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# A Review of IoT-Based Wearable Sensor Systems for Healthcare Monitoring

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**Abstract:** Many sectors have benefited greatly from the Internet of Things (IoT) during the last few decades. More individuals now have access to healthcare thanks to recent developments in the field, which has in turn improved the health of those receiving it. In the future, wearable sensors and IoT will be effortlessly integrated into healthcare. The numerous IoT topologies, diverse techniques of data processing, transport, and computing paradigms are thoroughly discussed in this paper. An overview of several IoT-assisted wearable sensor systems is provided, together with information on their numerous uses in healthcare and the benefits they provide for society as a whole. Additionally, a comparison of all healthcare wearable technologies is presented using data from numerous research and development projects. It also discusses the specific issues that need to be addressed in order to optimize these systems for healthcare and the various future implementations of architecture and technology that can be made in order to improve the healthcare industry, as well as the common problems that IoT-assisted wearable sensor systems face.

**Keywords:** Internet of Things; healthcare; sensors; wearable devices; cloud systems; healthcare monitoring; data processing.

## 1. Introduction

Most, if not all, technologies must now be networked, available from a distance, and able to be analyzed in order to keep up with the rapid pace of change. We were able to do this because to the Internet of Things. Smart watches, smart lights, and other connected gadgets are examples of the Internet of Things (IoT). The Internet of Objects (IoT) allows people to be more autonomous in their ability to engage with, contribute to, and cooperate with things [1-2]. Agriculture, home automation, traffic management, delivery management, water supply management, fleet management, smart grid, and energy conservation are just a few of the industries that have benefited from the Internet of Things.

Using IoT-enabled wearable sensor devices in healthcare is a growing and flourishing industry. As the healthcare industry grows, we need to be able to diagnose patients at their homes, monitor and govern their data, and do it in a timely manner. As a result, IoT will be used in everything from emergency services to smart homes to electronic health records [3-4]. Patients' symptoms may be tracked in real time using the data collected by smart gadgets and a smart hospital.

Research into healthcare, medicine, pharmaceuticals, and vaccinations can be aided by this. Cloud computing, fog computing, and other forms of distributed computing will be used to make data more safe and available to the appropriate parties.

For a smooth data transfer, many wireless technologies and communication protocols are examined. Additionally, data analytics may be utilized to further examine the information contained inside it. WSNs are sensor networks that communicate wirelessly using a variety of protocols. Deep learning algorithms and WSNs used to assess and strengthen IoT in healthcare are compared in this review [5,6]. Digital records of a patient's paper chart are stored in an electronic health record (EHR). To build a smart hospital, body sensors, ingestion sensors, electronic health records (EHRs), emergency services and remote monitoring are used [6,7]. Various communication protocols can be used to link this to the cloud [8,9]. It is necessary to have wearable sensors and a variety of healthcare monitoring devices in order to set up and maintain a WSN. We can accomplish smart healthcare by integrating all of these factors.

In this work, our goal is to review of IoT-Based Wearable Sensor Systems for Healthcare Monitoring. Therefore, we will review the articles that presented in this field. In this article, the applications of wearable sensor systems based on the Internet of Things for healthcare monitoring are presented in section 2. In section 3, an overview of Wearable Sensors has been presented. Also in Section 4 Open Problem and Future Opportunities is described. In addition, Section 5 is related to Discussion and Section 6 is conclusion of this work.

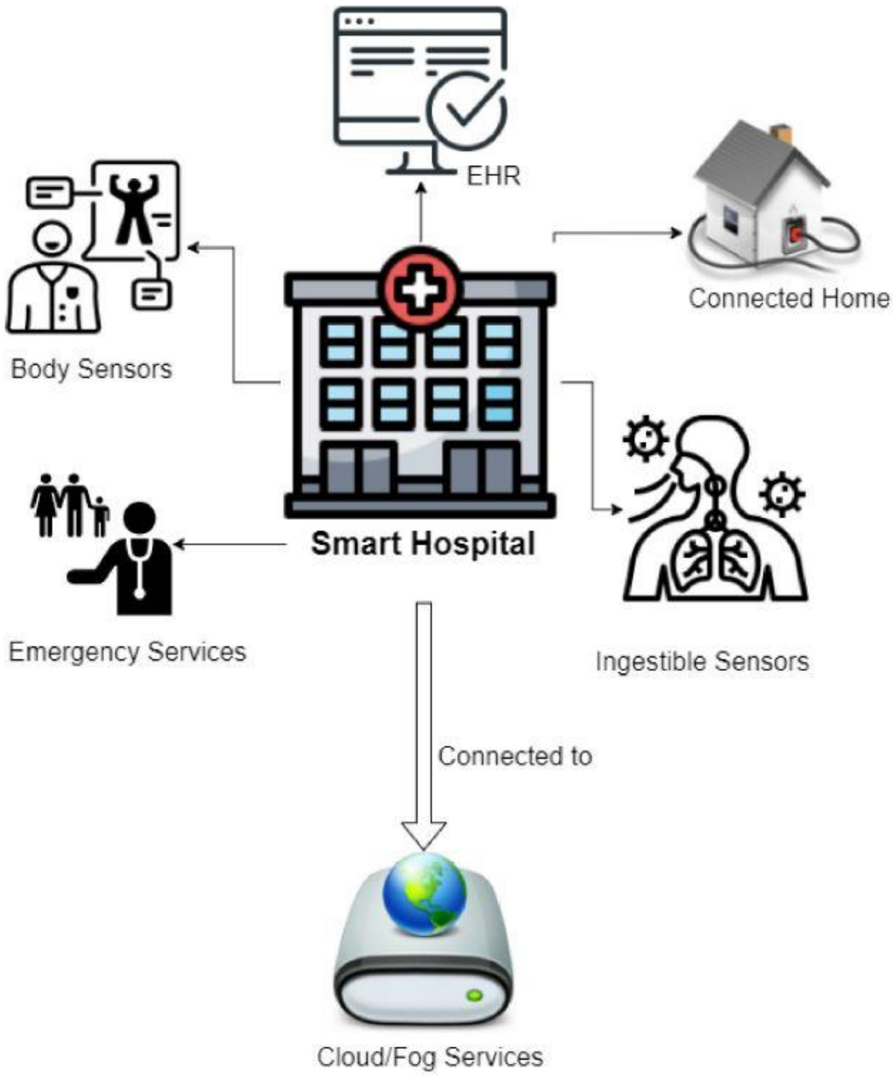


**Figure 1. An outlook of IoT-assisted hospitals for healthcare monitoring.**

## 2. Applications—IoT-Assisted Wearable Sensors for Healthcare Monitoring

Wearables aided by the Internet of Things (IoT) are becoming increasingly popular. In all disciplines, the usability of such gadgets has led to a huge increase in their use. A wide range of industries can benefit from IoT technology, including healthcare. In order to provide data for monitoring and analysis, a variety of technologies are coupled to current technology. Wearable sensors may be used in a variety of ways. A good example of this is a fitness tracker that is available from a variety of manufacturers. The main purpose of the device is to track a person's pulse, movements, and other vital signs while utilizing GPS and an accelerometer to determine what kind of activity they are engaging in. The program can figure out how many calories they've burned, how many altitudes they've visited, how many flights of stairs they've climbed, and much more based on their height, weight, and age.

These trackers provide a wide range of customized services. To combat the present epidemic, some have proposed assessing the blood's SpO2 concentration. In addition, the results are very accurate in and of themselves. Using a few simple changes to the wearables' design, they're capable of capturing the vitals of patients, and thanks to Wi-Fi and other networking technology, they can also be cloud-based. Papers and research articles have been the subject of our investigation. Figure 2 illustrates how these wearables can be used for IoT-enabled applications.

