An Overview of Patient Monitoring Systems Based On Machine Learning in The Internet of Things*

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Abstract
The Internet of Things (IoT) is widely used in many applications including patient monitoring systems. The purpose of healthcare systems is to monitor the patient in order to prevent risks, deal with critical cases quickly, and establish long-distance communication for remote treatments. The IoT has a long-term impact on patient monitoring, patient management, patient physiological information, and critical care. The sensors are connected to the patient to collect the data which are first sent to system controls and then autonomously to healthcare providers. There are a variety of biosensors that send the medical information to mobile applications or websites via wireless network. Healthcare providers are thus enabled to monitor the patient and control the treatment outside of hospital walls. Therefore, the IoT medical devices require accurate patient monitoring methods in order to predict patient condition more precisely, and increase the efficiency of the network. An overview of patient monitoring systems based on machine learning in the IoT is provided in the following article.

Keywords
IOT, Machine Learning, HealthCare, WBAN

1. Introduction

Healthcare Internet of Things (H-IoT) or the Internet of Medical Things (IoMT) is a turning point in the development of information systems in the medical industry. These systems play a major role in assessing patient health status and increasing their quality of life. They are complex systems which include other systems such as microelectronic systems, medical systems, computer science systems, and various other fields.

The 2017-2022 period is the growth phase of IoMT applications, which with the various beneficiaries' increasing interest will accelerate the improvements of the IoMT applications, as well as improving the medical industry as a whole. Therefore, there is no doubt that the IoT will transform the healthcare sector by redefining medical devices, applications, and integrated networks of healthcare solutions. IoT consistently offers new tools, and these tools make up the integrated healthcare systems and help it with better patient care. These additives have decreased health care costs and improved treatment results. [1]

Section two of this article will examine the general health care systems, and their applications specially in the IoT. Section three of the article will analyze the challenges that exist within IoMT.

Section four will provide the various methods used in patient monitoring, briefly; and lastly section five of the article will be the conclusion of this overview.

2. Healthcare System

Healthcare systems are a complicated network since they include: doctors, nurses, employees, healthcare providers, insurance companies, laboratories, and pharmacies. The parties involved are all

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located in different regions. Even so, they can all begin transactions on the healthcare systems regardless of their location, and the result of these transactions will be stored on the device and can be accessed by everyone on the integrated system. Right now, these transactions are stored on different systems that are not user-friendly; in addition, these current systems are time consuming, and prone to errors. All transactions in IoT healthcare systems are stored in a general ledger. This means that medical records, test results, benefits and eligibility, insurance coverage, medicines, and allergies, are all accessible and stored in a secure database (similar to blockchain). The need for medicine, equipment, and other consumables can be managed and monitored through the same database which makes managing the healthcare system more efficient altogether. [2] Smart healthcare plays an important role in healthcare programs through embedding patients, and their medications with sensors and actuators for monitoring and tracking purposes.

IoT is used by clinical care to monitor the physiological status of patients through sensors which collect their data, analyze it, and then send the information remotely to processing centers in order for them to take appropriate action.

There are various ways of assessing IoMT, but generally the quality of care, remote patient monitoring, and context awareness, are the three most important things to consider. The automated medical data collection in IoMT, decreases human error in the data collection process, which can be harmful to the patient's health. It also increases diagnostic quality, and promotes patient health. The following will review different components of clinical care.

2.1. Clinical care

In order to take quick life-saving action during a crisis, hospitals must have access to around-the-clock and continuous monitoring; especially for patients in the ICU. These patient monitoring systems use sensors to collect physiological data which they analyze, and store in the cloud; this data is then sent to the patient's online caregiver group (patient's family, and the nurse) for further analysis. Many medical professionals work together based on each of their expertise, to review the analysis IoMT has done with its collected data. Thus, it is easier to identify medical emergencies for high risk patients (patients requiring emergency surgery, cardiac patients, etc). [3]

