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CONTENT

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ANALYSIS OF THE USAGE OF MOBILE DEVICES AS DISTRIBUTED TOOLS FOR PATIENT HEALTH MONITORING AND REMOTE PATIENT DATA ACQUISITION

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Abstract. The COVID-19 pandemic raised the need for telemedicine systems. Wearable and mobile devices are often a crucial part of those systems. In accordance with current research, this paper presents an analysis of some means, sensors and devices for remote patient health monitoring which can be combined together to form a complete patient health monitoring system. A few ways of measuring the health parameters are described. Focusing on the benefits offered by contemporary technology towards a more complete use of the telemedicine potential, this paper also reviews topics from the field of biomedical engineering.

1. Introduction

Undoubtedly, there is a need for monitoring patient health data. The fast-paced development of sensors, telecommunication, wireless and mobile technology has opened the way for new innovative systems that will ultimately be part of the healthcare services. By incorporating technology and telecommunication in healthcare services, we stumble upon the terms telemedicine and telehealth.

2. Literature review

Telemedicine and telehealth are closely coupled terms. The difference between them will be explained in the next few lines, according to recent researchers. Namely, telemedicine is a medical practice for remote care and treatment of patients, while telehealth is concerned with electronic and telecommunication technologies and services through which care and health services can be provided to patients without engaging physical contact. Telemedicine is a remote clinical service, while telehealth is a broader term that also includes nonclinical services. Both have many applications in modern medicine. Around 80% of developed countries offer some form of a mobile health program. For example, with the use of telemedicine platforms, clinicians can review the prescriptions and drugs the patients use, provide education on that topic, review the patient’s medical history as they would in face-to-face appointments. Even telepsychiatry can be named here as an example, which uses cognitive behavioral therapy for interventions, including stress management, sleep hygiene, healthy life education and support programs [8].

Keywords. Telemedicine, patient data acquisition, sensors..

Not only patients benefit from the advanced development of information technology. Healthcare workers can also make use of its benefits. Increased confidentiality, efficiency, precision, and simplification of going through a lot of information, remote execution of tasks, to name a few examples. Telemedicine usage is also evident in connecting relevant health organizations throughout the world to improve epidemic control and monitoring, which has proved effective in limiting the crisis caused by severe acute respiratory symptom (SARS) and avian influenza (bird flu), in past years [4].

Depending on the specific application, the system for remote patient monitoring can include small wireless biosensors that form the body area network (BAN). In a general case, the energy consumption of BAN devices is very low, usually under 10 mW with small data transfer rates of around 10 Kbps. Still, some problems exist, namely, in the scope of BAN data security because in most cases data security mechanisms are not developed. Also, the antenna design can be a difficult task. Nonetheless, due to the high degree of flexibility in the possibility of placing various sensors, BAN enables health state monitoring for patients with asthma, diabetes, heart problems etc. Data from each different sensor is gathered within the BAN and is afterwards collectively sent for processing. In such case, the telemedicine system can incorporate different types of telecommunication networks. Actually, the patients wear the BAN on themselves, the data from the BAN is sent to the home local area network (LAN) where the data is saved and processed. Effectively, the LAN can provide a bridge between a hospital connected to the city network known as the metropolitan area network (MAN) and the patient’s home [4].

3. Network solutions

The transmission of medical information is common for all of the services that telemedicine and telehealth aim to provide. From a technical standpoint, one should carefully take into consideration the task of analyzing and filtering sensor data, while avoiding transmission of unnecessary data and noise. The devices used to monitor patients’ health mostly use Bluetooth and WLAN technology, although, generally speaking, other wireless technologies like GSM, satellites, and radio can be used as well. Bluetooth technology provides short range coverage, often used for connecting mobile devices in an ad-hoc network within one room. Such a network is also known as piconet. The main advantages are due to its low cost, simple circuits, and low energy consumption. What is interesting is that Bluetooth technology uses adaptive frequency hopping (AFH) to lower electromagnetic interference. It avoids frequencies that are being used by other nearby devices by detecting those devices in the spectrum and by hopping between 79 frequencies in intervals of 1 MHz. Bluetooth is useful for applications that require use of small biosensors because of the small power of 1 mW for 3 m, and the simple low-cost transceiver [4].

