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Patient Remote Health Monitoring Technologies

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Introduction

Technology has already irrevocably changed medicine. Despite the fact that the healthcare industry has always been ultra-conservative and difficult to accept change, especially in today's environment, when technology advances very quickly and information accumulates exponentially, most experts would agree that collaborative technologies that more closely connect healthcare providers with their patients help them provide more effective medical care.

The internet and big data are two heralds of big changes in the healthcare industry. Doctors and other healthcare professionals who do not begin to introduce advanced technologies into their medical practice will be left behind and after a while will be out of work.

One of the most obvious and, at the same time, relatively uncomplicated technology for implementation in practice is remote monitoring of patients' condition and observation of patients. Today, there are many different options for remote monitoring, but the main idea is to establish digital communication between a medical organization and patients in order to improve the quality and availability of medical care. Such systems allows adjusting the level and frequency of patient-doctor interaction and its frequency to best suit the needs of the individual health care plan.

Remote patient monitoring or distant patient monitoring is a health care delivery method that uses the latest advances in information technology to collect patient data outside of traditional healthcare settings. These are technologies that bridge the gap between the traditional physical health environment and where people truly live every day. At the same time, these technologies use modern, consumer-friendly personal digital medical products.

The comfort of modern digital medical devices and systems used by patients increases their level of involvement; and through increased participation, remote patient monitoring can improve the quality of care. Patients are not only motivated to become more involved in their own health care thanks to quality technology, but they also have a better understanding of their health situation, and for doctors, technology provides a constant stream of data that allows them to get a clearer picture of patients' health.

In recent years, remote monitoring systems for patient health have attracted considerable attention from developers. The increase in the aging population has an impact on the whole world [2]. To support the health of an aging population, we must face the challenge of developing resource-constrained remote monitoring systems. Despite numerous innovations in health care in recent years, health care costs are still very high, and they have become a problem, even for developing countries [1, 2, 3].

1. Significance of remote monitoring

Continuous measurement of patient parameters such as heart rate and rhythm, respiratory rate, blood pressure, blood-oxygen saturation, and many other parameters have become a common feature of the care of critically ill patients. When accurate and immediate decision-making is crucial for effective patient care, electronic monitors frequently are used to collect and display physiological data. Increasingly, such data are collected using non-invasive sensors from less seriously ill patients in a hospital's medical-surgical units, labor and delivery suites, nursing homes, or patients' own homes to detect unexpected life-threatening conditions or to record routine but required data efficiently. We usually think of a patient monitor as something that watches for—and warns against—serious or life-threatening events in patients, critically ill or otherwise. Patient monitoring can be rigorously defined as "repeated or continuous observations or measurements of the patient, his or her physiological function, and the function of life sup-port equipment, for the purpose of guiding management decisions, including when to make therapeutic interventions, and assessment of those interventions". A patient monitor may not only alert caregivers to potentially life-threatening events; many also provide physiologic input data used to control directly connected life-support devices, diagnostics and predicting of illnesses. Figure 1 shows the values of remote monitoring for disease detection.