2.2. Remote patient monitoring

Remote patient monitoring (RPM) is an important paradigm for many real world applications. There are many people across the globe today, whose health is at serious risk due to the lack of RPM. Children, senior citizens, and patients with chronic illnesses require almost daily checkups. Access to an RPM system helps the patient bypass the rigorous hospital examination process as shown in figure 1. Due to the patient's pre-existing conditions, sometimes their health is not considered at risk until their situation becomes critical. Remote access sensors help caregivers with more effective pre-diagnosis and early intervention before any life-threatening mistakes are made. [4]

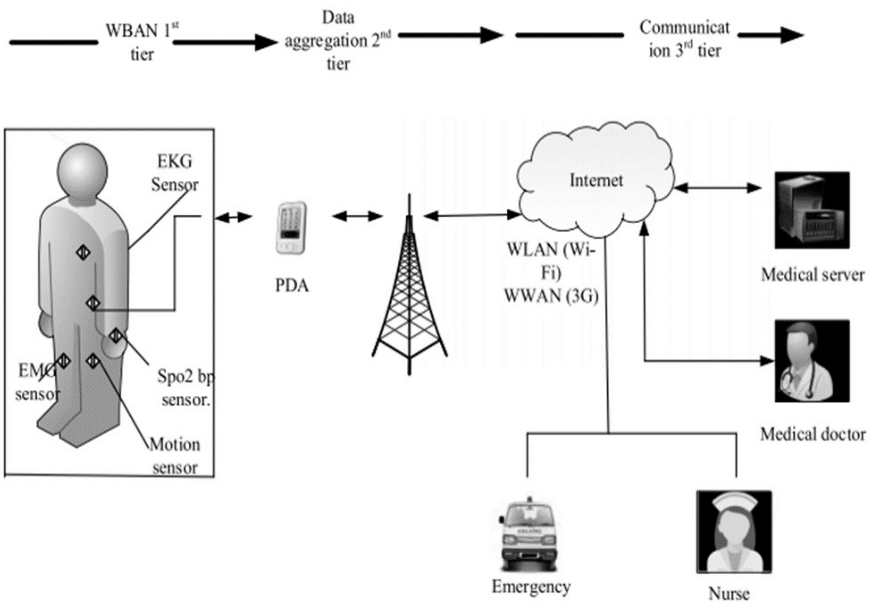

Figure 1: Real time remote monitoring systems

People-centric IoT is used in different cognitive units and helps physically disabled people have easier, and more independent lives. The sensors can diagnose heart disease and the effect of medicine on the heart's activity since it can be attached to specific parts of the skin. Many patients suffering from chronic diseases such as cardiopulmonary diseases, asthma, or heart failure live considerably far from clinical care centers. Real time remote patient monitoring for these patients is the most promising use of these systems.

Some of these real time remote monitoring systems are patient monitoring systems, tracking systems, and heart rate monitors. Real time remote monitoring systems include an RPM unit and a monitoring center. The system analyzes the data collected and analyzed by the sensors, and sends the emergency unit and diagnostics the appropriate alerts and notifications. The sensor's signals are transmitted to the appropriate medical care facility through a wireless local area network (WLAN). As a result, this system provides information about the patient's health status, and offers immediate treatment, which reduces further complications, and negative side-effects. Therefore, the system makes real time patient monitoring possible in the health care sector. It also helps input sensors with faster diagnosis, and consequently saving patient lives. [3]

2.3. Context awareness

Context awareness is a key criterion in IoMT applications. IoMT can help healthcare professionals understand the sudden changes which could affect the health status of patients since it has the ability to track patient health status, and the status of the patient's physical environment. Environmental changes can increase risk factors, and vulnerability to diseases, and thus put the patient at risk. The various specialized sensors gather meaningful data that help in understanding patient status either at the time of hospitalization, at the patient's house, or anywhere the patient might be; via gathering diverse data about the patient's physiological status through monitoring their walking, running, sleeping status, etc, and the patient's physical environment such as the hotness, coldness, humidity levels, etc; and the relation of the aforementioned with one another. Moreover, IoMT applications aid in locating the patient during medical emergencies, and provide the type of medical intervention that can be performed to deal with the crisis.