WLAN is a flexible data transmission system, implemented as an extension to the wired LAN. With the use of radio frequency technology, WLAN can transmit and receive data through air, therefore minimizing the need for wired connections. In that way, WLAN combines data connectivity and user mobility (Pattichis, et al., 2002). IEEE

802.11 standards are widely used in home networks, and they provide cheap and proper way of accessing the Internet. In comparison to Bluetooth and IR, WLAN requires greater effort to set up the initial configuration before communications can be established. A simple WLAN consists of at least one access point (AP) and one or more mobile client(s) (MC). In essence, MCs can be any mobile devices that want to achieve wireless connection with the network through AP. Wi-Fi provides a unified standard derived from IEEE 802.11 WLAN, while the wireless devices are connected through an access point know as hotspot. Because of its popularity in home networks and minimal required changes, Wi-Fi technology is used very often to monitor patients that are recovering in their homes [4].

4. Health condition indicators and monitoring

For the patients' health condition, some of the parameters of interest are associated with body temperature, blood oxygen saturation, blood pressure and respiratory rate.

According to authors [7], there is a possibility to leverage the advancement of technology for remote patient monitoring in a way that will enable early detection of diseases. Data from wearable sensors can warn about a potential SARS-CoV-2 infection before the symptoms become serious. The COVID-19 example can be linked to a few physiological changes that can be tracked with wearable and mobile sensors. Parameters derived from the heart's rhythm, such as heart rate (HR), heart rate variability (HRV) and resting heart rate (RHR), can serve as indicators and potential markers for a COVID-19 infection. The same parameters can also be measured using commercially available devices, Apple Watch, WHOOP Strap, Fitbit, Zephyr BioHarness, and VivaLNK Vital Scout, to name a few.

Respiration rate (RR) is a parameter of crucial interest in COVID-19 cases because of the serious effects that the virus can inflict on the lungs. Moreover, the measurement of SpO2 is also of high importance for the progression of the infection. There are some companies that have developed pulse oximetry through an app that uses the smartphones' camera, but it should be noted that it has shown limited precision in low blood oxygen detection [7].

Accurate measurements are essential for a relevant monitoring of a patient's condition. The success, accuracy and precision of the measurement requires and depends on solid knowledge of bioelectric signals. Having that in mind, a short description of some bioelectric signal of interest will be given in the next few lines.

The authors [2] explain how the source of almost every electric potential that emerges within the body is a semi-permeable membrane. Namely, the membrane is partially permeable for ions such as potassium (K^+) and sodium (Na^+) which can travel more freely in one direction through the membrane as opposed to the other direction. The result of those electric properties of the membrane is the generated potential on the membrane of around 0.1 V. Potential changes of that kind are a source for signals such as ECG. Thus, ECG can be obtained from electrodes placed on the skin since the body is a good conductor. From that aspect, the heart can be considered as a generator of electric signals enclosed in a volume conductor – the body.

Pulse oximetry relies on the optical absorption properties of the blood. It is a technique for oxygen saturation measurement. The measurement is based upon the key observation that the blood has a characteristic red or blue color depending on the concentration of oxygen in the blood. The pulse sensor usually consists of two LEDs with red and infrared wavelength, and a photodetector. Pulse oximetry is a simple and usually reliable technique that is in wide clinical use. A pulse oximeter can be tested by holding the breath for around 30 seconds, after that the SO_2 percentage should fall from around 98% to 80%.

Temperature measurement is also very important for health condition assessment. Continuous skin temperature monitoring can be done using commercially available devices such as the following: TempTraq, Oura ring, VivaLNK Fever Scout, and QardioCORE. Different devices have different means of usage. For example, the TempTraq sensor for skin temperature measurement should stay in contact with the skin for 72 hours. Devices like these can notify the medical personnel if sudden changes are detected in the sensor output values, indicating large variations in patient body temperature. Analog devices in the form of thermocouples and thermistors can also be used to measure temperature, but digital sensors have proven better for mobile applications due to their small dimensions, low energy consumption, and better control. It should be noted that sticky patches will probably prove to be reliable due to the continuous skin contact [7].

