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Application of IoT for telemonitoring patients diagnosed with coronavirus COVID-19

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Abstract: — **In the state of pandemic spread of the corona virus COVID-19, the most challenging task is the monitoring of thousands to hundreds of thousands of patients at once. The demand of automatic system to assist the medical doctors with monitoring and diagnosis is very high. This paper shows a concept design for an automated IoT monitoring system for telemonitoring patients, diagnosed with coronavirus COVID-19.**

***Keywords:* —IoT, COVID-19, telemonitoring, pulse oximetry, digital stethoscope, artificial neural networks, control center**

I. Introduction

The pandemic caused by the SARS-CoV-2 spread very quickly globally. As a best practice against the spread and reduction of the number of infected and victims, the method of isolation was established. This eliminates the possibility of people transmitting the virus to each other.

However, this cannot be applied to hospitals. At this stage, doctors cannot avoid contact with the infected, because there are still not enough well-developed tools and methods for remote treatment in hospital wards. Although special Personal Protective Equipment (PPE) is being used, this problem proves to be of great importance for the health and life of medical staff. According to the official statistics by 21.06.2020, the percentage of infected medical staff in Bulgaria, for example, is approximately 10 % of all infected with the virus.

This high percentage of infected medical personnel necessitates the study of new methods and devices for treating patients in hospital wards. One such method is telemedicine. This method provides opportunities for physicians to remotely communicate with patients and prescribe appropriate treatment and therapeutic regimes. But in these remote medical examinations, the doctor cannot directly influence the patient.

World Health Organization (WHO) [1] has released a toolkit [2] for clinical care of severe acute respiratory infections (SARI). According to this toolkit, in order to determine if the patients are having SARI, few high-risk vital signs checks should be confirmed:

- Heart rate <60 or >130
- Respiratory rate <10 or >30
- Temperature <36° or >39°
- SpO_2 (Oxygen saturation in blood) <92%

To help the medical doctors diagnose Covid-19 with higher speed and accuracy, methods for automation of the monitoring of patients are needed. In this article we will propose new concept for Internet of Things (IoT) based automated vital signs monitoring for either home-quarantined or hospitalized patients.

II. IoT hardware and communication

In order to build a good concept design and later create a proof of that concept, the project should have clear and precise requirements. From hardware perspective the requirements are:

- The quality should be medical grade
- Should be robust
- Should be easy to be maintained and disinfected
- Should not be cumbersome to wear for the patient
- Should be able to communicate reliably and securely with the Control center

From medical monitoring staff’s point of view, the requirements are:

- Each patient’s file should be easily accessible and well organized
- Data should be formatted correctly; visualizations should be precise and concrete

- Alerts should be available when one or more vital signs go above or below predefined thresholds, in order to prevent medical complications or even death.

One of the most common signs for COVID-19 is the dry cough. For the concept monitoring system to be able to register and classify coughs, we must first define what exactly is a cough. As described in [3], the cough is a primitive reflex. It typically has few distinct phases:

- Initiating deep inspiration
- Glottal closure
- Explosive expiration usually accompanied with sound.

The cough reflex often is repetitively occurring. It is initiated by irritating the cough receptors in the airways. The consequence of that irritation is that the nerve impulses from the cough center in the brainstem stimulate the diaphragm, intercostal muscles and the larynx to produce the cough. There are two types of methods to detect coughs:

- Using spirometry system
- Using microphones to detect and further analyze recorded sounds

The spirometry process is described by [4] as a term, given to the basic lung function tests. These tests measure the amount of air that is inspired and expired. There are three types of basic related measurements: volume, time and flow. The big advantages of spirometry are that it is objective, noninvasive, sensitive to early changes and it is reproducible. In [5] the authors propose a new method for automatic cough detection, using mobile spirometry system. Their method is based only on airflow signal processing. The classification is done by an artificial neural network, trained on the large database of spirometry curves from the NHANES database by the American National Center for Health Statistics and self-gathered data. The authors claim 0.86 (sensitivity), 0.91 (specificity), 0.91 (accuracy) results.

In [6] the authors describe the audio analysis aspect of the cough. Their research shows that the cough sound typically consists of three phases: explosive phase, intermediate phase and voiced phase. The explosive phase is an explosive expiration because of the glottis suddenly opening. The intermediate phase can be characterized with the attenuation of cough sounds. The voiced phase is observed when the vocal cord is closing. In fig. 1 is shown an example block diagram for the acquisition system of audio-based cough monitors.

