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# A Review on IoT Healthcare Monitoring Applications and a Vision for Transforming Sensor Data into Real-time Clinical Feedback

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***Abstract*—Ageing populations and the increase in chronic diseases all over the world demand efficient healthcare solutions for maintaining well-being of people. One strategy that has drawn significant research attention is a focus on remote health monitoring systems based on Internet of Things (IoT) technology. This concept can help decrease pressure on hospital systems and healthcare providers, reduce healthcare costs, and improve homecare especially for patients with chronic diseases and the elderly. This paper explores the use of IoT-based applications in medical field and proposes an IoT Tiered Architecture (IoTTA) towards an approach for transforming sensor data into real-time clinical feedback. This approach considers a range of aspects including *sensing, sending, processing, storing, and mining and learning*. Using this approach will help to develop useful and effective solutions for pursuing systems development in IoT healthcare applications. The result of the review found that the growth of IoT applications for healthcare is in areas of *self-care, data mining, and machine learning*.**

***Keywords - Internet of Things, IoT, healthcare, health monitoring systems, telecare, self-care, data mining, machine learning.***

## I. Introduction

The increasing trend of ageing populations all over the world in recent years [1], [2] has led to complex health issues, including the increase in chronic diseases and rise in hospital and clinical services expenditures [3], [4], [5]. Health monitoring is playing an important role in maintaining health for individuals, in particular for the elderly or people with chronic diseases because it can reduce hospitalisation and increase the quality of life [6]. Traditional health monitoring models are time-consuming and inconvenient for all involved [7]. These models will be insufficient to meet the need of medical services in our ageing society. There has been a demand for developing efficient healthcare solutions which help to decrease the pressure on hospital systems and healthcare providers, improve the quality of care as well as have a part in reducing healthcare costs by keeping patients out of hospitals for routine care. It is expected that New Zealands government health spending would increase 1.5 times in the period from 2016 to 2060, reaching about 11 percent of GDP in 2060, if there was no change in funding and delivering healthcare services [8].

IoT is promising for developing remote healthcare monitoring systems. IoT applications present a paradigm to connect physical and virtual things [9] and enables these things to communicate, share information and coordinate decisions. In recent years, IoT-based applications in the medical field have drawn substantial attention of researchers and technologists. Our research presents an IoT Tiered Architecture (IoTTA) towards a holistic and integrated application development to transform sensor data into real-time clinical feedback.

Following are the healthcare challenges that motivate our research. Firstly, populations are ageing all over the world. According to the United Nations [1], the number of people aged 60 and over in the world reached 901 million in 2015, and it is projected to grow to 1.4 billion in 2030 and nearly 2.1 billion in 2050. It is forecasted that the largest age group will be 65+, and the average age will be approximately 50 in many countries in Asia and Europe in 2050 [2]. Secondly, the increase in chronic diseases. In Europe, the most common diseases that affect 15 million people with an incidence of 3.6 million new cases every year are Chronic Heart Failure (CHF), Chronic Obstructive Pulmonary Disease (COPD) and Diabetes. The same trend is also recorded in U.S. [3]. Thirdly, hospital and clinical services expenditures are rising. The Centers for Medicare and Medicaids Services (CMS) reported that hospital costs in U.S. grew from 3.5% in 2013 to 4.1% in 2014, reaching to $971.8 billion in this year [5]. Similarly, physician and clinical services expenditures increased from 2.5% in 2013 to 4.6% in 2014, reaching to $603.7 billion in 2014 [5].

Present IoT applications and case studies in the medical field are often ad-hoc, focusing on implementation and technologies at specific settings and scenarios. For example, authors in [10] focused on the implementation of a telecare system. The prototype of the system was evaluated in Sweden using a two-step evaluation, including a ten-patient survey and a field trial at home with two chronic heart failure patients. The results show that the system is user-friendly and easy to use. However, it had limited wider integration or continuous usage. On the other hand, clinical support algorithms exist but are often underutilized. In [11], for instance, a diagnostic module is proposed using fuzzy logic to perform early diagnosis and alert for Hypertension and Hypotension. However, this is not widely adopted.

This paper aims to achieve the following goals. Firstly, provide an overview of present technologies that support IoT-based applications. Secondly, propose IoTTA for the design and development of solutions for integrating various technologies in healthcare systems. The IoTTA is an architecture to situate the IoT-based ubiquitous applications that may comprise multiple tiers of technology. Finally, suggest scenarios where IoTTA can be applied.