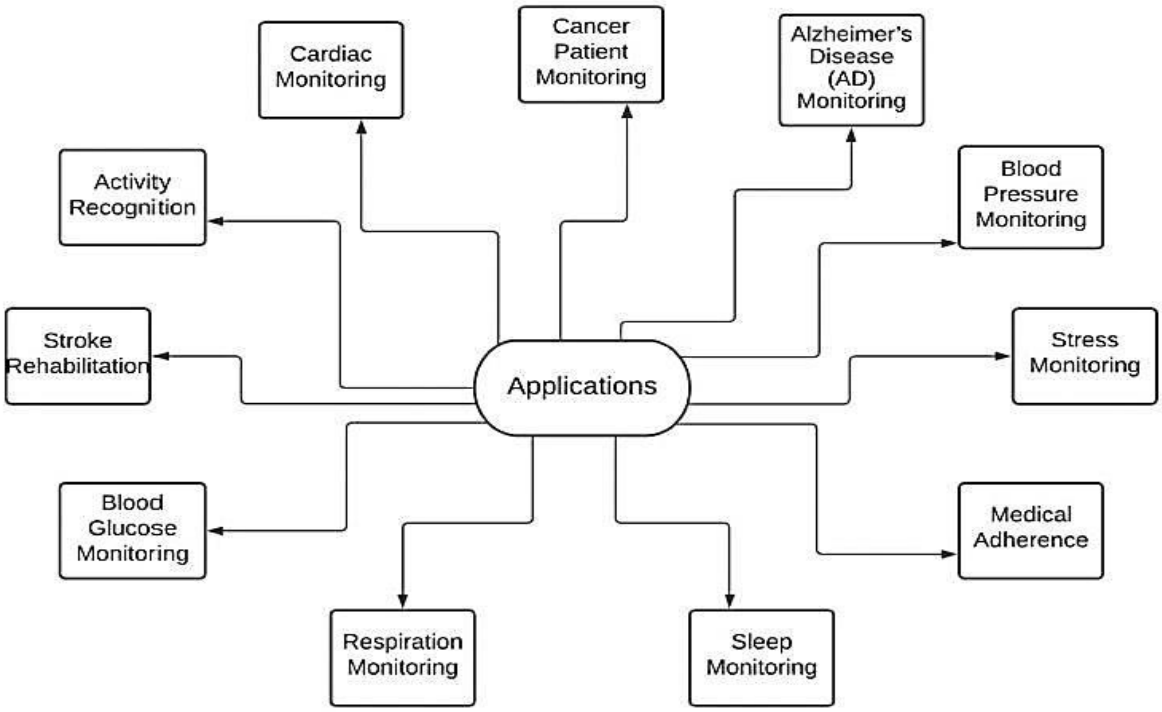


**Figure 2. Application of IoT-assisted wearable sensor systems in healthcare.**

### *2.1. Activity Recognition*

This is one of the most common uses of wearable medical devices nowadays. It is a common feature in most fitness trackers. Fitness trackers are now the most popular wearables for monitoring a person's physical activity. In most cases, the sensor uses a 3D accelerometer to determine acceleration, although there is a lot of guesswork going on behind the scenes. Furthermore, the wearable computers are able to tell if the user is walking, jogging, or sleeping because of this calculated guesswork. It is also possible to track the number of flights a person makes thanks to a built-in sensor that measures the height above sea level. The wearables' activity recognition approach is depicted in Figure 3.

The tracker runs and syncs its values through a mobile application. For the most part, these apps need the user's height, weight, age, gender, and other personal information when they are first installed on a smartphone. These data are essential for computing the steps and distinguishing between the tasks they are undertaking. They also utilize their data to train the program to anticipate the movements, activities and height and weight and BMI of the user, as well.

By combining numerous sensor nodes in the wearable sensor systems, a new approach for identifying human everyday activities is presented in the work [10]. This method's technique is as follows: For real-time activity recognition, features are extracted from each sensor node and then reduced in dimension by generalized discriminant analysis (GDA). Then, the reduced features are classified with multiclass relevance vector machines (RVM). Finally, the individual classification results are fused at the decision level, taking into consideration that the different sensor nodes can provide heterogeneous and complementary information.

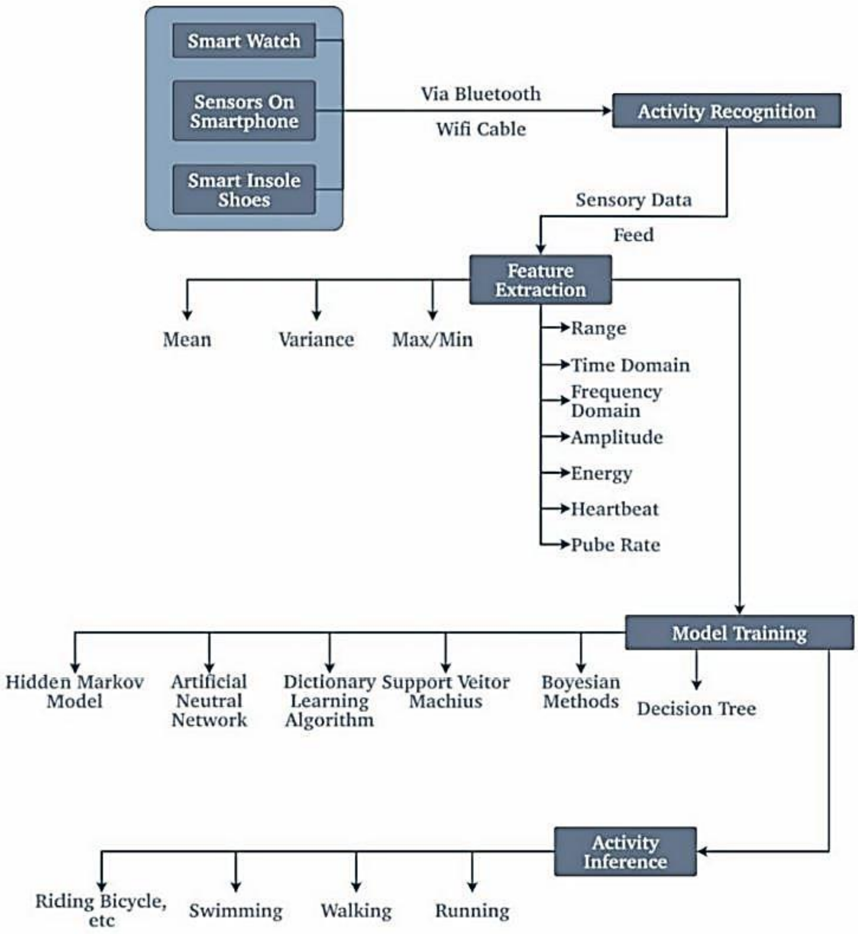


**Figure 3. A brief overview of activity recognition methodology.**

### *2.2. Stroke Rehabilitation*

If a good management system is not in place, heart disease is extremely difficult to treat. The WSN has been utilized by Uttara Gogate et al. for cardiac patients. Heart disease is more common in the elderly, according to research [11-13]. There is no guarantee that they will get better at any given time. This encompasses circumstances that are time-sensitive and life-threatening. This device may be utilized as a real-time monitoring system for cardiac patients because of the WSN technology. There are several medical-grade sensors and equipment in this WSN that can monitor vital signs such as blood pressure and pulse rate while also maintaining a real-time electrocardiogram (ECG) for the benefit of critically ill patients.

Care and monitoring during a patient's postcardiac arrest are likewise carried out using the aforementioned method. Post-cardiac arrest patients are extremely fragile, and the method outlined previously would be quite beneficial in this case.

Strokes other than cardiac arrest can affect the body's motor controls so severely that the brain virtually forgets to transmit electrical impulses to regulate the movement of the hands and legs, for example. Such tactics have been countered by a developing technology that incorporates the Internet of Things (IoT). The IMUs are specialized defense units created exclusively to confront such a threat. Their research on this subject is extensive. Correcting a user's bodily motions is accomplished by the IMU. In order to get reliable data, these IMUs construct a network of sensors throughout the body. Figure 4 depicts how an algorithm used in rehabilitation to regain motor control functions.

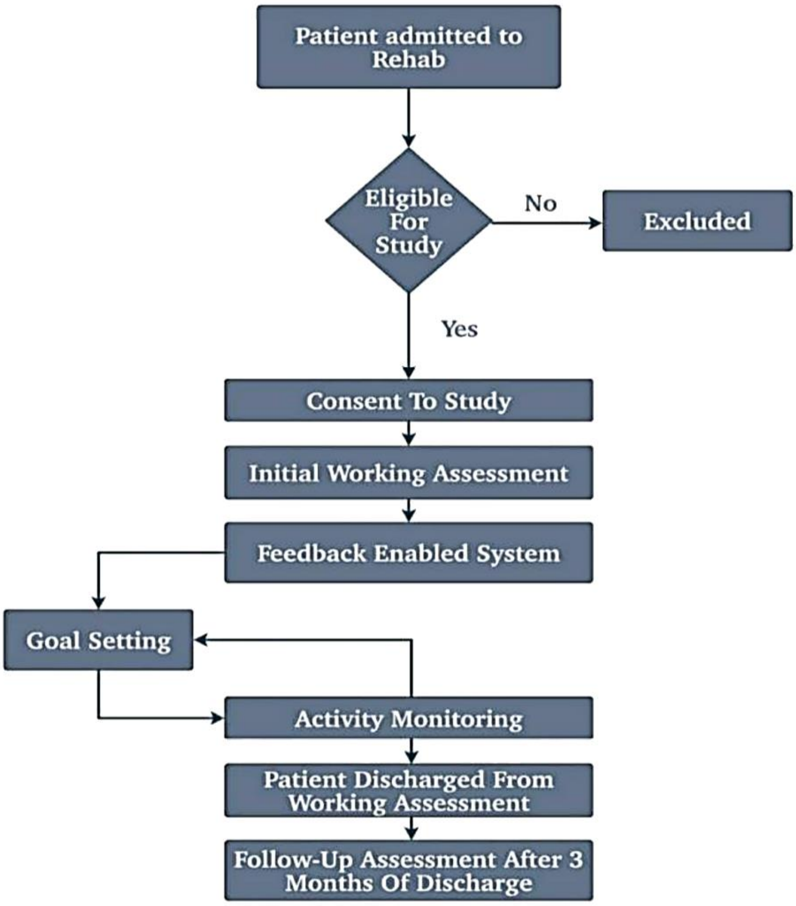


**Figure 4. The algorithm used for stroke rehabilitation (recovery of motor controls).**

### *2.3. Blood Glucose Monitoring*

The precision of glucose monitoring in the blood has risen enormously as a result of the development made possible by these IoT devices for diabetic patients. Monitoring a diabetic patient's vitals in this way can save a life [14]. [14] IOMT refers for the Internet of Medical Things. This is the IOT for the medical profession. The IOMT diabetic-based WBSN monitoring system comprises of the heart rate sensor, blood glucose monitoring, endoscopic capsules, and other sensors that interact via IoT. The suggested system incorporated medical-grade sensors and technology, making it more dependable than the other IoT-based comparable system since it was robust, versatile, and cost-effective. Glucose monitoring has been addressed in a number of additional contexts [6]. They created a healthcare monitoring system that focuses on monitoring vitals such as blood glucose. Using a body area network, mobile app, or web-based UI, Figure 5 shows a comparable system that notifies the patient about the issue by sending data to the smart watch and the appropriate clinicians.