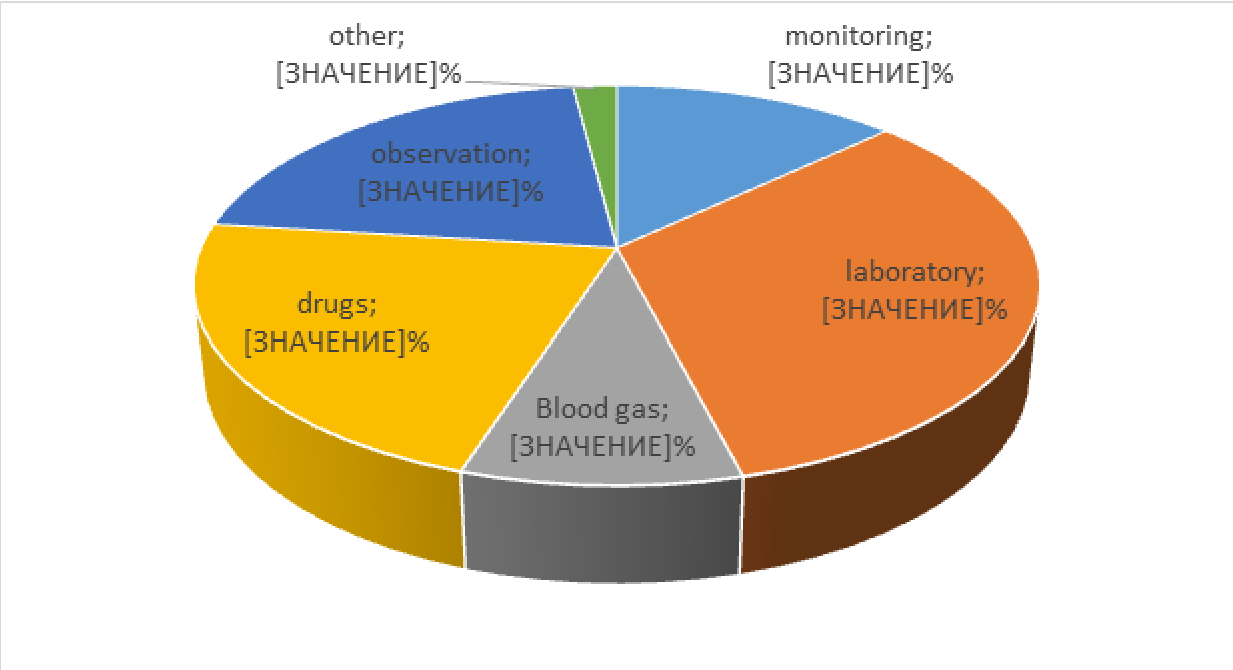

Figure 1. Disease detection means.

There are at least six categories of patients who need physiological monitoring:

1. Patients with unstable physiological regulatory systems; for example, a patient whose respiratory system is suppressed by a drug overdose or anesthesia

2. Patients with a suspected life-threatening condition; for example, a patient who has findings indicating an acute myocardial infarction (heart attack)

3. Patients at high risk of developing a life-threatening condition; for example, patients immediately after open-heart surgery or a premature infant whose heart and lungs are not fully developed

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4. Patients in a critical physiological state; for example, patients with multiple trauma or septic shock.

5. Mother and baby during the labor and delivery process.

6. Patients with chronic diseases.

Today, the monitoring process prevents many negative consequences, allows early detection, prognosis and treatment of the disease. Remote monitoring can prevent heart disease, mental illness, acute respiratory and other diseases. Including:

1. Diabetes control – 6.4% of the world's adult population, which represent 285 million people, suffered from diabetes in 2010. This number is estimated to reach 438 million by 2030, 7.8% of the adult population6. Research has shown Diabetes to result in long-term medical issues if not carefully monitored and treated7. Frequent monitoring provided by WBANs is capable of reducing the risk of fainting, enables proper dosing, and eliminates risks of loss of circulation, later life blindness and more complications.

2. Cancer Detection – Cancer death rates are estimated to increase by 50%, reaching up to 15 million by 20209. WBAN based sensors capable of monitoring cancer cells in the human body will enable physicians to continually diagnose tumors without biopsy providing more timely analysis and treatment.

3. Cardiovascular Diseases – Cardiovascular diseases are known as the major cause of death for 17 million people annually, which can be significantly, reduced or prevented with appropriate health care strategies. Myocardial Infarction (MI) can be greatly reduced by monitoring episodic events and other abnormal conditions through WBAN technology.

2. Remote healthcare monitoring methods

Remote health monitoring has several different methods of providing medical services. Basically, there are three main methods that are shown in Figure 2.

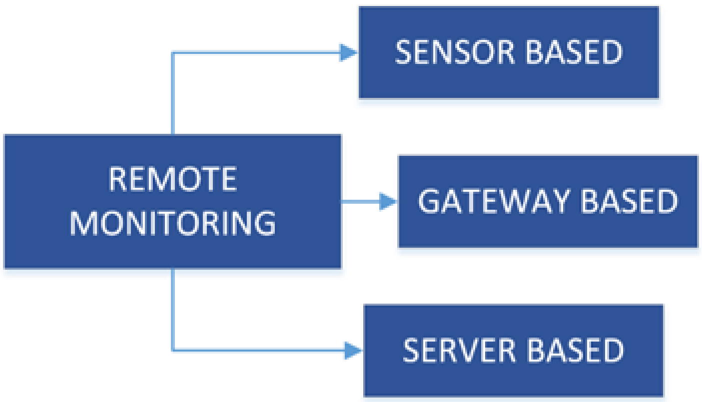

Figure 2. Remote health monitoring methods.

