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A REVIEW OF HEALTH MONITORING TECHNOLOGIES AND SERVICES

G. O. Atabo[1], J. K. Alhassan[2], O. A. Abisoye[3], O. A. Ojerinde[4] and I. R. Saidu[5]
[1,2,3,4] Department of Computer Science, Federal University of Technology, Minna
[5]Nigerian Defence Academy, Kaduna, Nigeria.

Email: [1]onuchegideonatabo@gmail.com, [2]jkalhassan@futminna.edu.ng, [3]o.abisoye@futminna.edu.ng, [4]o.ojerinde@futminna.edu.ng, [5]rambo@nda.edu.ng

Abstract

This paper presents detailed review of health monitoring technologies and services. Time-sensitive illness such as cardiovascular, respiratory, accident and injuries requires constant and close monitoring to avert complications and sudden death. Several researchers have surveyed health monitoring technologies addressing specific areas such as IoT-based, wearable-based, and smart-based health monitoring technologies. However, evidence from existing literature has proven that classifying and analyzing these systems into groups of interrelated works is a difficult task. To this end, this paper used narrative literature review approach to present the taxonomy of health monitoring technology and group research works related to health monitoring systems that share common attributes, features, and characteristics. Also, this paper presents the description of a health monitoring services. Finding from the review shows that the design approach of health monitoring systems are similar in terms of physiological monitoring, and patient tracking. However, the transmission protocols are not the same.

Keywords: IoT, Monitoring, Service-based, Technology, Disease

1. Background to the Study

Significant burdens of diseases are caused by time-sensitive illnesses and injury. Such time-sensitive illness requires a sustainable healthcare system that manages patients in real-time manna. Time-sensitive diseases include cardiovascular disease, respiratory disease, accidents and injuries, diabetes, and cancer. The major contributing factors to the disease burden are the growing number of elderly (Al-khafajiy et al., 2019), and lifestyle (Health, 2018). Time-sensitive illnesses like cardiovascular diseases result in 40% of all deaths globally, and 80% of the total death occurred in low-and-middle-income (LMI) countries (Omogbadegun & Adegoke, 2016). Global cardiovascular-related diseases practice guideline such as hypertension stipulates that patients with such disease require close and efficient monitoring (Unger *et al*., 2020). However, challenges are hindering the compliance of this guideline such as Access to healthcare facilities, access to reliable monitoring equipment, geographic distances, and overcrowding in the emergency department. There is a need for a monitoring system that can feel these gaps.

Health monitoring technology uses medical sensors to transmit patient's vital signs records periodically or in a real-time. This method is efficient in solving some healthcare challenges such as of overcrowding, geographical distances, and accessibility. With the help of artificial intelligence and machine learning, some health monitoring systems are designed to predict health deterioration to avoid emergency situations, and provide diagnostic support. Several researchers have conducted a survey, especially on IoT-based, wearable-based, and smart health-based health monitoring systems. For example, Baker *et al*. (2017) proposed an IoT-based model for healthcare systems that can be used for general systems and personalized monitoring systems. The paper further reviewed literature related to each component of the proposed model. Then different vital sensors were compared based on their suitability for health care applications. The finding from the study indicates that the thermostat-type and photoplethysmographic methods for human body temperature and blood oxygen level monitoring respectively are generally acceptable. The study reveals that there is no agreement on the use of the respiratory sensor for general purpose use. Also, the finding shows that more research is required particularly on blood pressure sensors. Rodrigues *et al*. (2020) reviewed smart-based health monitoring systems that monitor the vital signs and behavior of a patient. The paper identified requirements for a smart environment and machine learning techniques for analysis and predictions. Baig *et al*. (2017) conducted a study on patient monitoring systems using the wearable system. The review aims to identify current challenges and opportunities for clinical approval. The study reveals that acceptability is an important aspect of wearable system design. Also, there is a heavy dependency on wearable patient monitoring systems on communication technology. For that reason cost of mobile data and network connectivity has been reported as a major problem associated with the wearable patient monitoring system. This paper presents a summary of the currently available health monitoring technology. The paper aimed at identifying the best and most appropriate techniques for developing health monitoring systems. The paper presents the taxonomy of health monitoring technology and review health monitoring services.

The sections of the paper are organized as follows: Section I presents the background to the study. Section II presents the taxonomy of the health monitoring techniques. Section III reviewed related literature on health monitoring techniques and services. Finally, Section IV contains the summary, findings, and future research directions.