2.4. Healthcare networks in IoT

Various systems, and devices must work in the context of IoT in order to improve the health care system's performance. The IoT healthcare network is one of the critical elements in the Wireless Body

Area Network (WBAN). The efficient transfer of data, and general communication within the system is made possible by the WBAN. IoMT is made up of network topology, a platform, and an architecture.

2.4.1. IoT network topology

IoT network topology is made up of various components that play a role in identifying different scenarios which could arise in continuity care. The IoT in WBAN can be controlled remotely by wearable devices. Sensors, and wearable medical devices help the precise collection of patient's health data. The collected data is analyzed, and stored in a special database which is useful for data aggregation. This technology enables caregivers to monitor the patients remotely, and to respond according to the provided data. Figure 2 displays the pathway of healthcare data which uses an interconnected network with WiMAX, Internet Protocol Network, and Access service networks.

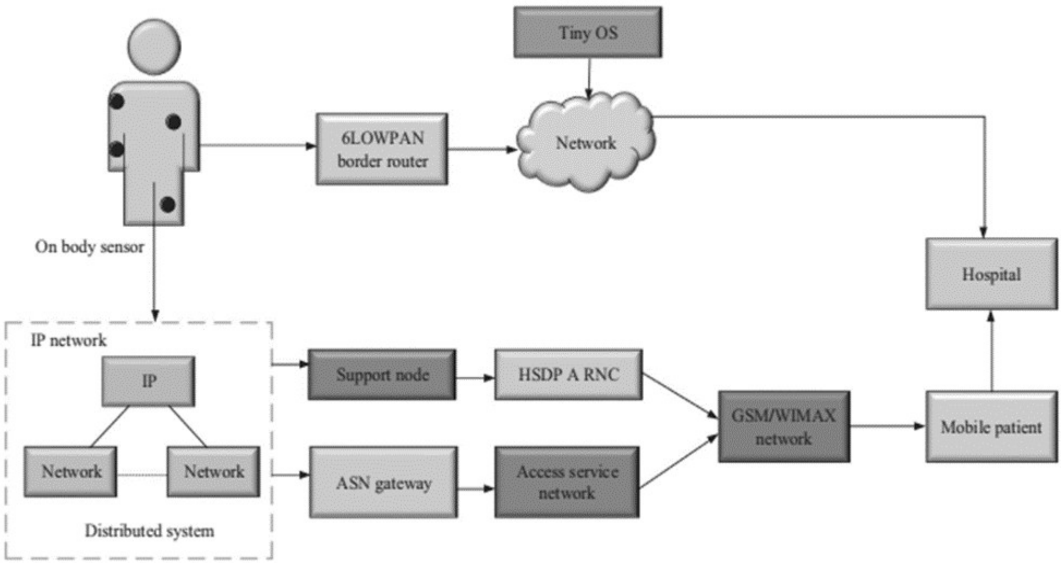

Figure 2: IoT network topology in remote patient monitoring [3]

IoT topology network showcases the gateway systems in figure 2. It also points out iMedpack (IoT devices) which manage drug compliance and prevent drug abuse. Additionally, various sensors, and wireless network topology interfaces create essential gateways for healthcare applications. IoMT makes diagnostics and analysis possible via connecting the different wearable devices to the healthcare gateway. IoMT is also able to store the collected data, analyze, review, and lastly: present them. All IoT network topologies are recognized and their infrastructures are connected with the integrated healthcare systems. The main IoT network topology components provide essential medical care, and they are generally used to help healthcare service providers. These faculties are used for medical emergency services. Therefore, network topology becomes important in medical systems. [3]

2.4.2. IoT network platforms

Two important IoT platforms are the IoT platform for healthcare service model and the cloud computing IoMT model. The healthcare service model mostly focuses on residents' health data as shown in figure 2. The figure also depicts the structure of the IoMT network platform which shows the user how to access the database layer for healthcare support from the very first layer of the application. This can ensure that the interoperability of the platform and its automated design, which are engineered for rehabilitation purposes, are used appropriately. The framework itself consists of an accessing layer, a support layer, a business layer, and a data persistent layer. An activation method is required to access the IoT gateway in order to manage multiple users attached to sensors.