One of the classic tools used for monitoring lungs and heart state is the stethoscope. The use of the stethoscope is one of the simplest nonintrusive methods to measure the Respiratory Rate, which is also an important vital sign for coronavirus monitoring. As described in [7], the stethoscope is an acoustic device that transmits the sounds from the chest piece through an air-filled hollow tube to the listener's ears.

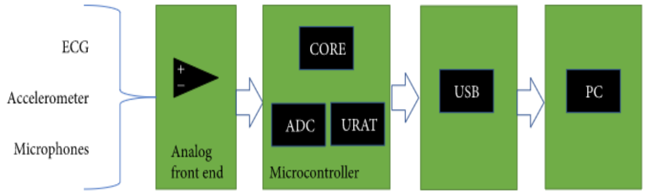

Fig. 1. Block diagram of audio acquisition system [6].

In the digitalization era, the stethoscope has received an updated digital version. The digital stethoscope usually uses piezoelectric sensor and a microphone and can transform the acoustic sound to an electrical signal, which can be further amplified for optimal listening. The main advantage of the digital stethoscope is its ability to be a network device and to be connected via various network protocols to other devices and/or control center. The current versions of digital stethoscopes offer connectivity through Bluetooth (BLE) and ZigBee.

So far it became clear, that for respiratory rate monitoring and cough detection to be easy and non-intrusive for multi-patient 24/7 monitoring, the digital stethoscope is the better choice. This is what we are going to use in our concept design.

The next two vital signs that must be monitored are the heart rate (pulse) and the concentration of Oxygen in the blood (SpO_2). Both vital signs can be easily monitored by the process called pulse oximetry.

The principle of pulse oximetry is based on dual-wavelength illumination of arterial blood. This results in an absorption contrast that depends upon the proportion of hemoglobin that is chemically combined with oxygen. The color of blood varies depending on the oxygen content and the hemoglobin molecules reflect more red light when they are oxygenated. The reflection of infra-red light increases with de-oxygenated hemoglobin molecules.

Most of commercially available pulse oximeters are attached on the finger. In [8] the authors show the concept of a network-connected pulse-oximetry system to a personal medical monitoring server which stores the data from the pulse oximeter and can make configuration changes to the pulse oximeter. In [9] the authors offer a novel method for chest-based pulse oximetry. They show that it’s not only possible to make measurements, but also that they are faster, have higher dynamic range and are as reliable as the finger-based pulse oximeters. As an additional feature, the proposed system can easily be integrated with ECG monitoring systems.

To be able to create real IoT system, all separate monitoring methods, that were seen so far must be able to connect to the Internet. To do so, the networking protocol that we propose is ZigBee [10]. The protocol architecture is shown on fig. 2. The ZigBee architecture does not completely comply with the OSI model, but there are distinct similarities. For example, there are the physical, medium access (MAC) and the Network layers at the bottom of the architecture. These layers are supported by the IEEE standard 802.15.4 [11] on the base of which the ZigBee protocol is created. The rest of the layers from the OSI model are accumulated into Application Framework and ZigBee Device Object (ZDO) layers. The layers interconnection is made possible by the SAPs – Service Access Points. The communication between each 2 layers is defined by IEEE 802.15.4 as using 2 SAPs between the layers.

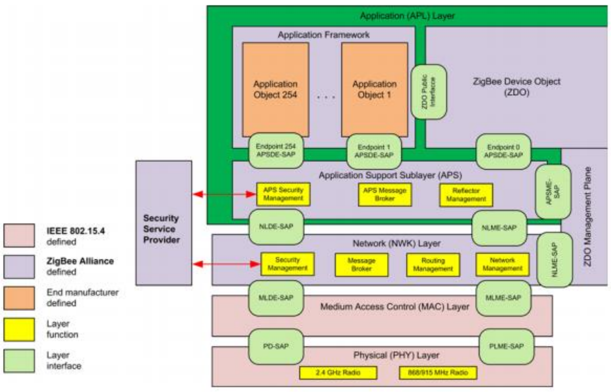

Fig. 2. Zigbee protocol architecture [10]