The sensor based method is based on sensor technologies that allow continuous monitoring of medical services. Wireless Body Networks (WBANs) include small wireless sensors that collect and transmit information about the vital functions of patients.

The gateway based method is mainly based on online consultations without the transfer of active data about the patient's condition. Gateway is a common literary term for the use of any wireless device, such as telephones and other communication devices that are often used to educate consumers about the use of "preventive health services" in health care.

The server based method is responsible for remote monitoring of patients in real time using a remote computer in a telemedicine environment. Patients' vital signs are collected and then sent to a telemedicine server for further analysis and research. After analyzing vital signs, the medical server can support healthcare professionals by remotely identifying the appropriate healthcare services for patients.

The modern healthcare system uses hybrid monitoring methods, where all three methods are intertwined to achieve the ultimate goal. At the same time, the combination of monitoring methods and the introduction of innovative technologies into these methods led to the emergence of the definition of IOMT based health monitoring.

3. IoMT based healthcare monitoring

The Internet of Things (IoT) can mean different "things" to different industries. Broadly speaking, any object or device connected over the internet and powered with the ability to collect, transfer and analyze data over a network can be labeled a "thing" in the emerging digital ecosystem known as IoT.

Narrowing it down specifically to the healthcare industry, any medical device that connects to a healthcare provider's network is sub classified as the Internet of Medical Things (IoMT). These include but are not limited to medical imaging systems, remote patient monitoring (RPM) devices, smart thermometers, infusion pumps, medical device gateways, and biosensors packaged into wearables for use in apparel or implanted inside the human body.

The main benefits of IoMT based remote health monitoring are the possibility to carry out regular tasks even though the patients are under continuous health monitoring and the advantage of low hospital bills. The conventional remote monitoring systems are making discomfort to the patients because of the size of the modules attached to the body and the frequent charging or replacement of batteries. Revolution of IoMT, resolves the above-mentioned issues by developing compact, ultra-low power sensor devices, and lightweight communication protocols. The remote health monitoring system mainly consists of a portable patient-monitoring unit (PPMU) at the patient's home or at emergency medical service vehicles and real-time monitoring with a decision support system at the hospital. The portable patient monitoring unit mainly consists of sensors and electronic circuits which is capable of acquiring vital parameters such as heart rate, heart rate variability, pulse rate, respiration rate, systolic blood pressure, diastolic blood pressure, oxygen saturation, body temperature, body mass index, level of consciousness, muscular activation, total lung volume, height, blood glucose level, urine report, a processing unit to process the acquired data and a network device to uploads to the server for further analysis. The schematic diagram of PPMU in patient's home or in an ambulance is shown in Figure 3. The condition of the patient can be viewed by using a graphical user interface by the physician.