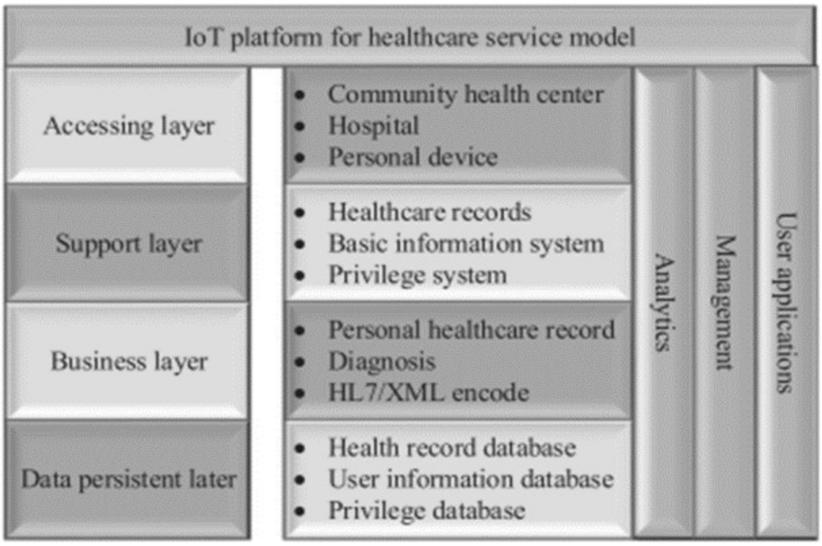

Figure 3: The framework of the IoT platform for healthcare service model [3]

This model makes the management of multiple users possible via the use of multiple sensors during the data collection process. The IoT database uses Multi-Tenant databases; and the source layer is mostly responsible for sharing the healthcare system's data and interpolation using the resource control mechanism. This systematic framework makes the user interface and the IoT's capacities possible in the health sector.

2.4.3. IoT network architecture

IoMT architecture includes the physical components, operational layers, and the principle of working defined for the device. Some key elements which have been identified for this type of network architecture include: The interoperability of the IoT gateway and the wireless local area network (WLAN), secure communication between IoT gateway and caregivers, and multimedia streaming. For a secure communication channel, the IoT network health system transmits the data of the wearable devices and the sensors through specified protocols. The data transmission framework responds to the sensor nodes through user Datagram Protocol (UDP). This provides the patient and the medical team with a secure integrated communication system. [3]

2.4.4. IoT network architecture based on Wireless Body Area Network

Wireless Body Area Network (WBAN) is composed of three different layers. Figure 3 shows on-body sensors, and different sensor nodes. These sensors are known as on-body or wearable sensors which are embedded on the patient's skin, and can work via wireless networks. The sensors receive signals from the body, and then transmit the patient's vital signs such as body temperature, blood pressure, blood sugar levels, heart activity, and humidity. The nodes' functions and capabilities can be found and/or predicted in the tags or low-level management system. The data collected from the on-body sensor is sent to the central controller system or the master communication controller using the adjacent personal web server (PWS). Therefore, it can provide information to the medical team for real-time processing using a WLAN system, or send emergency alerts when necessary. Patient's profile is collected from their electronic medical records, and stored in the medical server. The system provides different services to its intended users such as medical professionals, patients, or informal caregivers.