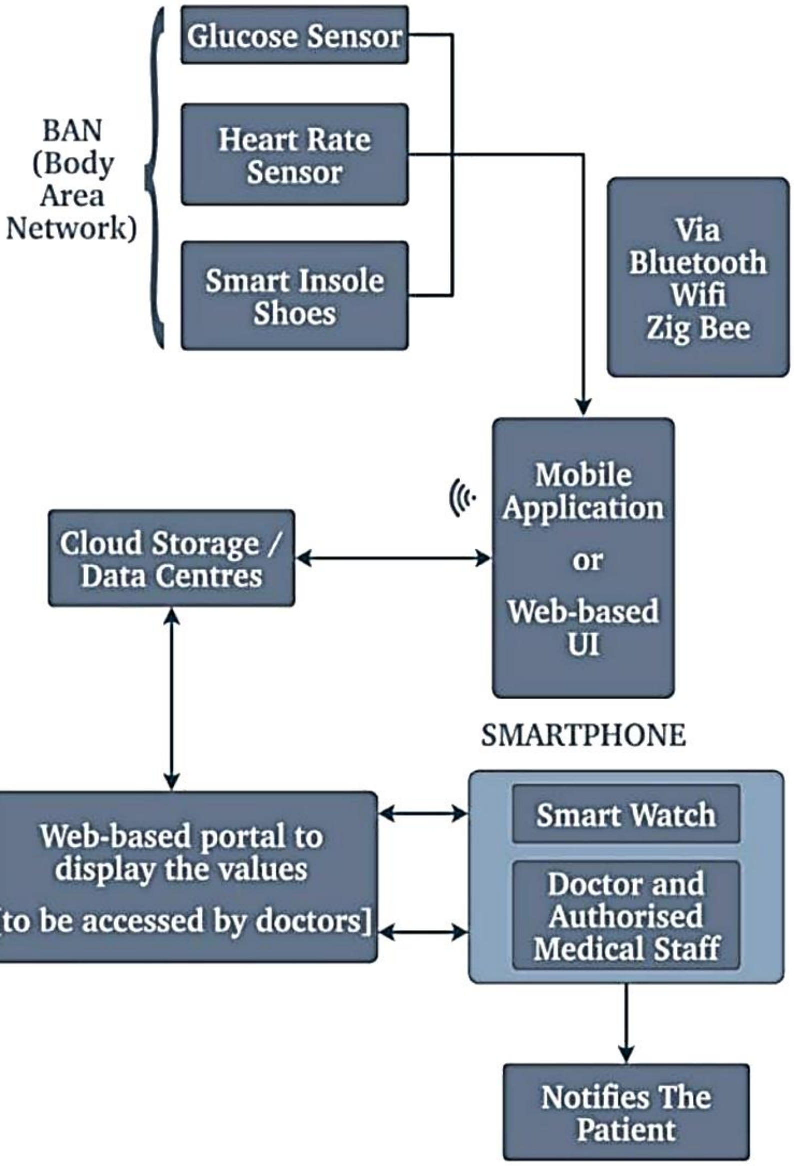


**Figure 5. Blood glucose monitoring methodology.**

Additionally, it serially transmits it to the cloud through a network using a Esp8266 WIFI module. Blood glucose (BG), blood pressure (BP), temperature (BT), and heartbeat (HB) rate are all constantly monitored by the CPS. They outline a foundation for CPS [15]. A single, dependable, and well-organized cloud data storage system should be the foundation of any data storage strategy (OCDA). Electromyography (EMG) is a technique for detecting imbalances and shifts in neuromuscular communication. The LCD displays all of the information. [16] Sweat gland activity is monitored with a GSR sensor, while blood glucose levels are monitored with an INA219 sensor. Electroencephalography (EEG) is a technique that employs an EEG sensor to monitor brain activity. Finally, the blood pressure and body temperature were measured using an MPXV5050GP sensor and an LM35 integrated circuit.

[17] A wide range of choices are available to suit a wide range of budgets and preferences. Optics, non-optics, intermittent, and continuous are all types of noninvasive methods. Non-invasive surveillance devices are also compared in this article. A variety of elements, including cost, time efficiency and convenience are considered in the evaluation of these solutions. A large number of users are calling for more research into recalibration, time, and energy saving. Artificial intelligence (AI) has been widely used by researchers to tackle these problems. Future AI-based estimation and decision models preserve their affordability, mobility, and efficiency. Connecting users with available solutions (hardware & software).

### 2.4. Cardiac Monitoring

Cardiac patients require a reliable health monitoring system that monitors all vitals and warns the appropriate authorities in the event of an emergency. The WSN has been used by Uttara Gogate et al. for cardiac patients [11]. This encompasses circumstances that are time-sensitive and life-threatening. The WSN system is utilized as a real-time monitoring device for cardiac patients who require constant monitoring. The WSN comprises medical-grade sensors and technology that can monitor the heartbeat, pulse rate, body temperature, and blood pressure, and for the most important cases, a real-time ECG is maintained so that the patient may be followed constantly. Additionally, the data is transferred to the cloud and can be viewed by the physicians, thus the bodily parameters are stored and exhibited sequentially. An alarm message is provided to the carers if an aberrant reading occurs. National Instruments (NI) LabVIEW hardware, identified as the myRIO 1900, has been utilized by Uma Arun et al. The ECG sensor may be connected to this NI my RIO, and the sensor output can be obtained using NI LabVIEW and the my RIO. People with long-term heart conditions are the primary beneficiaries of this system [18]. The LabVIEW program receives the data from the vernier EKG sensor, which detects any potential discrepancies. The program deciphers the text and displays it visually on the screen. In addition, the publication provides a thorough schematic of the LabVIEW software that may be used to make such a system work.

Based on Internet of Things (IOT) technology, the system is most suited to those with chronic heart illness. Following are some of its most important features:

a) getting info from the body's sensors;

b) using a smartphone to check one's health;

c) ZigBee and Bluetooth technologies are used to communicate physiological data to smartphones via a body sensor network and a wireless body area network.

There are a number of systems that recommend using an Arduino Uno with an LM35 body temperature sensor, a DHT11 humidity and temperature sensor, an AD8232 ECG sensor, and an ADXL335 body position sensor. The algorithm is laid down in ten phases, with a detailed description [11]. Pushbutton display, sensors, and Arduino Uno all make up the slave circuit. The Arduino IDE application for writing the slave circuit's code in embedded C is also included. The R-pi, WIFI module, and Bluetooth module are all part of the main circuit. Python is used to write the master code.

### 2.5. Respiration Monitoring

The human body's respiratory system may be monitored in a variety of ways. Sensors that track respiratory motions were employed by certain writers. Bioimpedance sensors come in beneficial for a variety of applications [19]. In addition to sending a little quantity of energy into the skin, this sensor also calculates the heart rate and respiratory movement on a crude scale. The MCU receives analog signals via a customized breathing sensor [21]. The sensor is affixed to the patient's abdomen. That medical-grade sensors must be used to connect the wearables to the belly if they are to accurately detect respiration.

There is a wearable device for continuous monitoring of the respiratory signal and its accompanying algorithm for signal assessments in the publication [22]. In order to construct the gadget, the company used a wireless body sensor network architecture and a validated respiratory inductive plethysmograph (RIP). It was possible to wear the textile RIP sensor around the chest or the belly to monitor breathing as you slept. The dynamic respiration rate was extracted using a sophisticated signal processing method.

### 2.6. Sleep Monitoring

This sleep tracking software helps the user adjust their sleep pattern and maintain a healthy life cycle. Different sensors are employed here. Sleep quality may be inferred from the data gathered by some wearables, such as heart rate, pulse, $SpO_2$, and breathing patterns.

Because they're multipurpose, these devices can tell whether or not a user is sleeping using the GPS, three-axis accelerometer, and altimeter. Also because of these advantages, individuals now use fitness bands on a daily basis, making them an essential part of their life.

IoT gateways are intermediary hubs between the physical layer (sensor nodes) and the server to provide effective real-time communication between the user and the medic [23]. While sleeping, people are being tracked. It demonstrates that the user is snoozing in normal conditions (see ambient parameters). There were a few noise spikes in the findings, but they quickly faded away and did not cause any significant interference. Data on heart rate, breathing rate, skin temperature, and level of sleep is shown and examined. Figure 6 depicts the WSN-based sleep monitoring system previously described.

Based on portability and interoperability ideas, a wristwatch and smartphone are integrated to develop a sleep monitoring system in this work [24]. This method combines data from the smartwatch's heart rate monitor, accelerometer, and sound sensor into a single display. The first results show that the suggested sleep monitoring system is viable and appropriate. An API for data interchange between wristwatch and smartphone has already been implemented in this system's architecture, notwithstanding its early state. To expand and supplement the proposed system, new algorithms for signal processing are needed, including the construction of multiple snoring and motion classifiers, as well as sleep detection classifiers [24].