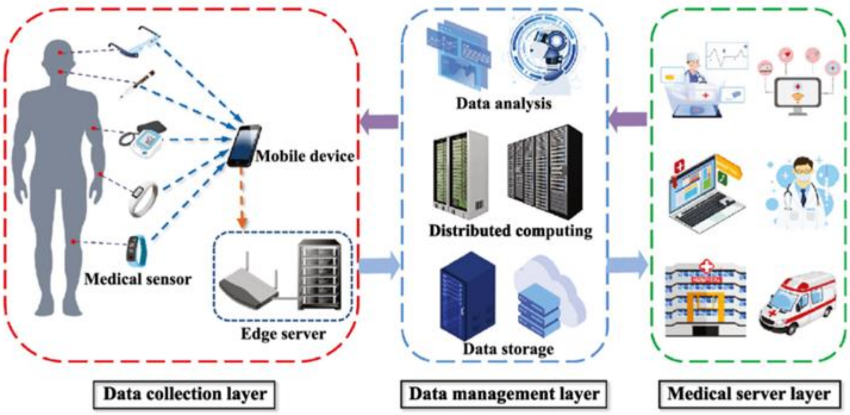

Figure 3. IoMT architecture

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Architectural Landscape Revisiting the Cyber-Physical system definition highlights the intertwined nature of the hardware and the software. Furthermore, the physical world we live in deals with information that is represented in an analog fashion. Such information is encoded as part of waves that can take on values over a continuum. On the other hand, computers and software only deal with a discrete set of values that can be mapped onto 0s and 1s. Both the health-care professionals along with the technology architects need to fully comprehend the underlying makeup of such systems to better address the implementation details along with the associated risks. Therefore, to delve into such details, we need to address the following:

1. Physical Components

2. Network Components

The Physical components allow the analog signals to be transferred from a device/body to a node that can process such information and receive instructions on steps to be performed. The Network components actually allow the messages to be transferred between devices – both in asynchronous and synchronous mode.

Physical Components. The IoMT paradigm is made possible by both a physical and network component. The physical components make it possible for the devices to both follow changes on the physical level and take an action. The physical level is composed of various Micro-Electronic-Mechanical Systems (MEMS) devices. In simple terms, MEMS systems are an amalgamation of both micro-electronic and micro-mechanical components along with a micro-sensor and a micro-actuator referred to as sensors and actuators going forward. The success of MEMS along with low cost of hardware has also given rise to Nano-Electronic-Mechanical Systems (NEMS), which follows the same idea, but the size of hardware is even smaller than MEMS. While a small number of experts works on the electronic and mechanical components, practitioners in the IoMT realm deal with the sensors and actuators components.

Network Component. The backbone of an IoMT infrastructure is the network component. While a wired network can be used, wireless networks are now considered the norm. The hardware components are connected via a network - hence the term Cyber-Physical systems. The term Wireless Sensor Networks (WSN) has become synonymous with the network component of the IoMT systems in healthcare. However, Wireless Body area Network (WBAN) more accurately describe the concept at hand. While a LAN allows connectivity with a high rate of transmission, WBANs specifically cater to devices that have limited power and bandwidth. While the narrow definition assumes that the components belong to a particular individual, in reality, WBANs take on a bigger meaning e.g., when applied to industrial IoMT.

4. Application of WBAN in remote health monitoring

In modern technology, wireless communication provides many possibilities to be able to share its information to each other at anytime and anywhere. Intelligent mobile communication network and WLAN, Wi-Fi are applied to various sectors such as education; health care service and industry in order to provide people a convenient way to communicate with each other. As the demand of ubiquitous network is increased, the devices for home, office and other information devices that can communicate wireless in short range have been getting more attention. The standard and technique development of ubiquitous network has rapidly put itself into the world market. Wireless Body Area Network (WBAN) is becoming a special application of such technique. WBAN differs with other wireless sensor networks (WSN) with some significant points. First difference between a WBAN and WSN is mobility. In WBAN user can move with sensor nodes with same mobility pattern whereas WSN is generally used to be stationary. Energy consumption is much less in WBAN than other WSNs

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arrangement. In addition, WBAN sensor devices are found cheaper than WSNs. For reliability, node complexity and density, WBAN nodes are however traditional. WSNs do not tackle specific requirements associated with the interaction between the network and the human body.

There are several wireless technologies such as Low power Wi-Fi, Bluetooth, ZigBee and IEEE 802.15.6. In this paper, we have discussed about the general architecture of WBAN, adopted technologies and its possible applications in different areas.

a. WBAN Architecture

WBAN is designed with special purpose sensor, which can autonomously connect with various sensors and appliances, located inside and outside of a human body.

Figure 4 demonstrates a simple WBAN architecture where the architecture is divided into several sections. Here we have classified the network architecture into four sections. The first section is the WBAN part, which consists of several numbers of sensor nodes. These nodes are cheap and low-power nodes with inertial and physiological sensors, strategically placed on the human body. All the sensors can be used for continuous monitoring of movement, vital parameters like heart rate, ECG, Blood pressure etc. and the surrounding environment. There are vast monitoring systems are being used already based on wired connections. Any wired connection in a monitoring system can be problematic and awkward worn by a person and could restrict his mobility. Therefore, WBAN can be a very effective solution in this area especially in a healthcare system where a patient needs to be monitored continuously and requires mobility.