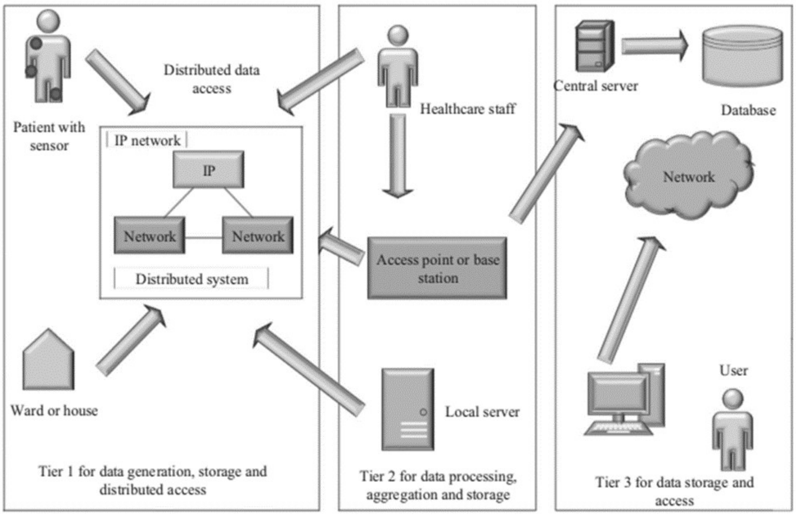

Figure 4: WBAN framework based on IoMT

The medical server is responsible for an array of things which include but are not limited to: authenticating users, and setting up an authentication process, formatting sessions, patient monitoring, data analysis, diagnostics, and following instructions given by doctors. The medical server can review the uploaded data and alert the users with different predictions about potential medical conditions. The clinical center may also be involved in the data observation and analysis process.

In the second layer system, personal web server interfaces and the WBAN sensor nodes' interfaces can communicate with other services using the information bank, which requires limited human bond communication (HBC). PWS nodes are connected to mobile devices that can run on personal computers (PCs). This is mainly used for monitoring elderly patients. The connection between the personal web server, and the body area network is stabilized through a network coordinator. The network configuration itself includes initialization, customization of sensor nodes plus their registration, and an overall safe and secure connection. A configured WBAN enables the personal web server to manage all processes available such as time synchronization, data recovery, etc. Personal web server can thus determine the health status of the user through their available health care information. It also provides feedback on the sensors, and the user interface.

Personal web server stores patient information and their IP address. Additionally, if there are medical servers available, it creates a secure connection between the medical server and the PWS, and then transmits the medical reports to the user's medical records in the medical server. In the instances where medical servers are unavailable or aren't linked to the user, the PWS stores the data locally; to be transmitted once a medical server becomes available. This system provides a highly secure connection, safe storage, and real-time monitoring remotely. IoT-based WBAN functions are listed below:

WBAN sensor nodes:

Though containing a small battery with limited power, WBAN sensor nodes are of high-performance computing, and communication capabilities. Some of the sensor nodes' components include:

1. Sensors: Detects vital signs through embedded chips into the patient's skin (2)
2. Micro-controller: Scans and controls other components in addition to local data processing, and data compression
3. Storage: Temporarily stores the data collected by sensors
4. Radio receiver: Connects to sensor nodes, and prepares the collected physiological data for wireless transmission
5. Power supply: Used for supplying the power required for sensors (these tend to be small batteries)
6. Signal conditioning: Processes, and improves the quality of the collected physiological data for digitalization

7. Analog to digital converter (ADC): Converts the analog signals into digital ones in order to enable digital processing

Personal web server (PWS):

Personal web servers are a set of technologies which enable the user to access their personal data, and information on their mobile phones through a public infrastructure. It is also defined as a gateway that connects smartphones to a wireless node using Bluetooth, Zigbee, etc. PWS is mostly used in the healthcare sector and can be set up by the medical server to be linked to a specific IP address. PWS processes the patient’s vital signs, and determines the priority of transmission for each critical symptom, and then sends this data to the medical server. Therefore, PWS determines the health status of the patient using different sensors, and provides feedback on the user interface, and the sensors themselves.