Still, thermistors can provide an adequate solution in a system for temperature monitoring. A thermistor is a semiconductor device the resistance of which changes with temperature change. The dependency between its resistance and the temperature is given with Eq. (4.1):

$$S = ae^{-bt} \tag{4.1}$$

where S is the resistance, t is the temperature, a and b are constants.

The measurement circuit, given in Figure 1, consists of a bridge and a differential amplifier.

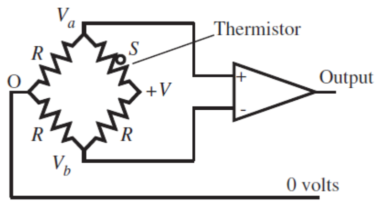

Figure 1. *The output from this resistive bridge and differential amplifier will be proportional, but not linearly, to the thermistor resistance, adapted from [2].*

The circuit shown in Figure 1 does not generate linear changes on the output with temperature change due to thermistor characteristics. Output voltage can be calculated in accordance with Eq. (4.2):

$$output\ voltage = V_a - V_b = V\frac{(R-S)}{2(R+S)} \quad (4.2)$$

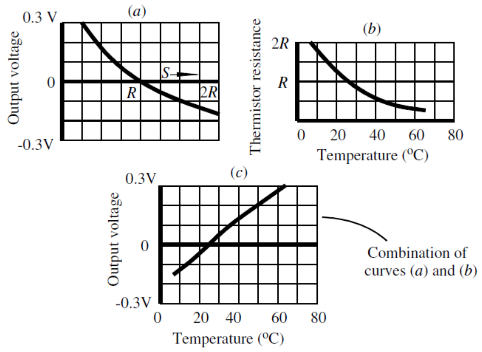

Figure 2. *An analysis of the circuit shown in figure 2. In (a) the output voltage is shown as a function of S; in (b) the thermistor resistance S is shown as a function of temperature; in (c) curves (a) and (b) have been used to show the approximately linear relation between output voltage and temperature, adapted from [2].*

The thermistor's characteristics are shown in Figure 2. The displayed curves (a) and (b) have similar slopes, while their combination results in an approximately linear ratio between output voltage and thermistor temperature. Additional corrections of nonlinearity can be made by adding resistors. Although the analysis of this circuit is not trivial at all, a response that is linear to 0.1°C at a temperature range of 25-45°C can be obtained, which is adequate for the patient monitoring system [2].

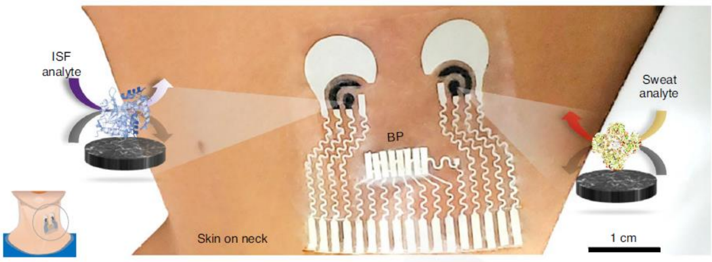

Figure 3. *An illustration of the placement of the sensor, adapted [6].*

An array of physiological parameters can be monitored using mobile sensors that people can wear. The authors [6] present in their study a conformal, elastic, expandable, integrated wearable sensor that can be used for monitoring blood pressure, heart rate, and levels of glucose, lactate, caffeine, and alcohol. Ultrasonic transducers are used for blood pressure and heart rate monitoring, while electrochemical sensors are used for the biomarkers. Their sensor is also remarkable from applied technology standpoint.

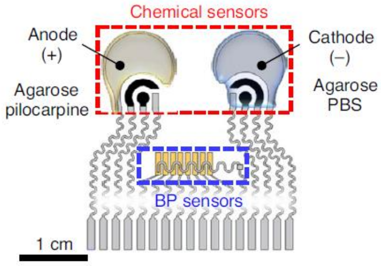

Figure 4. *Illustration of the acoustic and electrochemical sensing components of the sensor along with hydrogels for sweat stimulation (left) and ISF extraction (right), adapted from [6]*

As a substrate for that epidermal sensor, a material from the group of styrene-ethylene-butylene-styrene polymers is used. The blood pressure sensor is built of eight piezoelectric transducers aligned with the carotid artery when placing the sensor on the neck, thus getting optimal ultrasonic signals. The device emits ultrasonic pulses and measures the echo from the arteries while stimulating sweating and extracting tissue fluid through iontophoresis. In that way, blood pressure, heart rate and various biomarkers can be monitored simultaneously.