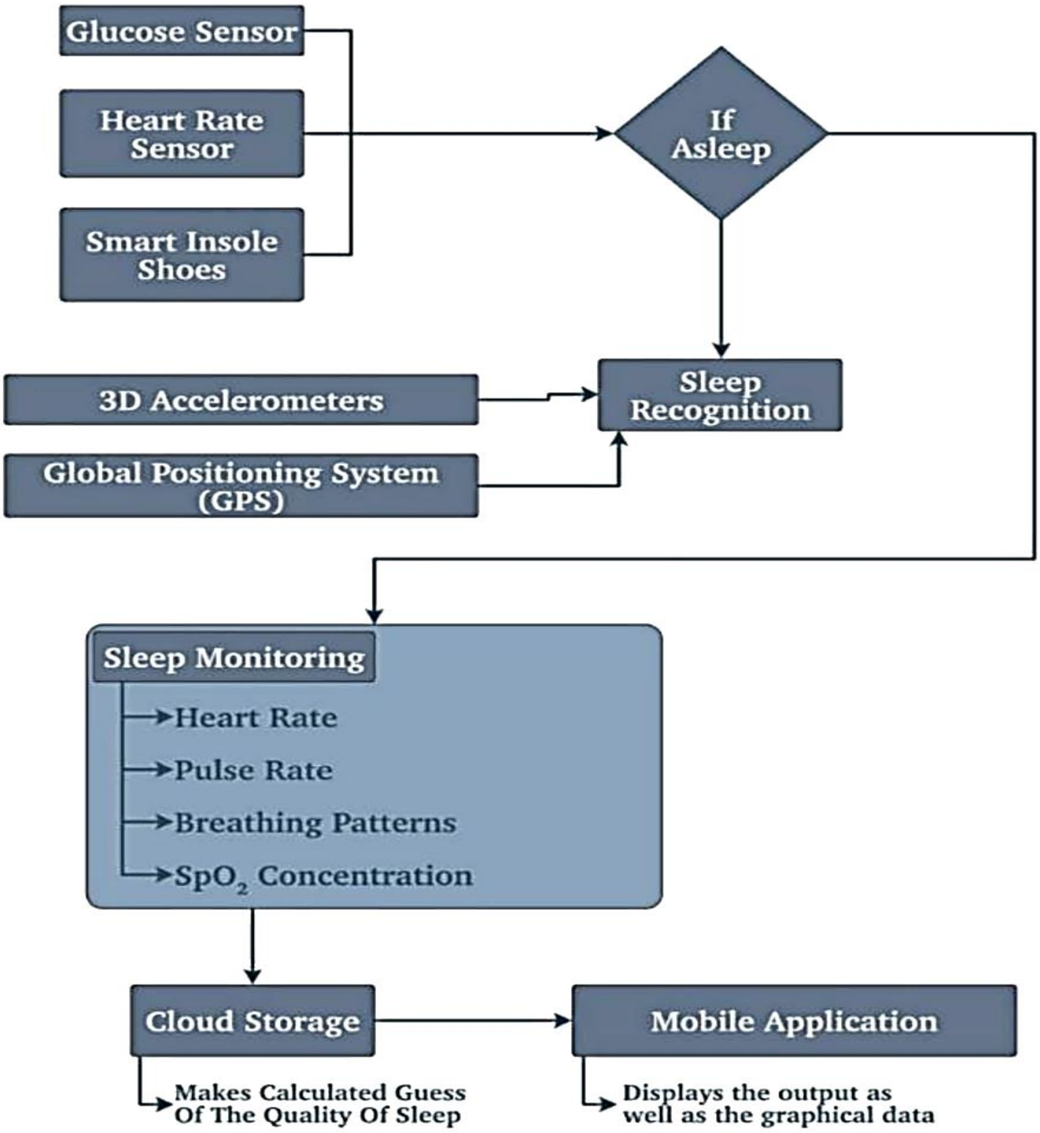


**Figure 6. Sleep monitoring in real-time using WSN.**

### *2.7. Blood Pressure Monitoring*

Because of the prevalence of high blood pressure, nearly every fifth person on the planet has a minor BP issue. The healthcare division is likewise serious about it. Signs of numerous bodily processes are indicated by a rise in blood pressure (BP). A patient's physical and mental well-being is stimulated by this increase in BP. A person's blood pressure (BP) varies when he or she is sad, so it's important to keep tabs on that number whenever possible.

There are a variety of methods for determining the BP. Most doctors use a sphygmomanometer to measure the patient's blood pressure. In addition, the heart rate monitoring system is used to calculate this for wearables. The wearables employ a sophisticated algorithm to predict the user's approximate BP based on the pulse wave analysis of the pulse oximeter reading. All relevant aspects, such as age, weight, and prior data, are taken into account. Because heart disease is more common in the elderly, anyone's health can change at any time. [11] This encompasses crucial and urgent circumstances. The WSN system may be able to provide a continuous monitoring system for heart patients. Monitoring the heartbeat, pulse rate, body temperature, and blood pressure is possible using the WSN system's medical-grade sensors, and a real-time ECG is maintained for critical patients utilizing these sensors. They've been working on a way to keep track of pregnant women's health data. In their model, blood pressure, temperature, beat of heart and motions of teeth would be analyzed [26].

The ultrasonic sensor would allow for the most precise tissue distinction (medical grade). It is possible to see and monitor the soft tissue in real time with this ultrasound. Proposals have been made to utilize an R-Pi as the central CPU, and they plan to employ sensors to assess temperature and blood pressure, respectively. Using the ECG and heartbeat sensors, the patient's vital signs are recorded [44]. The sensor data is transferred to the R-PI module for additional analysis via interfaces with all of the sensors. As a result, the R-pi saves the data locally and sends it to the cloud for further processing. The data is shown using programs such as MATLAB and LabVIEW. The GSM module sends an alarm message to the jail in charge if the readings are not what is expected.

There are several applications for wearable blood pressure monitors, including mental health evaluations and other tests. The usage of BP values in this field has shown to be far more favorable. It doesn't matter if you're using an intelligent health monitoring system [23] or a portable system [16]. Similar to the preceding blood pressure monitoring device, Figure 7 depicts a similar viewpoint.

Wireless wearable and ambient sensors work together to monitor a person's vital indicators including heart rate and blood pressure while they are engaged in normal everyday activities, as described in this research [25]. In order to give an accurate analysis of the incoming data, the wearable sensors require a high sampling rate and time synchronization. The user's presence is detected by the environmental sensors, which activate synchronization. Real-time sensing and time synchronization are made possible through the usage of Bluetooth and IEEE 802.15.4 wireless technologies. Consequently, the sensor response of this wearable health-monitoring sensor depends on the situation in which it is employed. For example, the system gives information about the user's position and vital indicators while the wearable sensors effectively monitor vital signs with a one-millisecond resolution [25].