2. Taxonomy of Health Monitoring Technologies

Over the last decades, researchers have proposed different technologies used in the area of health monitoring systems. Evidence from existing literature has proven that classifying and analyzing these systems into groups of interrelated works is a difficult task. This section attempt to group research works related to health monitoring technologies that share common attributes, features, and characteristics. Figure 1 presents health monitoring technology divided into two main groups. These groups include enabling technology and monitoring devices.

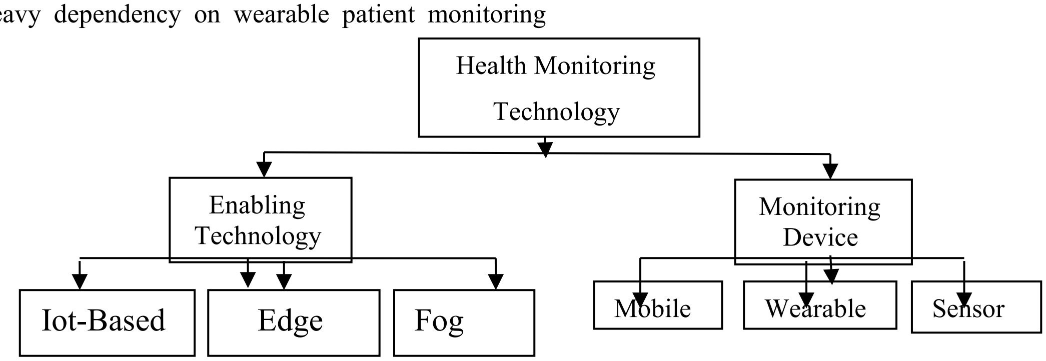

Figure 1. Taxonomy of Health monitoring Techniques

2.1. Enabling Technology

IoT has increasingly been used in different industries and more IoT devices are coming up almost on daily basis. IoT is a network of connected devices with the Internet using information sensing equipment to perform smart recognitions, positioning, tracking, monitoring, and administration (Patel *et al*., 2016). In the health industry, it is necessary to analyze time-sensitive data in a real-time manner, especially in real-time sensitive diseases such as cardiac disorder, respiratory disease, and blood pressure. Significant number of researches proposed IoT-based concept for health monitoring such as (Akhbarifar *et al*., 2020, Valsalan *et al*., 2020, Kirtana & Lokeswari, 2017, etc.) Most of the researchers proposed remote monitoring of patients using the IoT concept. The remote monitoring is aided by communication gateways such as Bluetooth, Wifi, and Zigbee to transmit health data into the cloud.

Table 1. Classification of selected health monitoring technology research.

Reference	**Purpose**	**Contribution**	**Application**	**Analysis**	**Technology**
(Akhbarifar et al., 2020)	Disease diagnosis in IoT environment	Early disease diagnosis in elderly.	Hypertension	K-star classification	IoT-based
(Li et al., 2020)	Continuous BP monitoring	monitoring using optical fiber wristband	BP	Estimation model.	Wearable
(Rajkumar et al., 2018)	Health monitoring system	Using Raspberry pi board as a personal server	General health	Python	Mobile-based
(Selvakanmani, 2018)	Health monitoring system	Design for care taker- to monitor Patients.	Elderly	No	Mobile-based
(Ali et al., 2020)	A decentralized peer-to-peer remote health monitoring system	Securing data using Ethereum blockchain	Cardiac, sleep apnoea, epileptic seizures	Ethereum Rinkeby	Sensor-based
(Chatrati et al., 2020)	Monitoring system	Predicting health status	diabetes and hypertension	SVM, k-NN, DT,LR, DA	Mobile based
(Wan et al., 2018)	Health monitoring system	Real-time personal health monitoring.	General health	SVM	Wearable
(Mena et al., 2018)	Mobile Personal Health Monitoring	Classification of ECG signals	Elderly	Neural Network	Sensor-based
(Adame et al., 2018)	Monitoring system for health care environments	Using hybrid sensor RFID–WSN	Patient care and asset management	No	IOT-based
(Chae et al., 2020)	Home rehabilitation system	Smart watch and machine learning model	Stroke	CNN	Wearable
(Kirtana & Lokeswari, 2017)	Monitoring system	Heart rate variability	Hypertension	No	IoT-based
(Izdrui et al., 2021)	Smart sensing systems	in-home health status and physical rehabilitation.	COVID 19	No	Sensor-based