The next section is the coordination node where the entire sensor nodes will directly connected with a coordination node known as Central Control Unit (CCU). CCU takes the responsibility to collect information from the sensor nodes and to deliver to the next section. For monitoring human body activities there is no such wireless technology is fixed for targeting WBAN. Most popular wireless technologies used for medical monitoring system are WLAN, Wi-Fi , GSM, 3G, 4G, WPAN. Except Cellular network standard, all of these technologies are commonly available for short distance communication. WMTS (Wireless Medical Telemetry Service) and Ultra-Wide Band are another technology that could be used for body monitoring system as they operate in low transmission power.

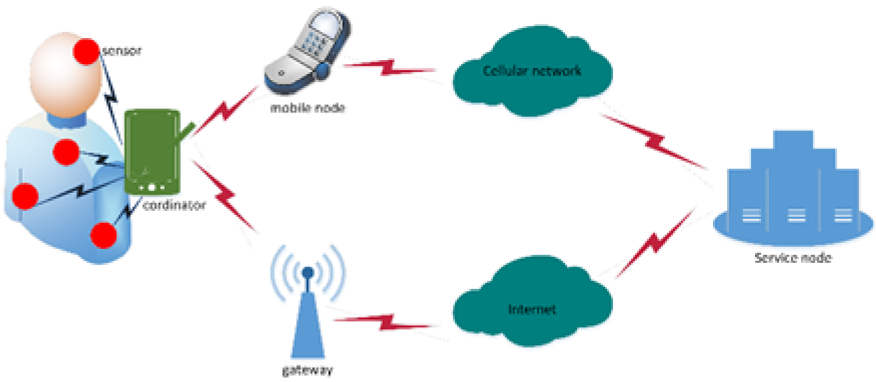

Figure 4. WBAN architecture

The third section is the WBAN communication which will act as a gateway to transfer the information to the destination. A mobile node can be a gateway to a remote station to send Mobile Message to a cellular network using GSM/3G/4G. A router or a PC can be a remote node to communicate via email or other service using Ethernet. The last section will be a control center consists of end node devices such as Mobile phone for message, PC for monitoring and email and server for storing the information in the database.

b. Traffic Types

In a WBAN traffic can be divided into three categories such as:

- Normal traffic
- Emergency traffic
- On-demand traffic

Normal traffic is the data traffic, which is used to monitor the normal condition of a person without any criticality and on demand events. Emergency traffic is initiated by nodes when they exceed a predefined threshold or in any emergency. Such type of traffic is very unpredictable. The authorized personnel like doctor or consultant to acquire certain information for diagnostic purpose initiate on-demand traffic.

c. WBAN Standards and Technologies

As WBAN is a short range wireless networks so different types of wireless short range technologies can be involved in different stages. In this segment we will describe most common technologies such as Bluetooth, ZigBee, Wi-Fi , IEEE 802.15.6 etc. that can be used to deploy WBAN.

Bluetooth is an IEEE 802.15.1 standard commonly known as WPAN (Wireless Personal Area Network). Bluetooth technology was designed as a short range wireless communication standard, anticipated to form a network with security and low power consumption. A typical Bluetooth network forms a Piconet where a Bluetooth device works as a master and another seven Bluetooth devices work as slaves which gives each device to communicate with each other simultaneously. Another type of Bluetooth network can be formed with more than one Piconet known as Scatternet. In Scatternet a node of a Piconet (can be a master or a slave) joins as a slave in another Piconet. Figure 5 shows how a Piconet and Scatternet are formed using Bluetooth nodes. Though, the basic Bluetooth protocol does not support relaying but it is possible to join together numerous Piconet into a large Scatternet, and to expand the physical size of the network beyond Bluetooth's limited range using this method.