## II. IoT-Based Applications In Healthcare

IoT technology is often applied to developments in remote health monitoring solutions, for those who require regular attention such as patients with chronic conditions, disabilities, and elderly. Such systems provide remote monitoring and support early detection and timely care for patients without compromising their convenience and preference of living independently outside hospital. Following is a review of IoT applications dealing with chronic patients, aged care, and emergency.

### *A. Chronic Patients Healthcare Monitoring*

Considerable research focused on developing in-home monitoring systems for patients with chronic conditions. Continuous monitoring of vital signs of patients helps to reduce re-hospitalizations by detecting anomaly early, allowing appropriate and timely interventions [12]. Some systems measured Electrocardiography (ECG) and transmitted data to the medical database via the Internet [10] or wireless communications [13], or the collected data are used to diagnose and call emergency services if necessary [14], [15]. In [16], authors have developed the system called ECGaaS based on the integration of Body Sensor Networks and a Cloud PaaS infrastructure, which allows monitoring the ECG data coming from not only individuals but also group of people. Some studies tracked parameters such as blood pressure, respiration, SpO2, pulse rate, heart rate, and weight collected sensors for triggering alarms if abnormal situations are detected [12], or support early diagnosis of Hypertension and Hypotension [11].

Along with measuring vital signs, a questionnaire method is used in systems [10], [17], [18], [19] to collect health status of patients. The results of the field test in Care@Distance project [10] showed that patients found the system useful, easy to use, but found the blood pressure monitor uncomfortable. Authors in [17] proposed a system for monitoring the weight, activity and blood pressure of heart failure patients, checking patients symptoms by questionnaire and sending alerts to the healthcare provider when the collected datas values are out of the threshold range, or patients develop critical symptoms. Suh et al. [18] presented a health monitoring system for CHF patients which consists of sensors, web servers, and back-end databases. Test results show that the number of weight and blood pressure reading that fell out of an acceptable range was reduced when patients were monitored by this system. The algorithms for predicting the worsening of heart failure symptoms and the predictor of daily weight changes using in health monitoring system in [19] enabled building prediction models that are up to 74% accurate, which is more than 20% higher than using daily weight change alone. Bisio et al. [20] designed a telemonitoring platform based on a smartphone for detecting activities of heart failure patients. In this platform, the smartphone is used as both a hub and a sensing, processing and transmitting device.

### *B. Aged Care Monitoring*

Telecare applications empower individuals, especially the old aged to live more safely and more independently in their homes [12]. The daily needs of the elderly can be supported by technology interventions such as smart home or telemedicine [21]. Chuang et al. [22] proposed a system called SilverLink which uses object and human sensors for indicating user activities or health status. Data collected from sensors are processed to detect abnormalities in the movement patterns. When a shift in pattern is detected, the system stimulates notifications/alerts to the emergency response team. Internal tests of the prototype conducted in Taiwan and showed that the pass rate of sensors was 70%-80%, while pass rate of human sensors was less than 60% (pass rate is defined by the number of times the system recorded the event divided by the actual number of events).

Authors in [23] developed a Help to You (H2U) healthcare system to enhance the quality of healthcare services for the elderly. This system makes use of various technologies including wearable devices, biosensors, wireless sensor networks to support real-time activity and monitor the health status for seniors. Applications of the proposed system include emergency calls, medication reminders and symptom checks. An IoT-aware healthcare monitoring system was designed and implemented in [24] to send alerts to patients caregivers or doctors in real time when an older adult needs medical attention or hospitalization. Alerts rules were configurable during runtime, and the solution supported adding new sensors without interrupting the system.

Medical adherence is a challenge amongst elderly patients; some studies focused on reminding patients of their scheduled medications and updating new medicine data of patients [25]. Parida et al. [26] proposed a drug management system based on RFID technology which uses RFID reader and camera to track patients medicine usage. Intelligent pill box was presented in [27] to remind patients to take medication on time. These solutions are useful for older adults who have a high risk of suffering from dementia.

### *C. Emergency Applications*

Emergency applications involving IoT detect abnormalities at the right time so that emergency services can be alerted [28]. A model to do this involves monitoring patient health by medical devices, after that, personal mobile devices analyze the collected data to identify emergency cases and transfer data to medical information systems. When a particular emergency case is detected, the ambulatory team can reach out the patient.

Consequently the hospital prepares for the clinical treatment, and the medical personnel send situation-aware instructions for providing first aid.

Authors in [29] presented a healthcare system consisting telemedicine diagnosis and emergency telecare. Telemedicine diagnosis provides the user with information on diseases, medical information, and treatments; while emergency telecare shows user location, emergency information, and instructions to help the users. Korzun et al. [30] introduced reference scenarios of digital assistance services for emergency situations.