(Savaridass et al., 2021)	Smart health monitoring system	To determine fitness level	Stroke	No	IoT-based
(Gaitan & Ungurean, 2019)	Remote EKG Monitoring	Remote diagnosis and monitoring of patient	electrocardiogram	No	edge / fog-based
(Baba et al., 2018)	Health remote monitoring application	WBANs	cardiac electrical activity	No	Wearable
(Dey et al., 2017)	Health monitoring system	Residential wireless network	ECG	No	IoT-based
(Mahmud et al., 2017)	Health Monitoring System	Monitoring using dry electrodes placed on Smartphone case.	Heart diseases	No	IoT-based
(Gokalp et al., 2018)	Monitoring of chronic disease	Home monitoring of vital signs and activity data	Elderly	No	IoT-based
(Souri et al., 2020)	Machine learning-based healthcare monitoring model	Detecting biological and behavioral change	Students health	DT. RF, SVM, MLP	IoT-based
(Wang et al., 2019)	Mobile health system	Ambulatory blood pressure monitoring	Stroke	abnormal BP data analysis algorithm	Sensor-based
(Pustozerov et al., 2018)	Mobile-based personalized prediction system	gestational diabetes mellitus	Blood glucose	Prediction algorithm	Sensor-based
(Sundarasekar et al., 2018)	Remote Health Monitoring system	The use of IoT with MODWT to identify the R peaks in the input ECG signal.	ECG	MODWT	IoT-based
(Ahmed et al., 2020)	Triage-based remote monitoring system	Combination of CIED risk stratification and telephone triage	Heart failure	HFRS algorithm	Sensor-based
(Liu et al., 2019)	An EMG patch for the real-time monitoring of muscle-fatigue conditions during exercise	The use of EMG patch to determine the muscle-fatigue conditions	muscle-fatigue	EMD algorithm	Sensor-based
(Kim et al., 2020)	Remote management of patients	Evaluation of health behavior management and risk factor control in stroke patients	Stroke	No	Mobil-based

(Egejuru et al., 2019)	Mobile-Based Monitoring System	Disease diagnoses	Hypertension	ANFS	Mobile-based
(Raj et al., 2018)	Remote telemedicine	Detection and estimation of general health profile of a patient	General health	No	IoT-based
(Fernández-Caramés et al., 2019)	Monitoring system	Incorporating IoT to commercial CGMs for remote monitoring	Diabetes	No	Fog/IoT-based
(Anitha & Baghavathi Priya, 2019)	Posture based health monitoring system	Abnormal activity monitoring and recognition system	Elderly	Dynamic Bayesian network	wearable

Table 1. *(Continued)* Classification of selected health monitoring technology research.

(Amitrano et al., 2020)	Remote health monitoring	e-textile-based wearable sock	Posture assessment	Passing–Bablok regression, Bland–Altman analysis	Wearable
(Iranpak, 2021)	Remote Patient Monitoring and classifying	Prioritization system for sensitive information	General health	LSTM deep neural network	IoT-based
(Kostoska & Bogdanova, 2018)	Real-time smart advisory health system	hybrid distributed system for triage processing	Injury	decision tree	Mobile-based
(Nath & Thapliyal, 2021)	Wearable Health Monitoring System	Stress detection for adult	stress	MLP , DT AdaBoost	wearable
(Hao, 2022)	Health Monitoring System	Cloud Computing	Knee health	Neural network	IoT-based
(Yin et al., 2018)	Wearable health monitoring system	Sound recognition	Bowel sound	SVM	Wearable
(Kim et al., 2019)	Ambulatory Physiological Monitoring system	Automatic detection of signal abnormality	Heart, respiratory and fall monitoring	CNN	Wearable

(Kassem et al., 2020)	Smart Health System	Wearable Monitoring	tracking the health care of patients	heart disease and fitness athletes.	Fuzzy Logic	Mobile-based

Relying on traditional cloud architecture may not be appropriate for some kinds of health situations. The fog/edge computing approach is more suitable because of the computing, storage, and network connectivity features. For example, Dilibal, (2020) presents the development of smart healthcare monitoring platforms using edge-IoMT computing architecture. Edge computing is incorporated into the proposed system to perform some functions like: communicating with the other layers of the smart healthcare system to provide accelerated streaming traffic, processing data obtained from the wearable sensor, and transmitting it to the cloud. Another function includes analyzing data at the patient location. Similarly, Fernández-Caramés *et al.* (2019) improved on the available commercial CGM for monitoring glucose levels by deploying fog computing that communicates with Smartphone's. The fog-based Smartphone collects data from the CGMs and transmits them to a remote cloud/blockchain. A similar concept was used in (Gaitan & Ungurean, 2019) where Edge/Fog Computing layers were deployed to process data from the mobile device. In (Ben *et al*., 2020) mobile application is employed to play the role of the Fog server which views and analyzes the environmental parameters of the hospitalization room in real-time, monitoring vital signs by nurses and preparing a medical report.