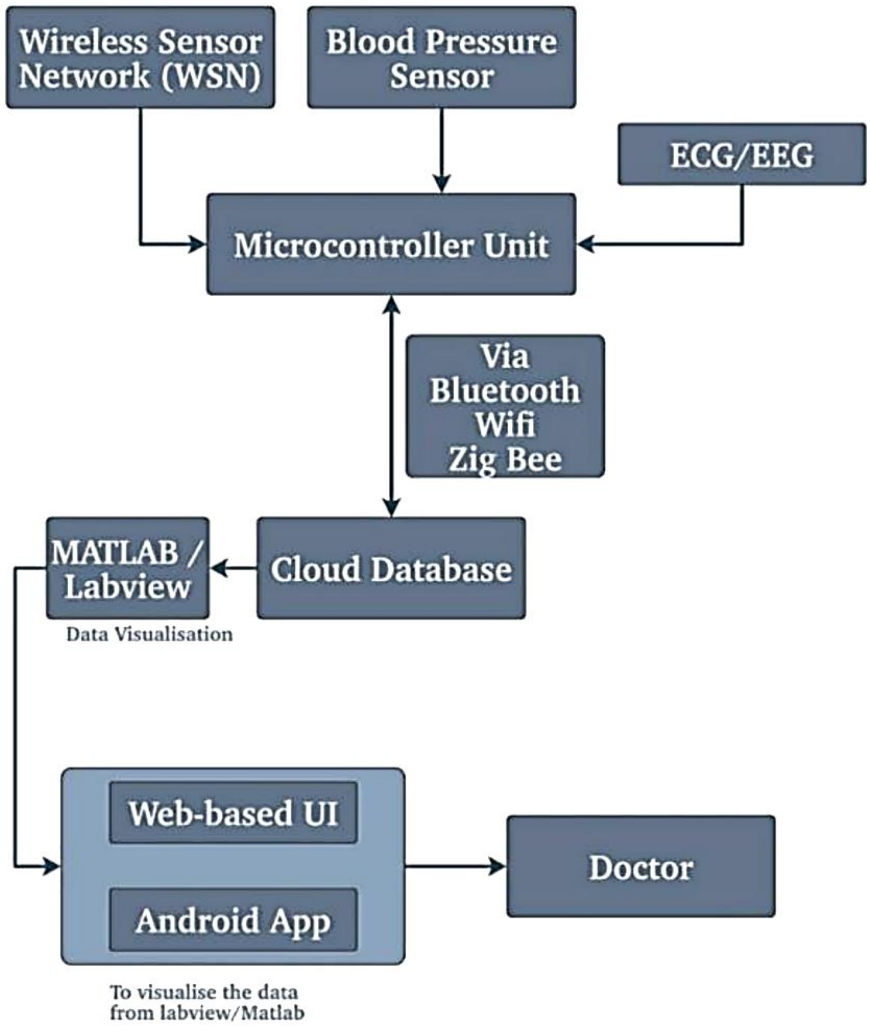


**Figure 7. Blood pressure monitoring system.**

### *2.8. Stress Monitoring*

In order to assess stress, vital signs are taken and compared to those taken during rest. This is an evident symptom of tension, and the wearables that a person is wearing monitor and warn them to keep it slow whenever their blood pressure or insulin levels dip or there's sudden unease in breathing. The alerts can be as simple as a gentle reminder to drink water or as complex as a reassuring message that lets the user know they are not alone for a brief period of time. As part of stress monitoring, the sweat glands also play a role. Additionally, tiny changes in bodily fluids, such as sweating, indicate that a person is under emotional stress. The true level of stress may usually be determined by the use of the TSST (Trier social stress test). The wearables can't utilize this method, but it's reliable.

An HRV index, breathing patterns, and heartbeat tracking may all be used in a stress monitoring system depicted in Figure 8. Variability in heartbeat patterns is measured by HRV, which is a term for heart rate variability (HRV).

Technology that may be worn on the body can help us understand how physical and psychological stresses are linked. In system design, it is important to strike a balance between information content and wearability. Psychological stress is well-correlated with selected physiological features measured by the wearable sensor. Integrating data from breathing power and heart rate fluctuations, the autonomic nervous system balance is assessed. Mental tension and relaxation are the two physiological psychological situations in which our approach of dual discrimination works best.

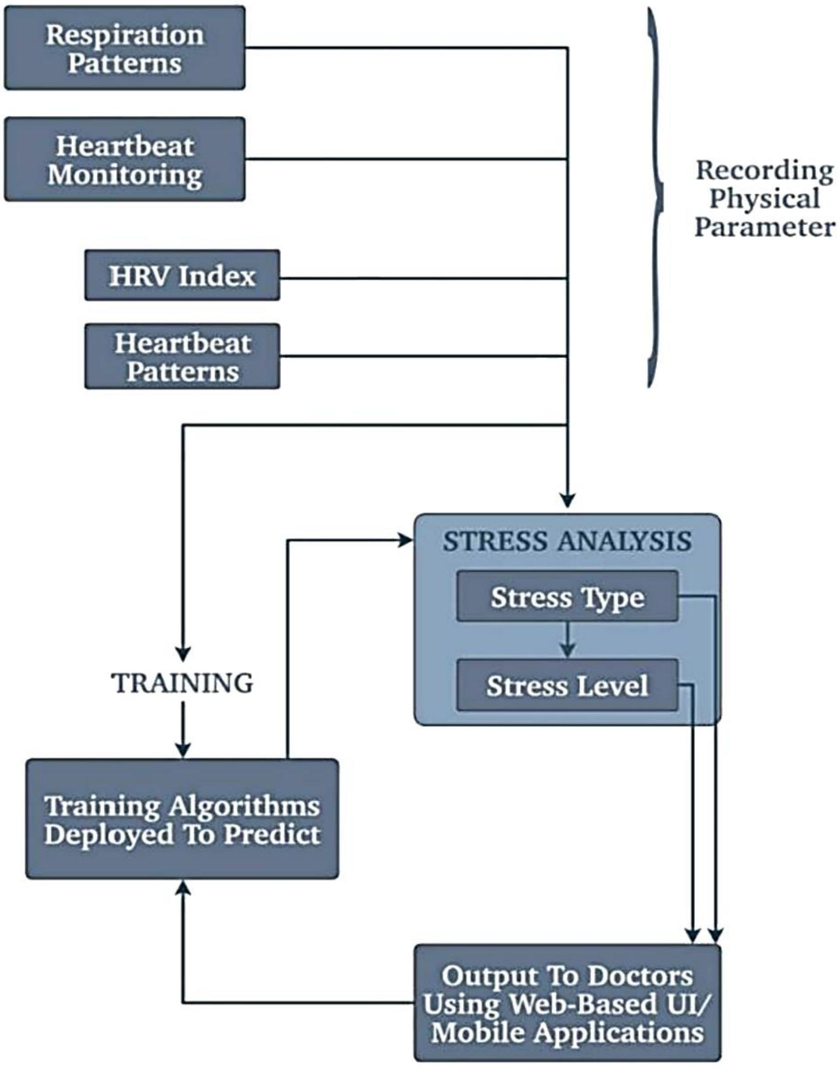


**Figure 8. Stress monitoring system.**

### *2.9. Medical Adherence*

In healthcare, medical adherence is an important application. If a patient refuses to take the medication provided by their doctor or follow the advise offered by the doctor, treating them is pointless. Even if they wanted to, it would be impossible to treat these patients in the future. This software comes in helpful in situations like this. In this regard, e-health [9] is one approach and concept that has been presented. Following an examination of the patient, electronic health systems are able to dispense the necessary medication.

In addition, the Internet of Things (IoT) is the foundation of these e-health systems, and a doctor or other qualified staff member can be assigned to oversee the system. These less critical patients may be taken care of by a system that can manage them, so the doctor has more time to focus on the more vital patients where he/she has a role to play. This method also makes it possible to do patient diagnostics through the internet. The e-healthcare monitoring system, denoted as EHMS [29], is illustrated. To monitor and operate the health monitoring system, the EHMS system was built. Monitored vitals include the ECG, the heart rate and SpO2 concentrations of the patients.

In rural locations, it focuses on a low-cost health monitoring system. Systems that gather data remotely utilizing wireless sensors, inquiries and telephone connections were discussed. Devices that can capture data such as photographs of body parts at a given sampling rate, depending on the patient, are part of the technique presented. It is also possible to use it offline. It makes use of digital-to-analog conversion (advantage: single channel for all sensors). Upload data when you have access to a reliable connection, rather than relying on the local storage. It allows users to log in securely. Logging in requires a visit to a default login screen. For each user, the website generates a unique reference ID. An alphabetical list of patients and sensor data are displayed in the doctor's interface [30, 31].

This e-health system is being used by some models to notify elderly folks of potential health issues. Figure 9 depicts one of the models. Elderly persons and those who have a hard time following doctors' orders can benefit from this strategy as well.

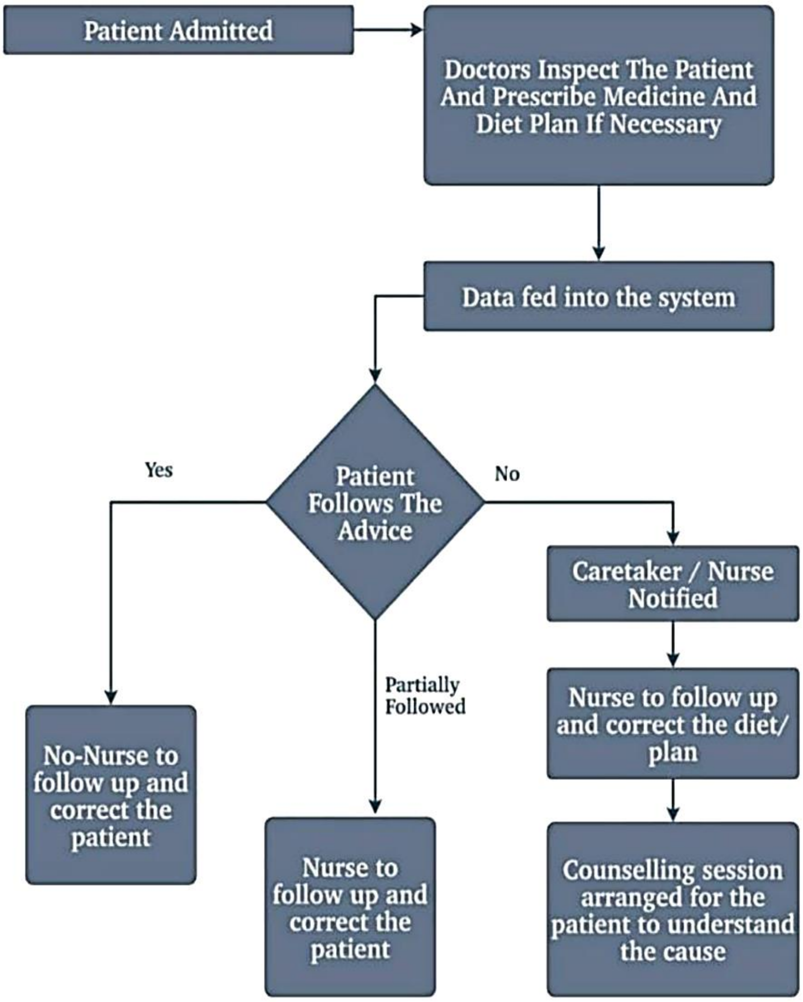


**Figure 9.** Medical adherence methodology.

### *2.10. Alzheimer's Disease (AD) Monitoring*

Monitoring for Alzheimer's disease has been fraught with difficulties, and it must be approached with extreme caution moving forward. People who are suffering from the early stages of Alzheimer's disease cannot be diagnosed themselves. Furthermore, the condition is difficult to observe even for members of the family. When the patient acts strangely and loses consciousness while performing simple chores, they know they have a sickness. They believe the Internet of Things (IoT) can play a huge role in improving the quality of life for people with Alzheimer's disease. The following are three of AD's most concerning signs and symptoms:

1. Severe memory loss
2. Wandering
3. Dementia [32]

Wearables connected to the BAN via communication protocols like MQTT, Zigbee, etc. can be used to counteract this. Caregiver's whereabouts can be easily tracked down by sensors in the city if a patient wanders away. In fact, patients can be taught to utilize the IoT framework to keep track of personal information like their name, the name of the doctor who is treating them, and their address. Using numerous servers and databases to collect vitals from patients and further advance technology makes it possible for doctors to monitor patients even when they are not there.