Bluetooth devices operate in the 2.4 GHz ISM band (Industrial, Scientific and Medical band), utilizing frequency hopping among 79 1 MHz channels at a nominal rate of 1600 hops/sec to avoid interference. It is classified with three classes of devices with coverage ranging from 1 to 100 m and different transmission powers ranging from 1 mW to 100 mW with 3 Mbps data rate. A key feature of Bluetooth is that all the Bluetooth devices can communication with each other in NLOS condition. Bluetooth is suitable for short distance data transmission applications such as between servers of WBANs or between a WBAN and a personal computer.

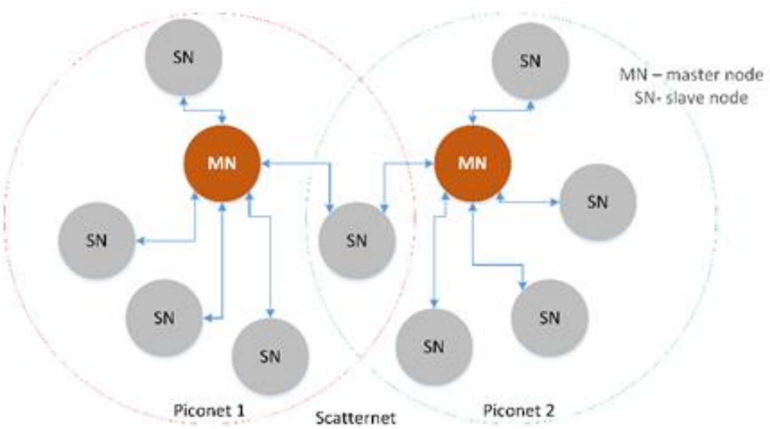

Figure 5. a Piconet and Scatternet forming using Bluetooth nodes

ZigBee is an IEEE 802.15.4 standardized solutions for wireless telecommunications designed for sensors and controls, and suitable for use in harsh or isolated conditions. One of the biggest advantages of ZigBee network is its low power consumption. Figure 6 shows a typical ZigBee network topology which consist of three kinds of devices or nodes such as coordinator, router and end device. One coordinator exists in every ZigBee network. It starts the network and handles management functions as well as data routing functions. End devices are devices that are battery-powered due to their low-power consumption. They are in standby mode most of the time and become active to collect and transmit data. Devices such as sensors are configured as end devices. They are connected to the network through the routers. Routers help to carry data across multi-hop ZigBee networks. In some cases ZigBee network topology are formed without routers when the network is point to point and point to multipoint.

ZigBee is aimed at RF applications that require low data rate, long battery lifespan and secure networking. Through the standby mode, ZigBee enabled devices can be operational for several years. ZigBee-based wireless devices operate in three different frequency bands such as 868 MHz, 915 MHz, and 2.4 GHz. Therefore, one substantial drawback of using ZigBee network for WBAN applications is due to interference with wireless local area network (WLAN) transmission, especially at 2.4 GHz. As ZigBee devices operate at low data rate so it can be unsuitable for large-scale and real time WBAN applications. However, it can be very much suitable for personal use like assisted living, health monitoring, sports, environment etc. within a modest range between 50 - 70 meters.