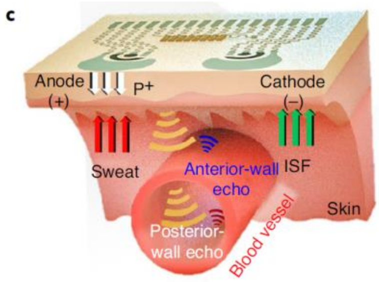

Figure 5. *Acoustic sensing and IP mechanism of the integrated sensor, adapted from [6].*

Figure 6 depicts how ultrasonic pulses generate an echo from the anterior and posterior wall of the artery. Chemical detection begins with applying current for iontophoresis from the anode to the cathode. This way, molecules of pilocarpine nitrate P^+ that stimulate sweating, are delivered by way of electrostatic repulsion. Once the pilocarpine nitrate molecules have been delivered, biomarkers such as caffeine, lactate, and alcohol, can be acquired and quantified on the left side of the device. The current from the iontophoresis causes osmotic flow of the biomarkers, such as glucose, from the tissue fluid towards the skin surface, thus enabling its acquisition and analysis on the right side of the sensor.

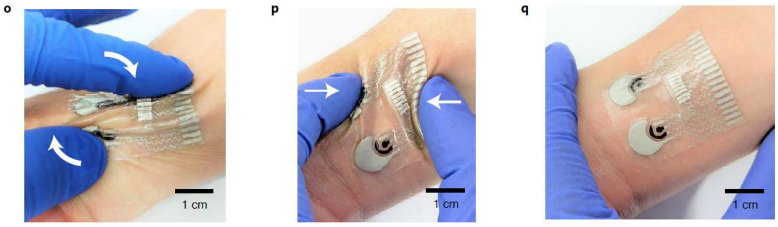

Figure 6. *Conformability and mechanical integrity of the device, adapted from [6].*

The rational design of this hybrid sensor which successfully integrates solid ultrasonic sensors, and soft expandable electrochemical sensors in one device, enables simultaneous monitoring of cardiovascular parameters and biomarkers in real time. At the same time, caution is given to mechanical performance, and mixing of the signals from the individual sensors is avoided due to the spatial distance between the acoustic and electrochemical transducers.

The authors [1] use capacitive strain sensors which contain a polyurethane dielectric sandwiched by stretchable carbon electrodes. One such sensor is shown in Figure 7. The working principles of the sensor are based on the change of the relative capacity ΔC/C_0. Such a sensor can be placed on the waist or the chest hence enabling monitoring of patient respiration through the sensor data. During the research, while placing the sensor in both positions, a considerable difference in the values was noticed during normal breathing and during deep breathing. Contrary to this, during irregular respiration, such as shallow breathing, small relative changes in the relative capacity (changes in relative capacity < 1%) were noticed when the sensor was placed on the abdomen. That research illustrates how various physiological patterns can be monitored through sensors placed at different positions. In the future of smart wearable devices for similar applications, the authors think that more sensor nodes can be used and small displacements or irregular displacements through dynamic ΔC/C_0 patterns.

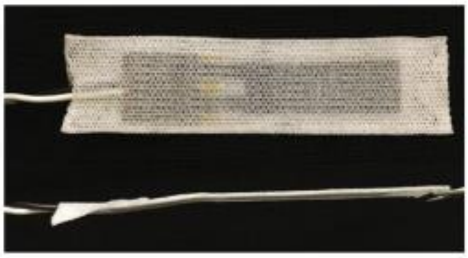

Figure 7. *Capacitive strain sensor, adapted from [1].*

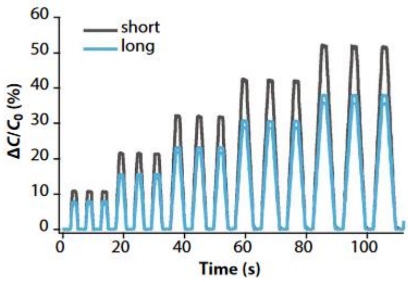

Figure 8. *Relative change in capacitance (ΔC/C_0), under repetitive cycling and increased strains,*

Figure 8 depicts the dependency of the relative change of the capacitance in time, in the case when strain is applied and removed, while also increasing the strain.