Wearable technology for people with Alzheimer's was the focus of this project to learn more about the difficulties and lessons relevant to this population. Alzheimer's caregivers can make use of commercially available equipment and gadgets that have been approved for use in laboratories. We used product searches on the internet, phone interviews with representatives from related companies, and recommendations from participants. Only a fraction of the things discovered during the examination met the study's requirements. Using key informant interviews, it was discovered that creating products for people with cognitive impairments requires certain considerations. To sum it up, there is no ideal solution, but there is potential for market innovation and a careful balance of safety and security.

### *2.11. Cancer Patient Monitoring*

Currently, there is no treatment for cancer that does not have any adverse effects. To eradicate the tumor, patients must undergo chemotherapy alone, which leaves them weak and unwell. Taking care of the patient is critical because of the patient's vulnerability to nearly anything. The author of this paper has made an effort to create an IoT framework and a layered architecture. This system has been broken down into five layers [34]:

1. Service layer
2. Datacenter layer
3. Cancer care layer
4. Hospital layer
5. Security management layer.

The names of each layer are sufficient to identify them.

Detection of tumor cells is possible because to the employment of medical-grade sensors in this system. Doctors could rely on cloud computing and analytical expertise to make quick decisions in time-sensitive scenarios. To convey data around the world, the sensors would be connected to WSN technology and other intelligent devices. Comparing the suggested system with the current one, they discovered that it was sound on nearly every metric.

Describe the current state-of-the-art method for wearable system-based cancer diagnosis and emphasize major challenges [35]. This study analyzed 11 of 472 records. In this case, 45% were research publications and 55% were manufactured. The review focuses on records released between 2009 and 2017. Breast cancer (36.3%), skin cancer (36.3%), prostate cancer (18.1%), and multi-type cancer (36.3%) (9 percent). Microcontrollers, Bluetooth modules, and smart phones were most commonly used. Some UWB antenna wearable solutions. C'est l'une des plus The present work integrates seamless sensor units and smart networking. No cloud computing or long-range connectivity. Wearable gadgets now demand AI and machine learning. In addition, clinical inertia, ignorance, and high expenses limit system extension. Assuming these issues are addressed honestly, wearable technology may be a key alternative to future cancer diagnosis [35].

## 3. Wearable Sensors

Patients' vitals and other important signals are measured by sensors in all IoT-based healthcare systems. This data is then converted into data that can be used for analysis and monitoring. In order to detect activity, this layer may comprise sensors that may monitor vitals such as heart rate and blood oxygen levels, as well as other specific signals that indicate an issue. Because the wearers must be able to go about their everyday routines and lifestyles without interruption, these sensors are largely wearable. For networking, several of these systems make use of BAN or WSN. Preprocessed, trained, and then utilized to forecast illnesses utilizing multiple algorithms [12] and artificial intelligence (AI) Sensors of various types are addressed in the following subsections. Various wearable sensors used in IoT systems for healthcare are listed in Table 1, with their utilization in various research projects.

**Table 1.** Various IoT-assisted Wearable Sensors for Healthcare Monitoring.

| SNo. | Application | Sensor | Characteristics | Sensed Parameter | Wearable Type | Ref |
|---|---|---|---|---|---|---|
| 1 | Heartbeat Monitoring | ECG; AD8232; MAXL335cc | Inexpensive, Obtrusive | Heartrate | Wristband | [53,29] |
| 2 | Temperature | LM35; DHT11 | Inexpensive, noninvasive | Body temperature | Wristband | [3–5,42,38,47,55, 56,66,68,] |
| 3 | Glucose monitoring | Glucose sensor; INA219 | Invasive, expensive | Blood glucose | Patch on arm/strip | [3,6,42,15,14,14,16,16, 17,29,29,30,42,45,46] |
| 4 | Respiratory | Airflow sensor | Obtrusive Expensive | Breathing rate | Worn on face | [22,43,44] |
| 5 | GSR | GSR sensor | noninvasive | Sweat gland activity | Patch on arm | [16] |
| 6 | Acceleration | Acceleration sensor; ADXL345 | Inexpensive, noninvasive | Movement | Wristband | |
| 7 | Breathing | MQ2 sensor | Inexpensive, noninvasive | Acetone in Breadth | Mouth piece | |
| 8 | Load | Strain Gauge load cell | Inexpensive, noninvasive | Weight of medicine | Medicine box | |
| 9 | Communication | GSM module, Wi-Fi module | Storage, Backup | Transferring data | Wristband | [5,6,61,53,54,5944, 55,56,67–40] |
| 10 | Touch | Pressure sensor | Non-invasive, Expensive | Pressure on skin | Patch on skin | |
| 11 | Moisture | Moisture sensor | Non-expensive | Moisture | Wristband | |
| 12 | Organizing | RFID sensor | Non-expensive | RF waves | Tag | [3,5,10,39,52,57,64] |
| 13 | Movement | PIR | Non-expensive, Not attached to the body | IR rays | Attached to fixed body | [39] |
| 14 | Touch | GSR sensor | Expensive, nonintrusive | Sweat glands | Patch on skin | [16] |

### *3.1. Activity Detection Sensors*

People's movements can be tracked using activity detection devices. In other cases, it can be limited to a specific portion of the body. In order to keep track of a person's health, their movements might yield a wealth of data. Elderly adults are more vulnerable to harm; thus, they must be closely observed for any signs of agitation. An accelerometer is the most commonly used sensor. Accelerometers are sensors that track the movement of the body they are attached to. Patients' movements can be tracked using sensor data, and possible dangers like tripping or slipping are flagged [37]. Paper [38] expands on the cloud-based health care monitoring system that transmits movement and other data. The device in [39] describes a healthcare monitoring system featuring a PIR sensor for movement detection and other data. The [40] system monitors and records patient movement using an ADXL345 module.

### *3.2. Respiration Sensors*

Respiratory sensors are vital in IoT-based healthcare. They track the patients' inhalation and exhalation rates. It has a pulse oximeter and oxygen sensors. A pulse oximeter is a noninvasive device that measures blood oxygen saturation. It detects light absorption changes in the finger or earlobe/toe blood. Nasal/mouth airflow sensors detect users' breathing rate. In the nose and on the ears, it is a flexible pipe. The publication [29] offers an e-healthcare monitoring system that uses the SPO2 and other heart sensors to check and manage health. References [30,41] employ a pulse oximeter sensor to detect the user's pulse [3,42,14]. A model using R-pi and an oximeter and airflow sensors to monitor the patient's respiration is described in [43]. A MAX30100 integrated sensor checks the oxygen level in %, with a normative range of 94 to 100. [45] employs a MAX30102 sensor to measure capillary oxygen saturation in reflected mode. The paper [46] employs a pulse oxygen sensor to detect hemoglobin and deoxyhemoglobin to determine blood oxygen levels.

### *3.3. Heartbeat Monitoring Sensors*

Heart rate sensors function by reflecting light via a vascular region of the body. Monitoring a person's heartbeat can assist discover several health concerns that have no obvious symptoms. ECG sensors [29,47] graph the heart's electrical activity. Heart disease is detected by ECG, which helps identify chest aches and other typical symptoms. [49] deals with detecting anomalies in ECG signals, employing filters, and estimating energy variances. The publications (50,51) cover devices with sensors to monitor the heart and other vitals (3,52,53,54,55,56,45,46,40,57,58). The system in [11] uses a wireless sensor network (WSN) [34,47] to continuously monitor cardiac patients and upload data to the cloud for analysis. [18] illustrates a heart monitoring system that sends data to NI LabVIEW for graphing [59]. The study compares single-lead and multiple-lead ECG recording devices [60]. A GPS gadget can track a patient's location and heartbeat [61]. [58] describes the advantages and disadvantages of utilizing wet and dry CVDs as ECG electrodes.

### *3.4. Blood Pressure Sensors*

The noninvasive blood pressure sensor is designed to detect human blood pressure. Monitoring blood pressure can help folks manage their health and predict future difficulties. The sensor data can be linked with other sensor data to detect patient abnormalities [46,62]. [5,38,52,54,20,29,64] describes a health monitoring system for athletes that continuously monitors their vitals and uploads them to the cloud. It presents a CPS framework that sends data to multiple cloud storage platforms. [65] gathers ECG and PPG data to determine blood pressure and sends them to the cloud through Bluetooth. [16] describes a system that employs an MPXV5050GP sensor to determine blood pressure and an Arduino as a slave to R-Pi.