Medical server:

The medical server’s main function is the storing, processing, and analyzing of medical data. This also includes the storing, processing, and analyzing healthcare applications which provide healthcare services. Patient authentication is a vital part of the medical server. Sensors based on the IoT medical servers transmit healthcare data for testing. If any deviation is observed in the patient's health, or any causes for concerns are raised; the medical unit will be immediately notified. Due to the aforementioned processes, patient authentication, secure connections, and the effective protection of the patient’s personal data are of the utmost importance, and are thoroughly considered in all aspects of healthcare systems. For this reason, and to also provide overall security in general communication, the range of wireless communication is limited. [3]

3. The Main Challenges of Healthcare Systems

Healthcare systems in IoT connect patients, clinics, and hospitals to an integrated system - regardless of the user’s physical location - to coordinate healthcare or healthcare services. However, there are many other issues to carefully consider in research before these systems can become viable for mainstream use.

3.1. Second level heading

There are some standardization concerns about IoT. IoT manufacturers, end users, and healthcare providers all need operational standardization across all IoT fields. Standardization for IoT can become a complex issue, since IoT manufacturers have the vision to expand into as many diverse fields as possible, fields which are regulated by different agencies, and regulatory boards, and all have a different set of standardization. This becomes even more complex with the strict guidelines that exist in the medical industry. For example, in the United States of America, the standardization of wireless medical devices requires a multi-agency regulatory collaboration including: the Food and Drug Administration (FDA), the Centers for Medicare and Medicaid Services (CMS), and the Federal Communications Commission (FCC). This means companies must carefully review and evaluate all the regulations, and policies set by these three agencies. IoT healthcare systems must also operate within a complicated structure of agencies to make IoT eHealth products available to the market. These complicated regulations and standardization processes are not limited to the US. Generally, eHealth faces the same issues and complications all across the globe.

3.2. Heterogeneity

IoT healthcare applications require a wide range of contextual data which are obtained through various heterogeneous sources. Heterogeneity is generally defined in two ways:

Data heterogeneity: Multimodal sensors that are different in terms of structure, format, and function can cause data heterogeneity. These collected datasets can be inconvenient or confusing to use or share since they lack formal descriptions.

Sensor heterogeneity: The integration of multiple sensors which work in different frequencies and need different network protocols can cause problems in interoperability. In addition, combining sensors and medical devices can increase these issues. The overlap of different frequencies, and interferences in the network's range can significantly affect the system, and prevent access to important data.

3.3. Interface and user compatibility

When accessing an application, it is vital to consider other factors such as human compatibility, and the extent to which users will accept a program, and to which a particular system supports human interaction. The electronic health of IoT is highly dependent on the user compatibility and interface of front-end technology, sensors, tablets, smartphones, etc. It is important for the IoT eHealth end users to be able to be trained directly on how to use the advanced medical devices, and their various tools. Generally, the end users have little knowledge of synchronizing sensors, wireless networks, or other technical things. Therefore, it is vital that the IoT eHealth devices made for remote access be designed as self-sufficiently and simply as possible. For example, one of the largest IoT eHealth end users are senior citizens so the interface must be user friendly, and require minimal professional assistance. Participatory design can help the human compatibility of the interface via encouraging the end users to engage with the design team, and communicating their user experience so the ease of use, likes, dislikes, and comfort levels in interaction can be devised.

3.4. Scalability

The smaller-scale IoT requires portable devices that contain data-collecting sensors and centralized servers to process user requests, and to ensure all medical services are accessible to users through personal devices such as smartphones. Expanding this process to the entire hospital can ensure all patients will have access to medical services, receive status updates, and benefit from continuous monitoring. The IoT can be upscaled to encompass the entire city, given that the city’s antennas and sensors have a data collection capability. Big data intelligence, algorithms and Application Programming Interfaces (APIs) can be used to process data, and evaluate user requests; and smart interfaces can also show users their request status being processed in real-time. A smart city based on e-Health can collect and process all data through smartphones, and mobile applications, and furthermore; send feedback to patients about their healthstatus, enabling everyone to have access to test results, and integrated medical services. IoMT allows users a more straightforward access to their medical records, and test results which cuts out patient waiting-times significantly, and is therefore more time-effective for users. Upscaling a small IoT network to the entire city can potentially improve overall efficiency, support relationship building between organizations, and promote trust between medical professionals, and patients.