The described sensors can be used as a part of a complete system for remote patient health monitoring. The values form the sensors and thus the patient health status can be monitored through a mobile or a web application. Such an application can even be linked to commercial devices like FitBit, Apple Watch and others, which can also provide temperature measurement.

In the following paragraph the idea of using IoT and Fog computing will be considered.

5. IoT and fog computing

Undoubtably, the topic of Internet of things (IoT) will come up when discussing a system for remote patient monitoring. The same paradigms also apply to contemporary industry systems, however different implementations and IoT applications can be seen in everyday life. IoT concepts can be directly applied in health applications as well. Wearable devices like FitBit and Apple Watch, as well as BAN networks serve well in patient health parameters data acquisition. Furthermore, the contemporary development of BAN networks enables the usage of machine learning algorithms for optimized signal processing and patient health assessment. There are examples that even include drugs delivery through actuator components. The authors [1] have presented a smart system for patient health monitoring. Their system incorporates bioelectrical sensors and machine learning algorithms. Separate components placed on the human body work together in order to gather information needed to determine the health condition of the patient and even provide medical therapy. The sensor nodes convert the physiological information into digital signals that are then wirelessly transferred to a central unit that makes the decisions. The data from the BAN network can be deployed to a cloud service or services and analyzed. Afterwards, the result can perhaps be useful to the medical personnel for better decision making and therapy improvement.

Mobile devices can be used to monitor the patients' data and health condition. By combining multiple wearable sensors into one sensor network which will later communicate with mobile devices, a platform that will easily provide patient data to medical personnel can be designed. The use of mobile devices, or smartphone apps, and also web applications should really be considered an effective and user-friendly way of presenting the previously gathered and analyzed patient data. Through the use of such applications, the medical personnel will be immediately notified of any sudden or negative changes in the patients' parameters. Fog computing can come as a layer between sensor devices and the cloud services. The term Fog computing has been introduced by Cisco, [3]. The main difference between fog and cloud lies in decentralization and flexibility. Namely, fog computer technology describes a decentralized computing structure placed between the cloud and the devices producing the data. The goal of this structure is to analyze the data closer to the data source, i.e., the sensor devices that are producing the data. Thus, the data transfer distance in the network is reduced. The data can now be provided to the analysis service through a shorter path. That results in performance improvements and better network efficiency. The implementation of fog computing includes fog nodes. Fog nodes can be any switches, routers, cameras, or industrial controllers that can be placed anywhere. The edge nodes obtain data from other edge devices like routers and modems, and then redirect the data towards the optimal location for analysis. Data that is most of the time sensitive should be analyzed closest to the place of generation. Data that can wait for analysis can be redirected to an aggregation node for analysis. The data that is least time sensitive is sent to the cloud for historical analysis, big data analysis and data storage.

Although the applications where fog computing can be utilized vary, they have some things in common. One example is that all of them can monitor and analyze data in real time through a network. A suitable action can then be initiated after the conducted analysis. Fog computing can be used in applications where data needs to be acquired from thousands or millions of edge devices distributed over a geographical area. This serves the goals of telemedicine very well. The field of telemedicine also benefits from fog computing because the wait time is reduced. The analysis is performed in real time and closer to the sensor nodes, hence the medical personnel get notified faster. In most cases, there is no need to transfer all data generated by the sensors. To that extent, fog computing eliminates the need to transfer large quantities of data, and in that way helps in improving the bandwidth, which in turn, results in a more cost-effective system. Data security, better data control and reliability can also be considered benefits when discussing the fog computing paradigm.

