provides the following features:

- Manage list of patients;
- Examine ECGs for each patient;
- View and download ECG reports.

Web App is written on React.js Framework [12]. React.js is an open-source JavaScript library that is used for building user interfaces specifically for single-page applications. It’s used for handling the view layer for web and mobile apps. React also allows us to create reusable UI components. React was first created by Jordan Walke, a software engineer working for Facebook. React first deployed on Facebook’s newsfeed in 2011 and on Instagram.com in 2012 [13].

React allows developers to create large web applications that can change data, without reloading the page. The main purpose of React is to be fast, scalable, and simple. It works only on user interfaces in the application.

7. Results. The developed system provides monitoring of any number of patients, analysis of cardiac measurement data, and their presentation to any number of doctors. The system is currently being piloted by the Finnish company Cardiolyse [14]. When analyzing the data, the created diagnostic methods of ECG scoring according to WO 2017/010963 are used [15–16].

The developed system can also be used for long-term monitoring of other user groups, including employees whose work is accompanied by a high level of physical or emotional stress, which include servicemen, police officers, other law enforcement agencies, for which, given the features of the activity, specific markers are used, such as pain levels, stress, etc … [17–20].

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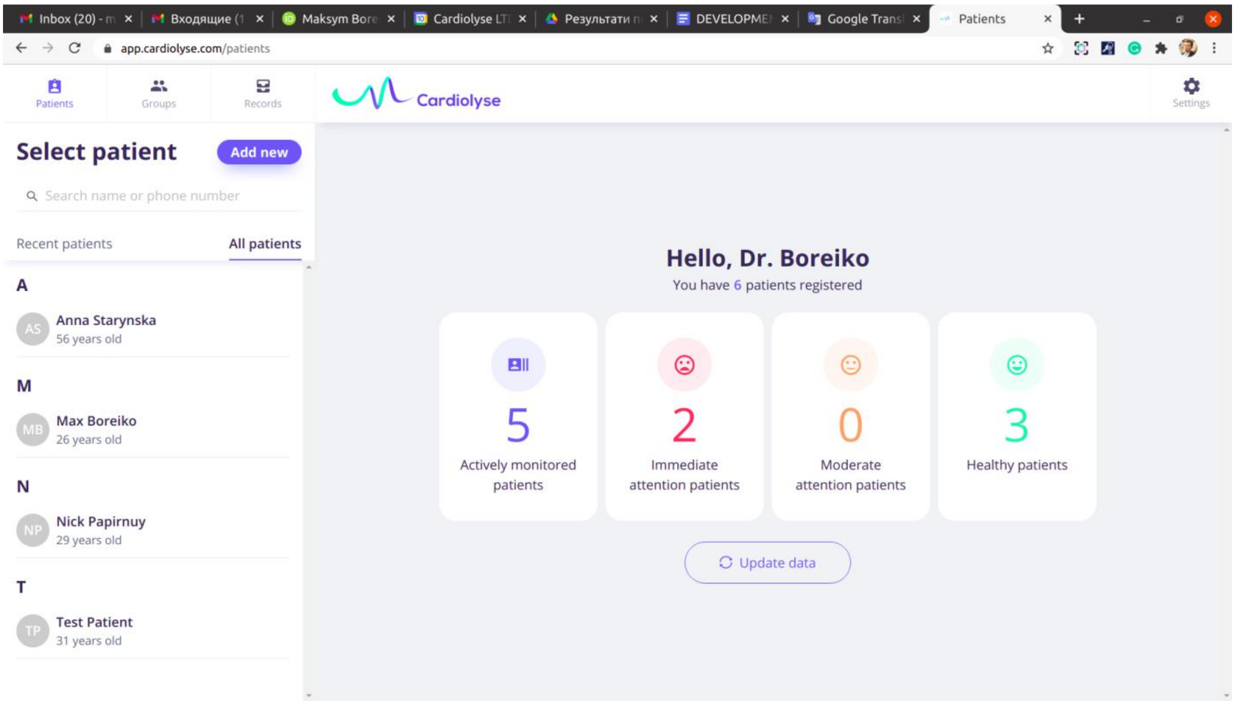