2.2. Monitoring Devices

Different types of devices have been adopted for use, since the emergence of smart healthcare for health monitoring systems. Such devices are classified into mobile-based, wearable-based, and sensor-based devices as shown in table 1.

Mobile devices are used within and outside the hospital by patients and physicians. Such mobile devices include mobile phones, smart devices, android, and pocket PC. These devices can be used either as the main processing station or as the main working module. Several researchers proposed mobile-based health monitoring systems for different diseases. For example, while Egejuru et al. (2019) presented a mobile-based hypertension risk monitoring system using unified modeling language and implemented using the Extensible Mark-Up Language for the mobile layout and content. Satoto et al. (2019) explore the method of designing offline tensimeter devices using ESP8266 to transmit real data of hypertensive patients. Of particular interest is the use of the mobile gamification method by Cechetti *et al*. (2019). The system was designed to improve user engagement in hypertension treatment using m-Health systems. The m-Health application was designed with Ionic Framework, version 1.7.10. The mobile device was used by researchers to propose pre-stroke and post-stroke management. For example, Wang *et al*. (2019) developed an ambulatory blood pressure monitor for early warning stroke using an inflation-type BP algorithm integrated into a mobile device. Also, Chae *et al*. (2020) employ a Smartphone application with Android Studio 2.3 to develop a home-based rehabilitation (HBR) system for chronic stroke survivors. Rajkumar *et al*. (2018) used the Raspberry Pi-3 computer to develop a health monitoring system for patient vital parameters.

Some research works such as (Li *et al.*, 2020, Wan et al., 2018, Chae *et al*., 2020) integrate wearable devices into health monitoring systems. The wearable is used either in the home setting to monitor different vital signs, in hospital settings, like the ICU and non-ICU, or in ambulatory settings. Most of the wearable devices are won in a different part of the body. For example, *Li et al*. (2020) presents a wristband system made up of optical fiber for blood pressure monitoring. Wan *et al*. (2018) describe the architecture of a proposed wearable IoT real-time health monitoring system. The wearable device consists of three categories of sensing devices that can be worn on the fingertip. The unique part of the system is that data obtained from the wearable device is transmitted to the cloud via WiFi without the adoption of a Smartphone. Also, an e-textile-based wearable system for biomedical signals remote monitoring was presented in (Amitrano *et al*., 2020). The proposed wearable system can be used for biomedical signals remote monitoring. The proposed e-textile-based system contains three pressure sensors embedded into commercial sports socks, and placed at three strategic points of the foot.

Sensing devices are the hub of the health monitoring system. Virtually all monitoring technologies (enabling technology and monitoring devices) integrate sensing devices which take the center stage in retrieving biomedical signals and forward it to the edge or fog layer for processing or visualization. However, this paper classifies research that emphasizes only health monitoring of vital signs and environmental sensors. Among this research initiative are selected paper presented in table 1. Table 3 presents selected sensors used in vital sign monitoring.

Table 3. Selected Sensor Used for Vital Sign Monitoring

Sensing Technology	**Usage**	**Application**
Blood pressure sensor	Blood pressure measurement	Hypertension
Blood glucose sensor	Blood glucose measurement	Diabetes
inertial measurement unit (IMU) sensor	human activity recognition	Stroke rehabilitation
pulse sensor	Heart rate variability	Hypertension
Pendant sensor	Optimal lymph flow	Lymphedema
EKG signals sensor	Electrocardiograph measurement	Cardiac
ECG sensor	heart electrical activity measurement	Heart disease
EMG sensor	Determine the muscle-fatigue conditions	Muscle fatigue

3.0. Health Monitoring System Services

In literature, health monitoring systems are developed for certain purposes and targets. It is referred to as services in this paper. A service-based system aims to perform the job of a health professional using a specific or a combination of a machine learning algorithm. This paper classifies the service-based health monitoring systems into four main categories: prediction, diagnoses, classification, and activities. Selected research on service-based health monitoring systems is presented in table 4. Numerous health monitoring systems have been designed for diagnosing specific or general health purposes. Diagnosis in a health monitoring system is the use of a machine learning algorithm or statistical analysis trained to identify the nature of illness the carrier of a specific sensor is carrying. For example, Saha *et al*. (2018) proposed a real-time hypertension diagnosis using the K-star classification model. Ashwini & Ramkrishna (2018) used multiple algorithms such as decision tree, support vector machine, random forest, and multi-linear programming to diagnose student health status. Other areas of application where researchers emphasized diagnosing the illness include posture using Passing–Bablok regression and Bland–Altman analysis (Amitrano et al., 2020), general health purposes using LSTM deep neural network, and decision tree algorithm (Omodunbi *et al*., 2018, Nedungadi *et al*., 2018).