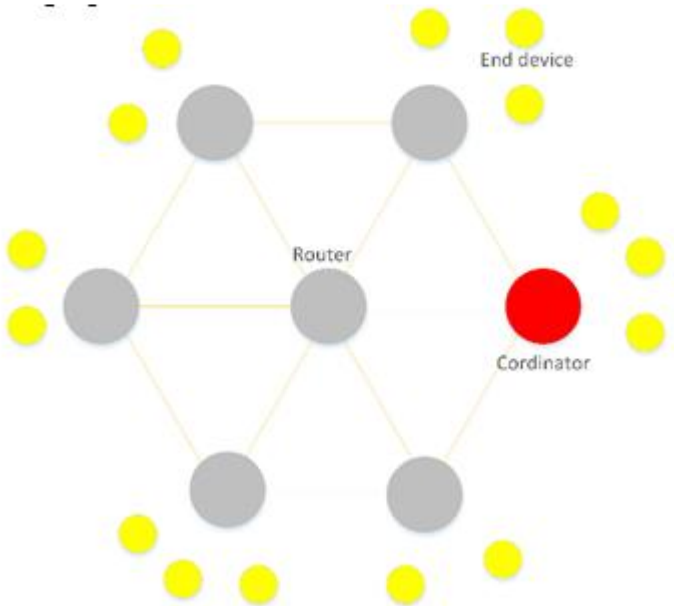

Figure 6. Zigbee network topology

Wi-Fi is an IEEE 802.11 standard for wireless local area network (WLAN). Generally, Wi-Fi technology comes with four standards (802.11 a/b/g/n) that runs in ISM band 2.4 and 5 GHz with a modest coverage of 100 meter. Wi-Fi permits users to transfer data at broadband speed when connected to an access point (AP) or in ad hoc mode. Figure 7 shows a Wi-Fi network where Wi-Fi sensor nodes and users can transfer data using internet by standard Wi-Fi router. In some modified version, Wi-Fi devices can be used in data acquisition applications that allow a direct communications between the sensors and the smart phones PC even without an intermediate router. Wi-Fi is preferably suitable for large amount of data transfers with high-speed wireless connectivity that allows videoconferencing, voice calls and video streaming. An important advantage is that all smart phones, tablets and laptops have Wi-Fi integrated; however the main disadvantage of this technology is high energy consumption.

5. SENSORS FOR REMOTE MONITORING

Remote monitoring of the patient's condition is carried out by means of sensors to collect and transmit useful information about the physical parameters of the patient's health. Based on the operating environments the monitoring sensors can be classified into two types. Wearable sensor devices worked on the human body surface and implantable devices operated inside human body

Wearable sensor devices allow the individual to follow closely the changes in her or his functions and in the surrounding environment and provide feedback for maintaining optimal and instant status. For example ECG, EEG, Blood pressure sensor can be used to monitor a critical patient, GPS sensor can be used to locate an area and different types of sensor that can be used to measure the distance, temperature, movement etc.

To measure heath parameters, implantable sensors are planted in close contact with the skin, and sometimes even inside the human body. Implantable biosensors are an important class of biosensors based on their ability to continuously measure metabolite levels, without the need for person interference and regardless of the person’s physiological state. The implantable biosensors have great impact to diabetes and trauma care patients, as well as soldiers in action. Figure 7 focuses on the sensor nodes with wireless capabilities.

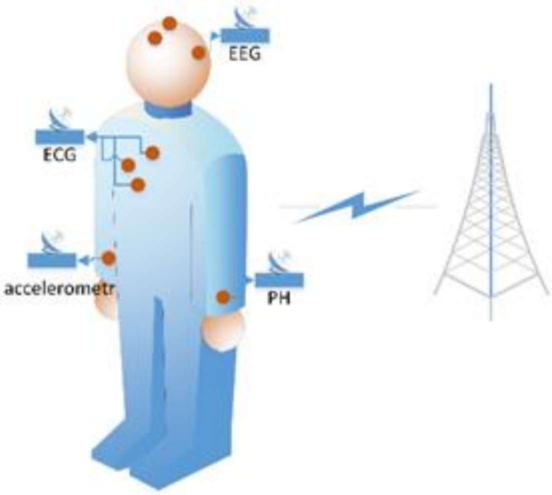

Figure 7. Sensor nodes

Sensors are an integral part of wearable remote monitoring devices. Wearable connected devices is very promising in healthcare. They provide ongoing access to important sources of patient health data and indicators. Wearable devices or wearables are mini-computers with built-in special sensors that measure environmental parameters, physical indicators of a person, and the level of activity. At the same time, the devices are connected to the network, and synchronized with a computer or smartphone. Wearable gadgets include fitness trackers, smartwatches, glasses, and even wardrobe items (like smart gloves that translate sign language into text).

Wearable device specifications:

- Direct connection to the network.
- Interaction with the environment and the owner.
- They function not only as a smart device, but also as an accessory (watches, bracelets, trackers).

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The prototypes of modern wearable medical gadgets were the Finnish heart rate monitors Polar, released in 1977 for the national team. In 1981, the same company created a watch with a cardio meter. However, until 1995, such devices were non-autonomous and worked only with the help of a computer. The prototype of more modern wearable gadgets was the Nike bracelet in 2013: it was able to independently track physical activity and send data to a computer using Bluetooth 4.0. In the same year, the Jawbone UP24 was released - a smart bracelet that monitors sleep phases.