3.5. Power consumption

Another important factor to consider for IoT is power consumption. The limited battery life of the sensors can negatively affect the lifecycle of the devices. Charging, or changing the batteries in IoT devices are extremely complicated, and often have little effect, especially if a system uses multiple sensors. The battery life of an IoT device will depend on varying factors such as the transmission range, the communication channel usage, overall time of use, and the complexity level of signal and data processing.

3.6. Disadvantages

Some IoT e-Health applications require the patient to constantly wear the sensors or carry them around, which can become tedious and inconvenient to the user. Thus, more efforts must be made in order not to decrease the quality of life for the subject, or cause unnecessary inconveniences to their daily routines.

4. Other Studies

Many scientists and researchers are working in the field, considering the importance of the healthcare systems and their application in IoMT. Therefore, the rest of this section will focus on reviewing some of these studies.

Azadeh Zamanifar, and her colleagues have introduced a system for IoT applications called DSHMP-IoT, whose function is the tracking of IP-based sensors - in smartphones - and their direction of movement in a multi-user environment such as a healthcare system. [5] This was the first time that an AI solution was used for tracking the direction of mobile nodes in an IP-based phone network. This design uses a Hidden semi-Markov Model (HSMM) to predict and track direction with high accuracy and low overhead. They also proposed a method to predict the ECG sensor data, and in addition, the patient's health status which would not require a joint analysis. [6] This method uses mobile sensors, and a HSMM to predict a patient's overall health status and has two prediction outputs.

They also introduced a design named DMP-IoT, which predicts the new distributed direction of mobile sensor nodes in healthcare applications to reduce the operation costs of the mobile sensor nodes. They have customized the Hidden-Markov second-order to achieve this. DMP-IoT includes a detection mechanism that identifies incorrect predictions, and avoids disconnecting the sensor nodes from the network in cases of false movement prediction. This mechanism prevents misprediction and losing the network connection. Zamanifar also emphasizes the importance of IoMT in predicting patient health status in a chapter of her co-authored book titled: "Remote Patient Monitoring: Health Status Detection and Prediction in IoT-Based Health Care, in IoT in Healthcare and Ambient Assisted Living." [8] They have used cloud computing and mobile edge computing to communicate between different Healthcare subsystems. Mobile edge computing is a distributed computing paradigm that moves computing and data storage to optimized positions in order to improve response time, and save bandwidth. Healthcare systems based on mobile edge computing are more effective since their computing is done near the patient. Thus, the patient's health status predictions are done in real-time, which is a vital function to have in healthcare systems. The same chapter presents IoT-based healthcare devices and methods which are used to identify or predict a patient's health status.

In their book"A new machine learning-based healthcare monitoring model for student's condition diagnosis in Internet of Things environment," Alireza Souri and his colleagues present an IoT-based student health care system that continuously monitors students via their vital signs to detect physiological and behavioral changes through IoMT devices. In this method, vital signs are collected through IoT devices and analyzed with Machine learning methods to detect possible risks or changes in the students' physiology, or behaviors.

Khizra Saleem and her colleagues have invented a system to monitor and analyze sleep patterns using environmental parameters in their book titled:"IoT healthcare: design of smart and cost-effective sleep quality monitoring system." The proposed system is effective enough to monitor the patient's sleep patterns using Commercial Off the Shelf (COS) sensors, and to furthermore; predict the results using the random forest model. The patient's physiological data including physical body movement, heart rate, SPO2 level (oxygen saturation level in the blood), and snoring patterns are monitored through this system, and the collected data can be sent to computer systems. This real-time system is made of two parts. One part consists of the behavioral data analysis collected through random forest and decision-rules in real-time. This system notifies the caregiver in cases of any changes to the sleeping participant's status. The second part enables batch data processing which establishes the condition of the patient at a given period of time through statistical methods. This cost-effective suggested method can easily analyze the sleep pattern of a patient and provide better treatments.