### *3.5. Blood Glucose Monitoring Sensors*

Glucose sensors are used to monitor and control diabetes. Strips or a strap-on sensor can continuously measure glucose levels in the body. Most people benefit from utilizing these devices and monitoring their own glucose levels. The ANS216 sensor is used in the study on [6] to monitor blood glucose levels noninvasively. [16] uses an INA219 glucose sensor connected to R-Pi via Arduino. The paper [29] collects blood glucose readings and uses ML algorithms to analyze them.

### *3.6. Temperature Sensor*

A temperature sensor is a commonplace sensor that can be used in conjunction with other sensor data to anticipate various health risks [38,47,66]. The primary and most direct way to tell if something is amiss with a patient's body is to check their temperature. According to the findings in [67], a safe and intuitive healthcare monitoring system employs a variety of sensors and displays information to the patient [52,56]. The study [68] outlines an intelligent system that monitors the environment along with body temperature data [42] and sets off an alarm when the threshold is crossed. An MCU with multiple sensors incorporated into it is proposed in the publication [55] as a system based on the body area network (BAN). A system is described in [5] that uses RFID to collect and organize data, and then uses a GSM module to send that data to the cloud.

## 4. Open Problem and Future Opportunities

### 4.1. Open Problems

As the Internet of Things (IoT) grows in popularity and possible applications, it raises a slew of new security concerns. Instability and a lack of trust among IoT users can result from a number of issues with cloud databases. Wearables are not exempt from this phenomenon. The sensors in the wearables capture data from the patient and transmit it to the host devices through Bluetooth or Zigbee. A wide range of issues must be addressed. Figure 10 outlines the most pressing issues.

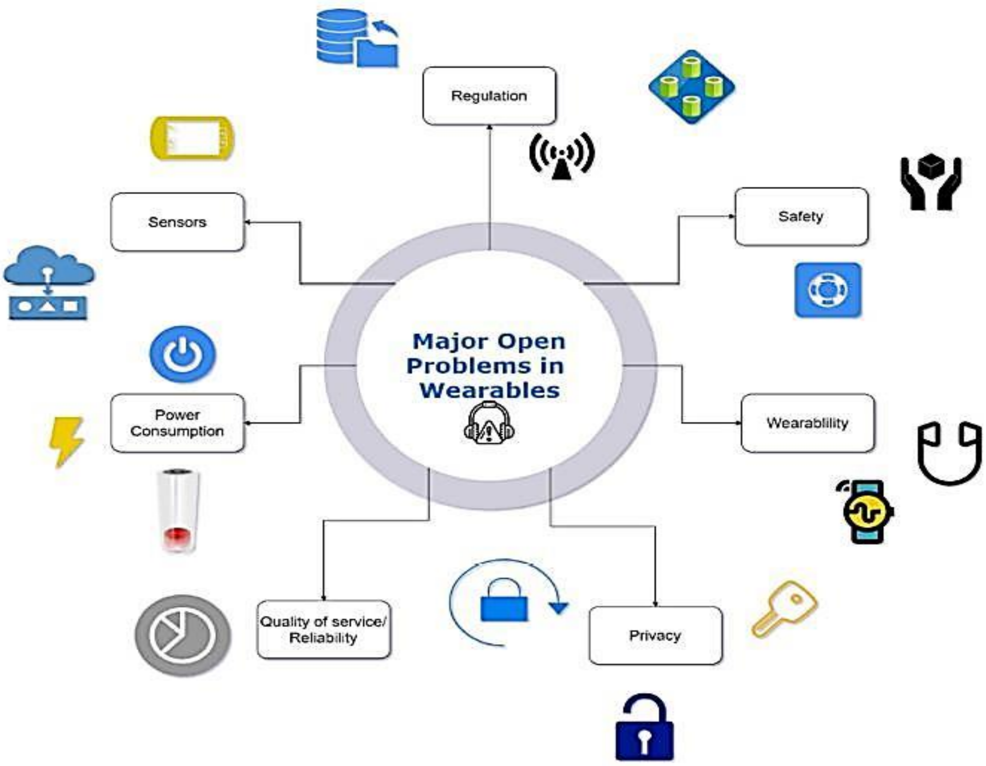


**Figure 10. Open problems—IoT-assisted wearable sensor systems in healthcare.**

#### *4.1.1. Data Resolution*

Sensors are the source of the problem with data resolution. The small physical factor of most wearable devices necessitates the usage of extremely small sensors. People do not want a bulky smartwatch on their wrists that is not at the same time compact, robust, and elegant-looking. But there are drawbacks to using smaller sensors. Data resolution is the most critical factor. The sensor's readings are highly unreliable due to its small form factor, and its range is likewise limited, necessitating the theoretical calculation of some essential values in the MCU. However, the sensor is less accurate and does not provide the results as compared to medical-grade sensors.

A basic heartbeat sensor, for example, can be used as an example. The ECG or EKG is a specialized sensor used in hospitals to monitor the heartbeat. There are several sensors attached to the abdomen to get an exact reading with all the necessary details, and doctors use this information to reach a conclusion, but a pulse rate sensor is used in wearables to get a reading that is not as accurate and detailed as the medical grade.

#### *4.1.2. Power Consumption*

The wearables are frequently utilized, resulting in a problem with the device's battery. When it comes to power consumption, smaller machines use less power, but there is a greater risk of damage from overpowering them. The necessity for a steady power source is critical in the wearable technology sector. As the number of sensors increases, so does the amount of power required, making the situation worse. The primary issue is finding a device that can accommodate all of the sensors while also having a battery life of at least one or two days.

#### *4.1.3. Privacy*

Because of this, the Internet of Things (IoT) poses a significant risk to individual privacy. In the past, there had been a number of privacy concerns with healthcare IoT. For a long period of time, the entire service was unavailable due to many attacks on the network. Nonetheless, when it comes to healthcare, this issue has gotten even more significant. Data from this healthcare can be exploited, making it extremely hazardous. Smartwatches can simply be used to gather data from a variety of sensors. The software is able to track a variety of personal information about us, such as our sleep patterns, eating habits, and daily schedules. As a result, it is imperative to protect the user's personal information and identity.

#### *4.1.4. Wearability*

'Wearability' is a self-explanatory term. The most important criterion in determining how comfortable something is to wear is its wearability. In order to operate a wearable device throughout the day, the wearer must be able to do so comfortably. There are a number of aspects that contribute to the wearability of a garment.

1. The weight: the device should be lightweight.
2. The design should be ergonomic: The design of the device should be based on the human body's contours. It shouldn't be protruding from the body in this manner.
3. Water resistant: Due to the device's intended purpose of being worn on the body for at least a couple of days and being utilized while traveling, water resistance is preferable.
4. A skin-friendly substance should be used to make the gadget. The person wearing the device should have no skin reactions to it.
5. In order for the device to function properly, it must be both flexible and durable.

#### *4.1.5. Safety*

This section's sensors should also be safe to operate. The user's safety is the most important consideration. There should be no danger to the wearer from the sensors or gadget. Wearing it shouldn't have any negative impact on you. In addition to being safe to wear, this item should have no negative long-term effects on the user's health or wellbeing.

The wearable should be created with the user's safety in mind, as well as the people around them. Ordinary folks continue to buy them despite the fact that they aren't deemed cheap or unregulated but that they are still available. When worn, these malfunctioning gadgets have the potential to cause injury to both the individual using them and anyone in close proximity.

#### *4.1.6. Regulation*

In healthcare, the Internet of Things (IoT) is a relatively new phenomenon. In order to fully enable the use of wearable technology to monitor individuals, a number of companies are conducting research in this area. As a result, there is no central authority that can set laws for the gadgets that come out in the field, as it is a very specialized area. As a result, many devices that aren't worth using in healthcare centers are still on the market and may be purchased at a lower price than the best and most reliable options.

Furthermore, these devices are labeled as "plain old" wearables rather than "healthcare" wearables, which is a clear error. The wearables for remote healthcare monitoring do not meet the standards that a healthcare equipment should meet.

#### *4.1.7. Sensors*

There are simply sensors in wearable gadgets, yet everything revolves around the sensors that are employed. The sensors used in wearables should meet the following criteria:

a. They should be small.

b. They should consume minor power.

c. It should not be very noisy.

d. They should be easy-use compatible.

e. Fairly accurate.

A healthcare monitoring system's sensors are its heart and soul, hence they need to be accurate. Wearable sensors, on the other hand, face the challenge of being both precise and tiny. The medical-grade sensors are bulky and cumbersome to transport, and the output of the readings must be analyzed by specialist equipment and qualified persons, i.e., doctors. To diagnose a problem with a patient's heartbeat, doctors utilize a heartbeat sensor in hospitals to generate an ECG graph, which is then analyzed by them.

When employing a wearable sensor, the output is only numbers, and these numbers must be reliable enough for the doctor to make decisions based on them. Remote healthcare monitoring systems rely heavily on sensors to send information about a patient's health to their doctor. The sensors need to be reliable in order to work properly.