Select patient

A

Anna Starynska
56 years old

M

Max Boreiko
26 years old

N

Nick Papirnuy
29 years old

T

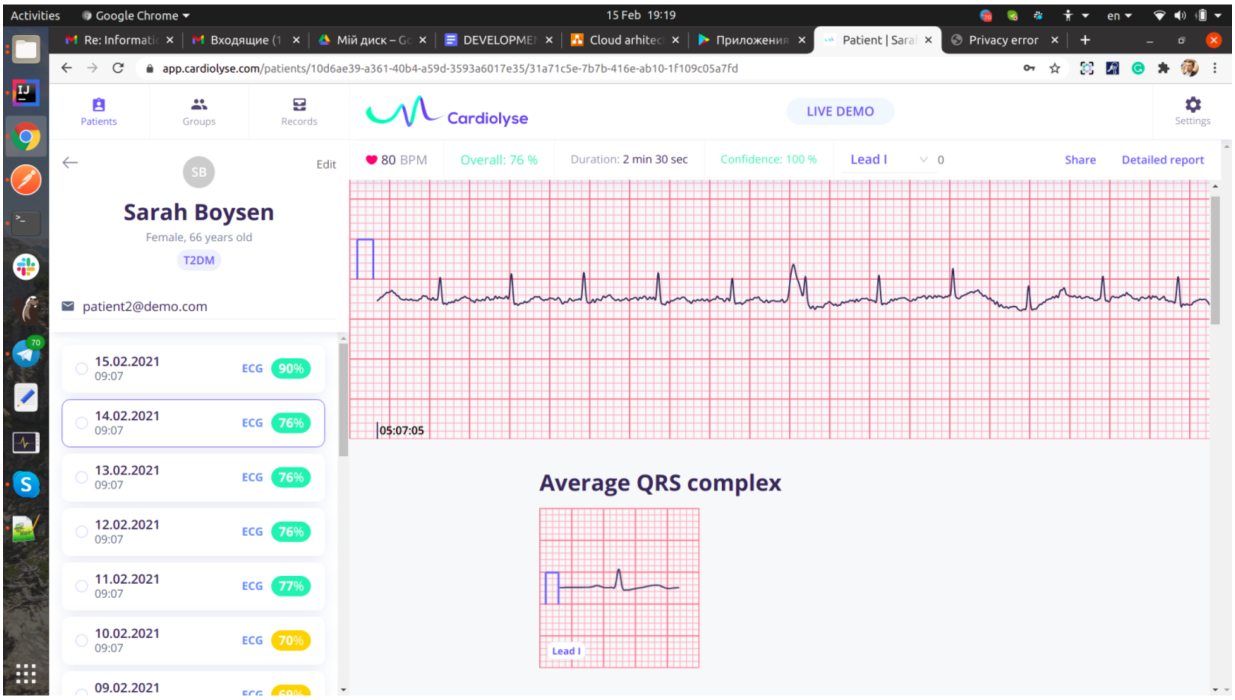
Test Patient
31 years old

Hello, Dr. Boreiko

You have 6 patients registered

5	2	0	3
Actively monitored patients	Immediate attention patients	Moderate attention patients	Healthy patients

FIGURE 7. Main dashboard for doctor in Web application



Sarah Boysen

Female, 66 years old

T2DM

patient2@demo.com

80 BPM | Overall: 76 % | Duration: 2 min 30 sec | Confidence: 100 % | Lead I | 0

Date	Time	Type	Score
15.02.2021	09:07	ECG	90%
14.02.2021	09:07	ECG	76%
13.02.2021	09:07	ECG	76%
12.02.2021	09:07	ECG	76%
11.02.2021	09:07	ECG	77%
10.02.2021	09:07	ECG	70%
09.02.2021		ECG	69%

Average QRS complex

FIGURE 8. ECG analysis report in Web application

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Boreiko Maksym Hennadiiovych,
PG Student, V.M. Glushkov Institute of Cybernetics of the National Academy of Sciences of Ukraine,
maxboreyko@gmail.com

Budnyk Mykola Mykolaiovych,
DrSc in Computer Science, Chief Researcher, V.M. Glushkov Institute of Cybernetics
of the National Academy of Sciences of Ukraine.

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М.Г. Борейко [*]**, М.М. Будник**

Розробка системи для віддаленого моніторингу здоров’я серця

Інститут кібернетики імені В.М. Глушкова НАН України, Київ
[*] *Листування:* maxboreyko@gmail.com

Вступ. Серцево-судинні захворювання (ССЗ) – найчастіша причина смерті в усьому світі. Ця проблема особливо актуальна для України, де на ССЗ припадає понад 68 % всіх смертей. При цьому за рівнем смертності населення (15,3 ‰) Україна випереджає всі країни Європи.

Електрокардіографія – найкорисніший діагностичний інструмент. В даний час на ринку є безліч портативних пристроїв ЕКГ, та є доступною для кожного пацієнта прямо з дому.

Віддалене спостереження за пацієнтами із серцево-судинними захворюваннями – дуже необхідне рішення, яке може врятувати життя пацієнта, час лікаря і кошти лікарні.

Існуюче рішення для віддаленого моніторингу не забезпечує достатньої кібербезпеки і масштабованості, особливо в контексті жорсткого регулювання медичного програмного забезпечення в Європейському Союзі.

Мета роботи. Розробка хмарного програмного рішення для віддаленого моніторингу пацієнтів із серцево-судинними захворюваннями за допомогою портативного пристрою ЕКГ.

Ми пропонуємо повну архітектуру, яка включає у себе серверні компоненти (бази даних, обчислювальні ресурси, шлюзи, черги, балансувальник навантаження та інші) і клієнтські компоненти (мобільний додаток для Android і iOS і додаток веб-браузера).

Результати. Ми запропонували, спроектували, впровадили і протестували повне комплексне хмарне рішення для віддаленого моніторингу пацієнтів із серцево-судинними захворюваннями. Безпека системи забезпечується поділом єдиної бази даних на три окремі бази даних (база даних з даними пацієнта, база даних з даними ЕКГ і база даних карт), приховуванням усіх серверних компонентів у віртуальної приватної мережі та передачею даних через безпечне з'єднання HTTPS.

Висновки. Розроблена система успішно вирішує поставлені завдання. Нині вона використовується у фінській компанії Cardiolyse.

Ключові слова: телемедицина, клієнт-сервер, медичні прилади, електрокардіографія, кібербезпека, варіабельність серцевого ритму.