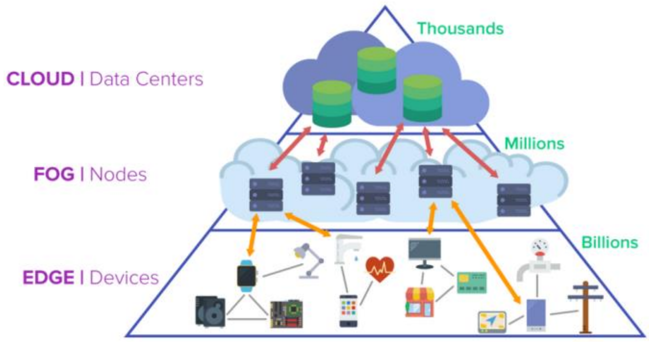

Figure 9. *Illustration of fog computing, adapted from [5].*

In the next few lines, a simple algorithm that can be used to detect pathological breathing will be presented. The data that is fed to the algorithm can be obtained from the sensor nodes, i.e., sensors such as those that were briefly discussed. Speaking more concretely, we can take a capacitive strain sensor as a data source example.

The algorithm begins by reading the values for the change in relative capacitance of the strain sensor. Afterwards, the read value from the sensor is analyzed and a check is performed to assess whether the change in capacitance is less than 1. If the change is less than 1, that means that there was no significant deformation of the sensor, and in turn that could potentially indicate a breathing irregularity, such as shallow breathing. In that case, an alert is sent to the medical personnel. A counter is then incremented by 1. The counter is needed to determine the respiration rate. The value of the counter is compared to a constant, i.e., the number 20, which can be considered the normal upper limit of respiration rate. If this limit is exceeded, an additional alert regarding the respiration rate is sent to the medical personnel. If the limit is not exceeded, then the current iteration is completed and the algorithm begins with a new iteration, with a new reading of the sensor value for the change in relative capacitance.

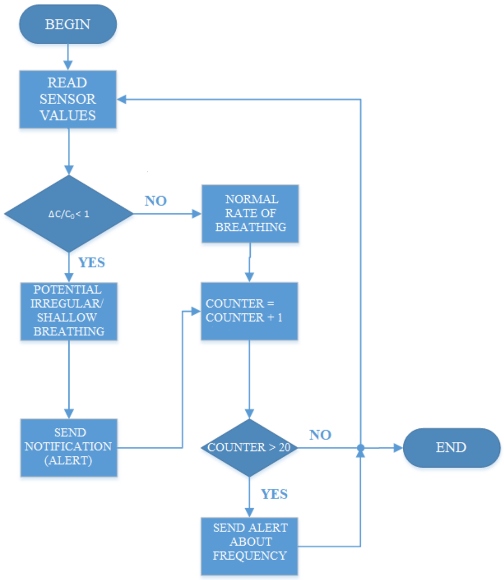

Figure 10. *Algorithm for detection of breathing irregularities*

If the analysis during the step that follows after reading the ΔC/C_0 value confirms that the change is not less than 1, then the breathing is considered normal. However, the counter variable is used again to completely assess the respiration cycle. Again, the value of the counter is compared, and if the limit is exceeded, the algorithm sends an alert for the respiration rate. If the limit is not exceeded, then normal breathing can be confirmed, and the algorithm proceeds with reading the next value from the sensor. It should be noted that the value of the counter variable should be reset every minute in order for the calculation of the respiration rate to be correct. Cloud and fog services can provide the computing resources needed to constantly run such algorithms and serve client devices through which the medical personnel can be notified and alerted about the patients' health parameters.

6. Conclusions

The contemporary way of living has induced an unbreakable bond between mobile and wearable devices and humans. Bearing in mind the ever-rising number of such devices, and their acceptance by people, we can conclude that it is only expected for different systems that utilize their usage to emerge. The field of telemedicine is no exception. Contemporary research indicates that the usage of mobile and wearable devices is on the rise and can lead to better and improved ways of remote patient health monitoring. There are devices and sensors specifically developed to enable measurement of the relevant parameters and health indicators. Of course, there are commercially available devices that can accomplish that to some extent, however there is also large interest among academic researchers who are constantly working on improving the quality and reliability of similar devices. If there is a large data set that needs to be analyzed one can always consider using cloud and fog services, through which even whole hospitals can potentially be part of one large system for patient monitoring.

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