Table 4. Service-based Health Monitoring system

Reference	**Service-based**	**Algorithm**	**Application**
(Akhbarifar *et al*., 2020)	Diagnosis	K-star classification	Hypertension
(Afeni *et al*., 2017)	Prediction	Naïve Bayes	Hypertension
(Chatrati *et al*., 2020)	Prediction	SVM, k-NN, DT, LR, DA	Diabetes and hypertension
(Mena *et al*., 2018)	Classification	Neural Network	ECG

(Chae *et al*., 2020)	Activity	CNN	Stroke
(Souri *et al*., 2020)	Diagnosis	DT. RF, SVM, MLP	Student health
(Pustozerov *et al*., 2018)	Prediction	Prediction algorithm	Gestational diabetes
(Egejuru *et al*., 2019)	Classification	Adaptive Neuro-Fuzzy Inference System	Hypertension
(Amitrano *et al*., 2020)	Diagnosis	Passing–Bablok regression, Bland–Altman analysis	Posture
(Iranpak, 2021)	Diagnosis	LSTM deep neural network	General health
(Nath & Thapliyal, 2021)	Diagnosis	MLP , DT AdaBoost	Elderly
(Priyadharsan *et al*., 2019)	Prediction	KNN classifier	General health
(Hao, 2022)	Activity	neural network	Sport
(Alazzam *et al*., 2021)	Diagnosis	decision tree algorithm	General health
(Yin *et al*., 2018)	Classification	SVM	Bowel

Some researchers emphasize prediction-based health monitoring in various aspects of health conditions, such as hypertension and diabetes (Mena *et al*., 2018, Li *et al.*, 2019), and general health (Bandyopadhyay *et al*., 2022). In a health monitoring system, the classification task is very crucial especially as it helps to identify the severity level of disease using vital signs obtained from the sensor. For example, Omogbadegun & Adegoke (2016) describe the design of an automated classification system of ECG signals for older adults. This is achieved using a machine learning classifier (Neural Network) which discriminates between normal and abnormal cardiac rhythms. Also, an adaptive neuro-fuzzy inference system was used in (Mukherjee & Dolui, n.d.) to classify and manage hypertension risk. Also, a wearable device and Support vector machine were used in (Nachiar *et al*., 2020) to recognize the sound of a bowel. Research on activities monitoring focused on post-stroke rehabilitation, exercise, and sport. Research conducted by (Baker *et al*., 2017) proposed a smart watch and machine learning algorithm to evaluate rehabilitation exercises conducted by a chronic stroke survivor. Likewise, (Hao, 2022) presents an Athlete's Knee Health Monitoring System using data generated from the lower limb alignment of the athlete.

4.0. Summary, Findings, and Future Direction

In this paper, a thorough review of the existing health monitoring techniques was carried out with special attention to enabling health monitoring and monitoring devices. Also, the paper reviewed health monitoring services and also identified current sensory devices used for different vital signs.

Finding from the review shows that the design approach of wearable health monitoring systems are similar in terms of physiological monitoring, and patient tracking. However, the transmission protocols are not the same. Some of the reviewed research revealed that vital sign data transmission is directly from the wearable device to the central server, while other design consists of a mobile device that is used as the main processing unit. Such a mobile device is located around the patient. The advantage of the latter is its ability to make visible the outcome of the processed data to the patient view. The size of a wearable device is a challenge to some proposed wearable monitoring systems. This is as a result of multiple components integrated into the wearable device. More research will be needed to reduce the size of wearable devices by considering the types of the component to be used. Designing health monitoring systems require consulting health professionals at each stage of development. Most of the reviewed proposed health monitoring systems did not address the area of medical professional consultation. Medical professionals' consultation and feedback should be core at each stage of health monitoring development.

Evidence from the reviewed literature shows that most of the proposed health monitoring system addresses part of the process rather than taking a holistic view of the system. Further study is intended to conduct a comparative study on the existing research on health monitoring systems to identify the use of each stage of the health monitoring lifecycle.

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