Fall prevention and fall detection are emergency applications because falls are serious health problems with older adults. Fall detection can be classified into three types: wearable device based, ambient sensor based, and vision based [31]. Cheng et al. [32] proposed a real-time fall detection system based on wearable sensors to detect the motion and location of the body. The proposed system was tested with 15 activities including ten intentional falls and 5 activities of daily lives. Each activity was performed 30 times. Test results showed that the proposed fall detection algorithm achieves an overall accuracy of 96.4%. Another solution uses the Microsoft Kinect depth sensor [33] for tracking the movement of the human objects in the depth frames and detects if a fall occurs.

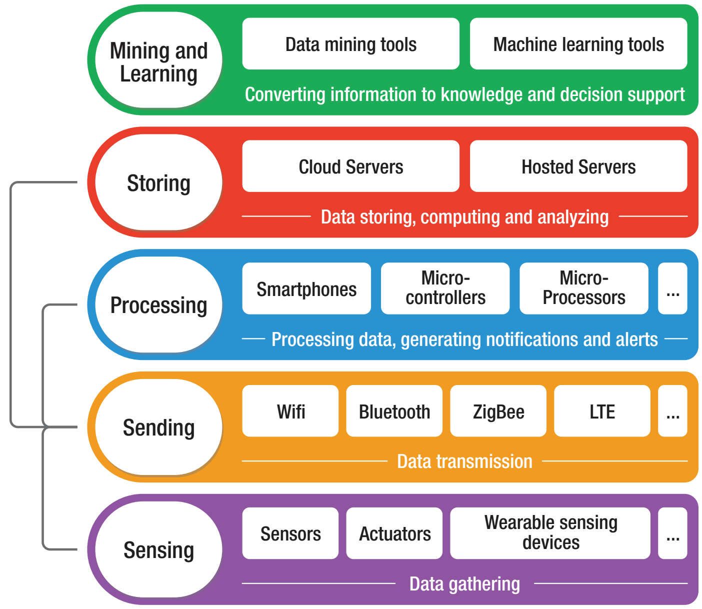


Fig. 1. IoT Tiered Architecture

## III. IoT Tiered Architecture (IoTTA)

IoT-based applications can be implemented by integrating various technologies such as wireless communications, sensor networks, data processing, and cloud computing. The combination of these technologies in an IoT system can be represented as shown in IoTTA (Fig. 1). We present this architecture as five tiers named Sensing, Sending, Processing, Storing and Mining and Learning. Sensing layer means gathering different health parameters of patients and sending these data to processing layer for pre-processing. Data then continue to be transferred to storing layer for further analyzing using tools in mining and learning layer as well as for storing. Data transmissions between layers are implemented by sending layer as being illustrated with inter-layers connection lines in Fig.1. The following sections outline functions and main elements of each layer.

### A. Sensing Layer

Sensing layer involves assembly of sensors or wearable devices for recording health parameters of patients. Vital signs such as body temperature, blood pressure, pulse rate, and respiratory rate are most common parameters used [34]. However, depending on application purpose, other parameters are included. For example, heart failure patients need monitoring for following parameters: ECG, Oxygen Saturation (SpO2), heart rate, and weight [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20]. Whereas blood glucose needs to be measured for diabetic patients [35]. In applications that support Ambient Assisted Living (AAL) for elderly people or disabled, activity monitoring will be required [36]. A combination of accelerometers and gyroscopes are used for gathering data in many health monitoring systems for predicting the risk of falls [22].

Sensors are regarded invasive or non-invasive sensors. Invasive techniques are more efficient than non-invasive techniques, but they may not be the right option for the elderly unless the problem is severe [21]. In some systems, actuators are used for triggering alerts [22] or adjusting environment parameters [23]. Presently there has been much development in many types of intelligent sensors which can be used in IoT systems, with in turn extends the capability of IoT applications [37]. Monitoring solutions based on body sensor networks have been introduced recently as in [16], [38], [39] which enable to monitor a large number of people and generate large amounts of contextual data. Designing sensing layer of an IoT should take into consideration the following aspects: the cost, size, energy consumption of sensing devices; how to deploy and organize sensors; communication capability of sensors [37].

### B. Sending Layer

Sending layer in IoTTA provides a protocol for things to connect and share data. Also, sending layer enables data from existing IT infrastructure to be accessed [37]. The data communication in IoT includes local and global communication [36]. In monitoring systems, wireless technology is used for data transmission. Wireless communication standards are helpful to ensure standardization and compatibility in IoT health monitoring systems.