Modern wearable devices that are worn on the wrist are able to measure the pulse, count the kilometers traveled, the speed of movement, calories and sleep phases. Some of them are equipped with separate medical sensors like a glucometer or cardiometer, sensors to track brain activity, stress levels.

Since the announcement of the first wearable devices, the directions of their use for fitness and medicine have emerged. Wearable technology has become one of the pioneering and challenging advancements in the technology sector through advances in sensor and wireless technology.

All sensors in wearable technology must be biocompatible so that the devices can safely collect important information from the wearer's body.

Gyroscope and accelerometer. The gyroscope measures angular velocity and is intended for navigation. It accurately determines the orientation of the body in space and its rotation. The accelerometer is another common motion detection sensor that monitors multidirectional movement activity (inclination, tilt, and body orientation). Most fitness trackers on the market often combine a gyroscope with an accelerometer to capture your training in 3D.

Wearable electrodes. The electrical impulses in the electrodes read a person's heart rate, so the devices are designed to attach directly to the skin. Electrodes in medical wearable devices are used for measurements in EMG, EEG and ECG. Modern electrodes are built into clothes so that they can be washed without removing the sensors. The optical heart rate sensor is an improved version of the wearable electrodes used in healthcare. The sensor consists of a photodiode and LEDs. It is commo knowledge that the human body constantly emits bio photons. The photodiodes in the sensor capture the light that is present in the blood. Therefore, the photodiode signal reads the heart rate.

Temperature sensor. This sensor monitors body temperature. The higher the temperature, the more intense the training process.

Altimeter. The altimeter is one of the most essential sensors for wearable devices used by climbers. The improved version of the altimeter is the aneroid barometer, which is necessary for measuring altitude and pressure.

Non-contact sensors. The devices detect the presence of a specific object nearby. They are able to determine if a person, an inanimate object, or even a wall is nearby. However, when choosing a proximity sensor, keep in mind what range will be needed to determine the distance or even the beam width to control the distance. The wearable proximity sensor is useful in devices with applications related to the detection of obstacles, certain metal objects in industrial installations, etc.

Biochemical sensors. These sensors in the wearable device convert the chemical component they come into contact with into an electrical signal. Biochemical sensors operate on the principle of chemi-resistive detection in a wearable configuration. The electrochemical sensor is configured to continuously monitor EtG (Ethyl glucuronide) secretions from the human sweat glands to help track metabolic rate. Such sensors are widely used in wearable devices to track the amount of alcohol consumed and lifestyle.

Typically, the success of a wearable device depends on integrating sensors with algorithms into wearable form factors that allow doctors, patients and anyone looking to monitor and improve their

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health to focus on preventing chronic disease. Advances in technology and the development of improved sensors are opening up broad prospects for digital health. In conclusion, all sensors can be divided into the following groups as shown in table 1.

SENSORS	SENSORS LOCATION
Heart beat	Wrist
Temperature	Wrist
Ecg	Chest
Eeg	Head
Oxygen saturation	Shoulder
Accelerometer	Leg and arm
Gyroscope	Leg and arm

Table 1. Sensors group

The sensors mentioned above can be either wired or used as wireless transmitters. Our further activity will be to study the characteristics and possible applications of wired and wireless sensors.

Conclusion

Remote monitoring is an integral part of the modern healthcare system. Modern sensors and network technologies, in turn, are capable of providing continuous monitoring of the patient's condition in real time. For this, it is advisable to carry out monitoring based on IoMT. IoMT consists of several nodes such as sensor tier, network tier and service tier. In this paper, we have explored sensory tier and identified possible sensors and their health applications. In addition, the study of the network node has led to the need for research in the field of WBAN.

WBAN is an emerging technology, which is expecting to have a great impact on our society as well as in the field of medical and non-medical sector. In this paper, an overview of WBAN has been outlined where we have highlighted the WBAN architecture and deploy requirements of this technology. We have also discussed about development and the technology adoption with different fields of application here.

In the end, we feel that several non-technical factors would also play crucial roles in the success of the remote monitoring technologies development such as affordability, legal, regulatory and ethical issues, and user friendliness, comfort and acceptance.

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