In their study "Iot based patient monitoring and diagnostic prediction tool using ensemble classifier. in 2017 International conference on advances in computing, communications and informatics," Aitor Moreno-Fernandez-de-Leceta suggested a monitoring system for stroke patients to alert physicians and caregivers for minimizing future risk factors. Decision-making based on real-time data analysis helps the doctor in systematic diagnostics, and more efficient treatment of ailments. In the article, a combination of classifications are used to predict the patient's health status and prevent future strokes.

Sahoo, and Mahapatra have presented a mechanism for probabilistic data collections, and analyzing the correlation between said data in their “Analyzing healthcare big data with prediction for future health condition.” study. Large volumes of multi-structured patient data has been generated from medical reports, physician notes, and wearable body sensors. The analysis of these healthcare parameters, and predicting patient’s health status are still largely in the development stage. A cloud-enabled big data analytics platform is the ideal way to analyze the structured and unstructured data generated in the healthcare systems. Finally, a stochastic prediction model is designed to predict the patient’s health status based on the patient’s current condition.

Table 1
Table compares the above mentioned methods

Author	Source	Method & function	Advantage	Disadvantage
Zamanifar	[6]	HMMS	Predicts patient’s health status Prediction of ECG data sensor	Does not consider patient’s movement Does not determine health in the movement between states
De-Leceta	[11]	Identifying abnormal situations at home	Monitoring elderly patient’s lives Only tracks relevant signals Reduction of raw data Understands the patient’s normal status	Does not predict patient health status
Souri	[9]	Monitoring student health	Monitors student’s health status Identifies antisocial behavior	Does not predict student’s health status in the future
Ani R	[12]	Monitoring stroke patients	Alerts the physicians and caregivers Notes the dangerous changes in patient’s health status	Only predicts for patients who have already suffered a stroke
Sahoo	[13]	Mechanism for probabilistic data collection	Predicts patient’s future health status Analysis of health care system’s parameters	Does not consider patient movement
Saleem	[10]	Monitoring and analyzing sleep patterns	Analysis of sleep patterns Identifying issues during sleep Preventing sleep disruption	Does not predict patient’s physical movement pattern

5. Conclusions

In a rapidly evolving world, if not for all, for most people, remotely accessible, interconnected devices which can analyze data have become necessary. To meet this demand, IoT has been created. IoT is a tool for connecting various devices to the internet. This is how smart watches, smart lights, etc, become “smart.” The Internet of Things makes people more independent, and increases users’ willingness to participate, interact, and collaborate with technological devices. IoT is used in various fields such as agriculture, home automatization, traffic control, delivery management, water supply management, navy management, energy saving, etc. Wearable sensor technology, with the help of IoT has become a lucrative market in the healthcare sector. As IoT expands into the medical sector, we require more detection gateway in order to manage data easier. The ultimate goal of this new technology is to embed IoT in emergency services, smart hospitals, and smart homes, etc. The data that we collect through smart devices, and smart hospitals, can help the monitoring of patients in real time. This can help us learn more about diseases, medicines, and vaccines. Healthcare systems are a huge part of the IoT applications. The large data collections in these systems need to be extracted so they can be analyzed for the information hidden in them. An important function of IoMT is its precise prediction of a patient's health status remotely, especially in intensive care. Various health applications are increasingly including predictions of patient movement, and health status changes in their interfaces; and due to the IoMT's significant contribution to disease study, and gathering intelligence about the physical environment of the patient, pervasive systems, and assistive technologies, it has become an outstanding field of research.

An overview of healthcare systems in the Internet of Things was done in this article and the many challenges, and benefits of the field were examined. Also several methods in predicting patient health's conditions using machine learning were analyzed.

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