Local communication between sensing layer and processing layer, is normally implemented by Bluetooth [17], [18], [19], [20], [22], [24] or ZigBee [25]. Bluetooth is a low cost, low power consumption technology to transmit data over short distances at the frequency of 2.4GHz [12]. ZigBee offers low power consumption, but it is not as prevalent compared to

Bluetooth. Some specific communication protocols are also used including: Radio Frequency Identification (RFID) [26], Near Field Communication (NFC) and ultra-wide bandwidth (UWB) [40]. RFID enables information to be exchanged between two objects - RFID tag and a RFID reader able to identify, trace and track objects within a range of 10cm to 200m [41]. NFC works at high-frequency band at 13.56 MHz that allows active readers and passive tags or two active readers to communicate with data rate up to 424 kbps and in the range up to 10cm [42]. UWB supports low energy, high bandwidth but short distance communications between objects [43]. Internet communication, is often the choice of connection between processing layer and storing layer, is established using WiFi technology or cellular networks. WiFi uses radio waves to transmit data within 100m range [44]. Smart devices can communicate and exchange information via WiFi without a router [40]. Standard wireless communications such as 3G, 4G, Long-Term Evolution (LTE) are used in many health monitoring systems [22], [26], [32] for data transferring between mobile phones based on GSM/UMTS network technologies. Network management technologies, network energy efficiency, quality of service, security and privacy are some issues that should be addressed in sending layer [37].

### C. Processing Layer

Processing layer performs the following: firstly, aggregate data from sensing layer, secondly transfer data to storing layer, and finally process data. This layer consists of processing units and software applications that apply computational part of the application [37]. Processing units may be smart phones, microcontrollers, microprocessors, hardware platforms, System On Chip (SOC), Field Programmable Gate Array (FPGA). Hardware platforms such as Arduino, Phidgets, Intel Galileo, Raspberry Pi, Gadgeteer, BeagleBone, Cubieboard as well as operating systems such as Contiki, TinyOS, LiteOS, Android, and iOS have been developed recently for running IoT applications [40]. The collected data is processed for further analysis, decision making, generating notifications and alerts.

### D. Storing Layer

IoT systems connect a large number of physical objects and generate a huge data that needs efficient storage [40]. In IoT-based healthcare systems, the collected data from sensing layer are stored for further analysis. Many cloud platforms are available for data storage from IoT such as ThingWorx, OpenIoT, Google Cloud, Amazon, GENI [40]. Cloud Servers and Physical Servers in storing layer have three functions including storing data, computing data and analyzing data. These functions are performed based on cloud computing technology to extract valuable knowledge and trends [40]. With the emergence of cloud computing technologies, the burden of managing and maintaining the massive and complex medical data is shifted to the cloud. Hence the efficiency and effectiveness of the health data storage and management is improved remarkably. Simultaneously, universal healthcare has been promoted by using cloud computing as a medium for e-health service delivery [44]. For example, medical professionals and patients are allowed to review the health data remotely.

### E. Mining and Learning Layer

Mining and learning layer involves tools that support data mining and machine learning processes. These tools are used by servers or processing units in storing layer or processing layer, respectively, for converting information to knowledge and decision support. Data mining involves discovering novel, interesting, and potentially useful patterns from large data sets and applying algorithms to the extraction of hidden information. Its functions include classification, clustering, association analysis, time series analysis, and outlier analysis [45]. Machine learning techniques are very useful in healthcare applications as they enable managing huge databases, learn from data and improve through experience [46]. Supervised learning and unsupervised learning are two types of machine learning [47]. Supervised learning (also known as predictive learning) generates prediction rules based on training data and uses these rules for predicting unseen data labels. It includes algorithms such as classification and regression. Unsupervised learning (or descriptive learning) searches the similarity between records to find the structure of unknown input data.

In the report of PWC, mobile health revenue increases from $4.5 billion in 2013 to $23 billion in 2017. In 2017, it is expected that monitoring services account for about 65% of the market, following are diagnosis services and treatment services with the percentages of the market are around 15% and 10%, respectively [48]. Future development can utilize IoTTA for real-time clinical feedback rather than monitoring. Furthermore, feedback should come from machine and learning layer rather than from clinicians as in current IoT healthcare applications.

## IV. Opportunities of IoTTA For Transforming Sensor Data into Real-time Clinical Feedback

Based on our review of recent IoT applications in health applications, we can categorize the studies into three groups: monitoring, self-care and clinical support. Table I presents strengths and weaknesses in each of the groups of applications. The strengths and weaknesses of studies reviewed in this paper have been evaluated using the SHARP framework [49]. SHARP is an acronym of five aspects: *Sustainable, Holistic, Adaptive, Real-time and Precise*, which are considered to approach systems development in healthcare. The key findings from Table I show that many implementations focus on monitoring and clinical support applications, fewer of them focus on self-care applications. Applying IoTTA will enable systems development that appreciates data collection and analysis at multiple tiers. Table II shows to what extent all of IoTTA layers are being used by studies reviewed.