#### *4.1.8. Quality of Service*

One of the most difficult things for IOMT to do is to keep the QoS (quality of service) high. Healthcare management systems (HMS) tend to be quite diverse. Since this is the case, integrating them and assessing their QoS is tough. Hospitals are also feeling the effects of a lack of standardization in the level of service they provide. Quality of Service (QoS) is hampered by the amount of data and error tolerance necessary. The difference between life and death can be as little as a few seconds or as small as a single byte.

We need to improve service quality to ensure that IoT devices are dependable, fast, and usable. Quality of service (QoS) is hampered by a number of factors, including a lack of available resources, heavy traffic, and redundant data. For real-time healthcare applications, the criteria for determining Quality of Service (QoS) are [69]:

$$QoS = f\ (cloud\ QoS, network\ QoS, location, battery\ \ldots\ldots, N) \quad (1)$$

N is the total number of Quality of Service (QoS) variables. The parameter has been meticulously chosen." When evaluating diverse network and cloud parameters based on QoS evaluation criteria, the analytical hierarchy process (AHP) is frequently utilized [70].

## 5. Discussion

The paper provides a comprehensive overview of the rapidly developing field of Internet of Things (IoT) in health care. In the last few decades, the Internet of Things (IoT) has transformed and connected numerous industries, including healthcare. An IoT-based wearable sensor system for healthcare monitoring is presented at the beginning of the article based on its design. Further advancements in healthcare are discussed by comparing over 107 studies on the Internet of Things (IoT). It provides an overview of the sensors employed, as well as the publications' focuses and contributions to the area. As a starting point for future study, we believe this compilation will help us make healthcare more accessible for all. A few generalizations about the IoT-assisted wearable sensor system architecture might be made after studying all of these articles [71–73]. There are a number of components that must be in place before the Internet of Things may be implemented in healthcare. After that, a thorough examination of data gathering, data transfer, data processing, and computing paradigms is provided. A wearable device is used to gather and transport data from the patient, but the storage, calculation, and processing are all handled by a virtual system that is very easy to access. Parallel, cluster, grid, edge, fog, and cloud-based computing approaches are explained in detail. It discusses the various methods of transmitting data obtained to the server and to medical personnel, as well as the advantages and disadvantages of each. ZigBee, Wi-Fi, Bluetooth, and LoRaWAN are just a few examples of the various technologies that can be utilized. In an IoT-based healthcare system, these are the most commonly employed short- and long-range communication technologies. The speed of data transfer, range of communication, power consumption, type of networking, and the many devices that can be used to execute these technologies have been thoroughly discussed. There is a comparison of the technologies in terms of the above variables and frequency bandwidth, payload, and security [74-77]. In this way, we can see which technology is most suited for a given system. The importance of privacy and security in the implementation of these technologies is also examined, as is interoperability. Health metrics and other sensitive data must be kept private for the sake of the patient because wireless technologies make it easier to modify the data, which might be fatal to the patient. It's important to remember that privacy is an important consideration when adopting IoT devices in healthcare. Additionally, the report goes into great detail on the many studies that have been carried out with the use of IoT wearable sensor systems in healthcare. Real-time monitoring and the ability to predict potential irregularities and severe repercussions in at-risk patients are two of the advantages of IoT systems for these applications. Another benefit is that there is no chance of missing an indicator. They all give doctors the information they need to make the best possible decision for the patient and assure their recovery [78–81]. A total of 11 healthcare-related IoT apps are covered in the review. The Internet of Things (IoT) has many applications, and activity recognition is one of the most common. It enables individuals to monitor their own health and maintain a healthy lifestyle. It's also useful for older patients who are at risk of falling or slipping and need to be closely monitored. Similarly, monitoring the elderly for heart disease necessitates constant attention and fast treatment in the event of an emergency. Diabetes is a condition that affects a wide range of people, including people of all ages [82–85]. And with IoT devices, the ability to monitor critically ill patients has grown enormously, thanks to the precise data collecting they provide. In cardiac patient monitoring, IoT technology has substantially improved the ability to detect anomalies before they occur. For respiratory monitoring, sensors are used to continually compute and record the patient's breathing function. One application made possible by the usage of IoT devices in healthcare is the monitoring of sleep. Sleep and other vitals are monitored with multipurpose sensors to keep the user healthy. Since nearly one in five people suffers from high blood pressure, the field of blood pressure monitoring has grown significantly [86–90]. Furthermore, because it has no significant impact on them, the bulk of the populace disregards it. With the help of an Internet of Things (IoT) system, people may keep an eye on their blood pressure, which shows their physical and mental well-being. IoT solutions have also had a positive impact on medication adherence. It refers to ensuring that the patient complies with the doctor's orders. Keeping track of every patient and verifying that they are adhering to their prescribed treatment plan is nearly impossible. To avoid unwanted difficulties, it is important to help patients follow their prescriptions. The adoption of Internet of Things (IoT) devices has tremendously aided the monitoring of Alzheimer's disease. Due to memory loss, Alzheimer's patients must be carefully supervised because they frequently go lost [91–94]. Monitoring cancer patients, taking their treatment progress, and constantly monitoring if the tumor is growing back has been made possible thanks to the Internet of Things (IoT). Wearable sensors for heath monitoring are also discussed in the article.... Users can monitor their health and maintain a healthy lifestyle on their own with the help of activity detection sensors, which are widely available these days. Sensors for the respiratory system are vital. They keep tabs on the oxygen saturation and respiration rate of patients who are unconscious and in the recovery phase after major operations. The use of heartbeat sensors allows us to collect vital health data that can help us avoid a slew of problems down the road. Heart disease can suggest a wide range of health problems in a person. Users' general health can be monitored by using blood pressure sensors.

Blood pressure can be used to predict a wide range of problems, yet it is generally ignored. As previously stated, diabetes is a life-threatening condition, and glucose monitoring sensors enable us constantly check the blood glucose levels of diabetic people. Detection of a person's temperature is one of the most ubiquitous sensors, and it is also one of the most primitive. Body temperature fluctuation is frequently a sign of concern. All the sensors and their applications, sensing parameters, wearable type, and attributes are listed in detail [95–98]. An overview of current IoT systems in healthcare is provided by the articles listed in the table, which cover a wide range of sensors. A quick overview of current healthcare technologies and systems follows, giving us a sense of what is now available and how it may be improved to make healthcare services more easily available. Additionally, the purpose of CE and FDA approval is explained. The quality of service (QoS) of these technologies and devices is then discussed. The following section of the article explores the still-unresolved issues with IoT systems in healthcare that must be addressed before they can be widely used. The sensor's data range and sensing capabilities, as well as its size, are the most frequently encountered issues. The sensor must be small in order to be worn by the user, which may have an impact on the sensor's other properties. The use of electricity is the next major issue that needs to be addressed. Considering that the system will be wearable, we must reduce the amount of power it consumes. That's a violation of the system's intent. In order to protect the patient's privacy, it is crucial to address the issue of data collection and utilization. Furthermore, in order for the Internet of Things to be implemented on a broad scale, it must identify and solve a problem. Another issue with wearable technology is that it must be comfortable to wear and mix in with current fashion in order to be effective. Even though it isn't a priority, IoT in healthcare nevertheless has a significant impact. We must also ensure user safety, and this cannot be achieved by using sensors that harm the user's health in the first place. In order to determine the long-term impact of these devices, further research is required. In addition, there are several IoT technologies currently in use that are not in compliance with medical standards [99–102]. The article provides a comprehensive look of wearable IoT technology in the healthcare business, including both its benefits and drawbacks. It is possible to create a flawless system with no errors and endless possibilities based on the needs of the patients and their conditions. Real-time data collecting, analysis, and calculation are all part of this system's future physical implementation. Explore several communication and security options, then record the results. Customized sensor arrays can make wearability more convenient and less noticeable. We can also use ML to speed up and improve the accuracy of data processing [103–105]. We may also use blockchain to add a layer of security to the system that is required for it to perform at its full potential [106,107].

## 6. Conclusions

This paper provides a comprehensive overview of the rapidly developing field of Internet of Things (IoT) in health care. In the last few decades, the Internet of Things (IoT) has transformed and connected numerous industries, including healthcare. Further advancements in healthcare are discussed by comparing over 107 studies on the Internet of Things (IoT). It provides an overview of the sensors employed, as well as the publications' focuses and contributions to the area. In this work, a thorough examination of data gathering, data transfer, data processing, and computing paradigms is provided. A wearable device is used to gather and transport data from the patient, but the storage, calculation, and processing are all handled by a virtual system that is very easy to access. Parallel, cluster, grid, edge, fog, and cloud-based computing approaches are explained in detail. It discusses the various methods of transmitting data obtained to the server and to medical personnel, as well as the advantages and disadvantages of each. The speed of data transfer, range of communication, power consumption, type of networking, and the many devices that can be used to execute these technologies have been thoroughly discussed. The importance of privacy and security in the implementation of these technologies is also examined, as is interoperability. A total of 11 healthcare-related IoT apps are covered in the review. The Internet of Things (IoT) has many applications, and activity recognition is one of the most common. It enables individuals to monitor their own health and maintain a healthy lifestyle. The following section of the article explores the still-unresolved issues with IoT systems in healthcare that must be addressed before they can be widely used. The sensor's data range and sensing capabilities, as well as its size, are the most frequently encountered issues.

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