The first SAP is used for data exchange and the second one for management purposes. The physical and the MAC layers are also directly implemented from the IEEE 802.15.4 specification. The physical layer transmits the packets in the form of bytes over the air. The MAC layer provides the concepts of a network including PAN ID and network discovery, using broadcasts and responses from other devices in the same network. The network layer is responsible for the creation and maintenance of the mesh networking architecture. This includes sending network packets for device discovery as well as checking existing and creating new dynamic routes through the network. In this layer are included methods, used for securing the network like protection from adding the same device multiple times to the same network. The application layer is used as a filter for the user-provided applications that are processed by the end-devices. This is done to ensure simpler logic on these applications. The application layer also filters duplicate messages provided by the network layer. The ZDO layer is used basically for either local or “over-the-air” management of the ZigBee network. This layer provides the necessary tools and services to discover additional nodes and services inside the network and is directly responsible for the current state of a single node in the network.

The monitoring methods shown so far are the needed components of a complete medical monitoring of patients with symptoms of COVID-19. Our concept design includes chest-based pulse oximetry, digital stethoscope and digital thermometer all attached on the same chest strap. All systems will communicate via ZigBee media protocol to a local IoT gateway. The reason for the local IoT gateway is to become a concentration point of all separate devices, to locally store the transmitted data for limited time and to communicate with the control center over the internet over secure channel, providing additional layer of cyber security to the endpoints. Artificial Neural Networks will be used for cough pattern recognition and classification. This is important for the correlation between dry cough and the lowered/elevated vital signs.

III. Control center with Graphical User Interface (GUI)

The control center of the telemonitoring solution will consist of easy to use GUI frontend, adapted for non-technical medical personnel and backend which collects data from connected IoT devices and stores them into a SQL database. The whole solution will be developed in .NET C# in client-server architecture.

Client-server architecture, architecture of a computer network in which many clients request and receive service from a centralized server. Clients are often situated at workstations or on personal computers, while servers are located elsewhere on the network, usually on more powerful machines. In hospital data processing, a client computer can be running an application program for entering patient information while the server computer is running another program that manages the database in which the information is permanently stored. Many clients can access the server's information simultaneously, and, at the same time, a client computer can perform other tasks, such as sending e-mail. [12]

.NET is a free, cross-platform, open source developer platform for building many different types of applications. It supports multiple languages, editors, and libraries to build for web, mobile, desktop, games, and IoT. .NET apps can be coded in C#, F#, or Visual Basic. [13]

- C# is a simple, modern, object-oriented, and type-safe programming language.
- F# is a cross-platform, open-source, functional programming language for .NET. It also includes object-oriented and imperative programming.
- Visual Basic is an approachable language with a simple syntax for building type-safe, object-oriented apps.

Independent of the language written, the code will run natively on any compatible OS.

There are Different .NET implementations:

- .NET Core is a cross-platform .NET implementation for websites, servers, and console apps on Windows, Linux, and macOS.
- .NET Framework supports websites, services, desktop apps, and more on Windows.
- Xamarin/Mono is a .NET implementation for running apps on all the major mobile operating systems.

SQL Server is a relational database management system, or RDBMS, developed and marketed by Microsoft. Like other RDBMS software, SQL Server is built on top of SQL, a standard programming language for interacting with the relational databases. SQL server is tied to Transact-SQL, or T-SQL, the Microsoft's implementation of SQL that adds a set of proprietary programming constructs [14].

The solution workflow is shown in fig. 3.

It can be deployed in two scenarios depending on the resources and IT capabilities of the medical institution:

- Hybrid cloud solution – backend runs on an on-premise server located in the medical facility; the SQL database engine and GUI runs in the cloud.
- Fully on-premise solution – all three components run locally.

The backend will be separate native Windows application. Its specific function will be to query the IoT devices for data, associate them with a patient, perform calculations and store them into the SQL database. It will run on dedicated on-premise server so large quantities of data can be processed. The backend will be always deployed on-premise because the IoT devices are locally accessible and the data collected from them is secured and encrypted before is written in the SQL database

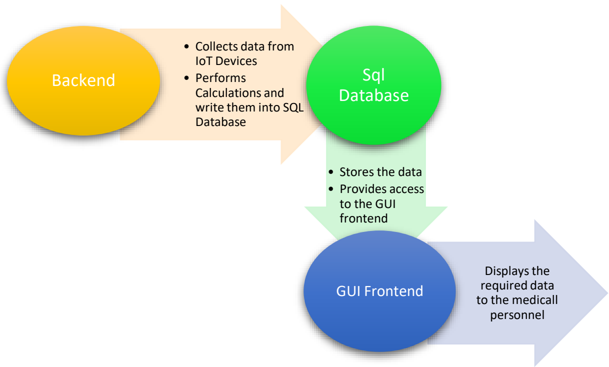

Fig. 3. Concept workflow diagram

Microsoft SQL Server 2019 will be used for database engine. It will run on a dedicated server to enable lots of concurrent connections to the GUI frontend. Depending of the chosen scenario it can be run on-premise or in the cloud.