The result of the review conducted by the paper  the growth of IoT applications for healthcare is in areas of 1) Self-Care and 2) Data Mining and Machine Learning.

### A. Self Care

Effective self-care among individuals seems to be one of the most difficult tasks that clinicians are facing today [50]. For instance, heart failure patients can be traced to failed self-care because of the two most common reasons including nonadherence to medications and diet as well as failure to seek timely medical care for escalating symptoms [50]. Authors in [51] suggested that promoting self-care abilities should go beyond the knowledge about their disease but also the skills needed for monitoring along with their signs and symptoms. Future healthcare systems with real-time clinical feedback using IoTTA can potentially deliver step-by-step instructions to patients about how to measure their vital signs, how to use their medicine, as well as giving recommendations on how to keep their parameters in normal ranges. These will be promising and cost-effective solutions for improving self-care for the elderly. Also, personalization of health solutions by adapting to the individuals characteristic plays an important role in improving the quality of care [52].

### B. Data Mining and Machine Learning

As indicated in Table II, the mining and learning tier is applied in fewer studies. Clinical support applications are usually based on comparing collected data with patients normal ranges and generating alerts if an abnormal situation is detected. Creating notifications should be the last resort in clinical support applications because this mechanism may place a significant burden on emergency systems in case of false alarms. Other methods such as using questionnaires should be performed after detecting an abnormal value in the monitored parameter for reducing false alerts. On the other hand, current IoT healthcare applications can be further developed by using data mining tools and machine learning tools to provide clinical decision support that can assist patients effectively. Predicting changes along with decision support will lessen involvement of clinicians. Feedback such as recommendations about medicine, healthy eating and exercising can be given to personal patients without clinicians intervention.

## V. Conclusion

This paper outlined health issues that traditional healthcare models are facing in our ageing society, including the increase in chronic diseases and rise in hospital and clinical services costs. To decrease pressure on hospital systems and healthcare providers, improve the quality of care and reduce healthcare costs, effective and efficient medical systems need to be developed. Remote healthcare monitoring systems based on IoT technology has tremendous potential. This paper reviewed recent IoT studies and presented IoTTA architecture. The architecture in Fig.1 is a representation of existing technologies and frameworks. However, the usage of each tier of IoTTA in the reviewed studies varies. The results of the review show self-care, data mining and machine learning as areas where next generation of IoT applications for healthcare should focus on. Future work will focus on data collection and analysis for the development of the falls detection and prevention system based on IoTTA approach.

TABLE I
Studies Evaluation Based On SHARP Concept

| **Type of Application & Related Studies** | **—Strengths** | **Weaknesses** |
|---|---|---|
| **Monitoring** 7, 10-21, 23, 24, 25, 35, 36 | - Allows monitoring patients continuously and remotely.<br>- Allows accessing patients' health data in real-time via the Internet.<br>- Provides accurate detection based on algorithms as in [20], [22]. | - Monitoring without follow up.<br>- Some systems are manual, for example in [10], the measurements and results recording are performed by patients.<br>- Most of the systems are not flexible, only in [24], new sensors can be added in the system during run-time. |
| **Self-care** 23, 24, 27, 28, 30, 35 | - Provides high accuracy in diagnosis capability.<br>- Provides medicine management at home with excellent performance, especially in [26]. | - Clinically validated advice and instructions are not provided sufficiently.<br>- Patients' involvement in the care process is still limited. |
| **Clinical Support** 7, 11, 12, 15, 16, 18, 20, 23, 24, 25, 30, 33-36 | - Allows early detection of clinical exacerbation.<br>- Provides personalized diagnosis as in [14].<br>- Provides high accurate prediction models as in [19]. | - Clinical support algorithms are underutilized.<br>- Data are not mined effectively for high level outcome. |

TABLE II
Applying IoTTA In Reviewed Studies

| **Tier** | **Studies** |
|---|---|
| Mining & learning | 11, 20, 23, 24, 30, 35 |
| Storing | 7, 10-21, 23, 24, 25, 27, 28, 30, 33, 35, 36 |
| Processing | 7, 10-21, 23, 24, 25, 27, 28, 30, 33, 35, 36 |
| Sending | 7, 10-21, 23, 24, 25, 26, 28, 30, 33, 35, 36 |
| Sensing | 7, 10-21, 23, 24, 25, 26, 28, 33, 35, 36 |

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