The GUI frontend will be WEB based so the medical personnel can access from different devices (computers, tablets etc.) without the need to install separate client software. Also, the WEB technology will enable the use of different type of devices without compatibility problems (OS independent). The fronted can be situated on-premise on a dedicated server or in the cloud.

The frontend will provide options for selecting and searching different patients located in the medical facility. It will provide Realtime status of the selected patient (current values of the patient connected IoT devices). Also, it will have an option to see the medical history of the patient and compare it to the current stats.

The frontend will query the SQL database for the required data and display it.

An option to write medical data (comments, findings) will be given to the application operators. The data will be stored in the same SQL database and linked with the required patient.

Reporting will also be included the frontend. The medical personnel can produce reports on the specific patients which contains medical history of the patients (data from IoT devices, charts etc.) with clinical findings.

The medical personnel will have the option to set critical values for different monitored parameters so they can receive alerts when some patient medical status is becoming critical.

Several concept windows from the GUI frontend are shown:

- Mockup of the patient list with options to search for a patient and select a patient - fig. 4

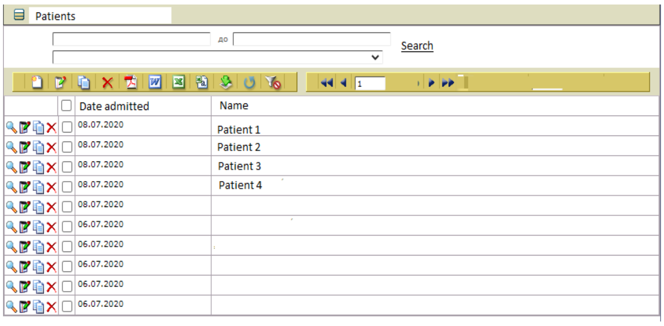

Fig. 4. Patient list window

- Mockup of the clinical finding entry window – fig. 5

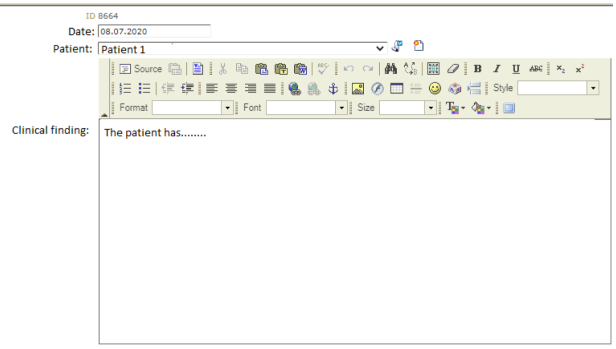

Fig. 5. Clinical finding entry window

- Mockup of the Realtime patient statistics – fig. 6

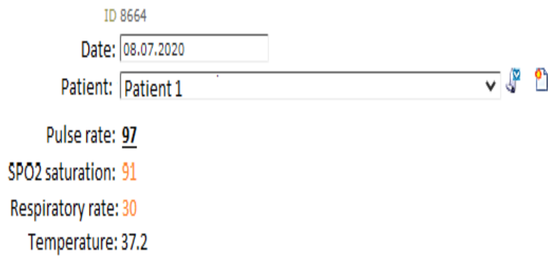

Fig. 6. Realtime patient statistics

IV. Conclusion

In this paper is described the application of IoT for telemonitoring patients diagnosed with coronavirus COVID-19. Shown are the main vital signs that are monitored on patients with pending or active diagnose of COVID-19. Described were the modern ways of monitoring these vital signs. A concept for new IoT-based patient monitoring system was discussed in length with classic client-server architecture and optimized methods for patient monitoring and telemonitoring in the current pandemic state, necessity for social distancing and self-isolation.

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