



# System Architecture of a Proactive Intelligent System to Monitor Health of Older Adults Living Alone

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**Abstract:** Worldwide improvements in the quality of life highlight immense need to have a remote health monitoring system that can provide critical biomedical data. This paper presents a low-cost health monitoring system, forming part of the Internet of Things (IoT), which aims at continuous, 24/7 monitoring of elderly people and disabled people. The system is implemented with a variety of sensors, for example, temperature, heart rate, and movement measurements, to observe a person's status. Doctors may also prescribe this system with a specific number and type of sensor, depending on a patient's condition. In a case study, three sensors measured the status of a person during the day. The measurements reflected the actions of the person as he/she relaxed or was active, in addition to monitoring his/her state of health. The observed data were recorded in a database that can be displayed by authorized caregivers. Results witnessed the efficacy of the proposed system. The proposed system finds enormous potential in giving remote healthcare facilities, especially to unaccompanied older adults.

**Keywords:** Healthcare Services, Health Sensors, IoT, Medical technology, Remote Monitoring

## 1. INTRODUCTION

Statistics from around the world show that the proportion of people aged 60 (and older) has grown at an unprecedented rate in recent years; and that growth is predicted to accelerate within the near future. Based on a report of the United Nations Department of Economic and Social Affairs/Population Division [1], there were 607 million people in the world aged 60 years or over in the year 2000. This population grew to become 962.3 million elderly people in 2017 [2], which was an increase of 58.5%. By 2030, the number of people in the world aged 60 years or over is projected to grow to 1.4 billion. By 2050, the global number of older people is anticipated to be more than 2.1 billion [2]. Fig. 1 shows the estimated population aged 60 years and over for the regions in the world in the years 2000, 2017, 2030 and 2050. Clearly, Asia is easily the most affected region.

Many elderly people need continuous care over a long period of time [3]. Providing uninterrupted healthcare services to elderly persons staying in a residential care home or nursing home may require a government to offer services free of charge. Annually, these services cost countries a significant amount. Good health and medical services matter for both individuals and society [4]. They affect the economic, political, social and environmental prosperity of any country, which is why provision of these services is one of the largest industries in the world [5]. Health monitoring is becoming part of everyday life especially for elderly people. The cost of medical care is steadily increasing and the growth rate in 2017 was estimated to be 6.5% [6]. In particular, an aging population has led to a rapid increase in the healthcare

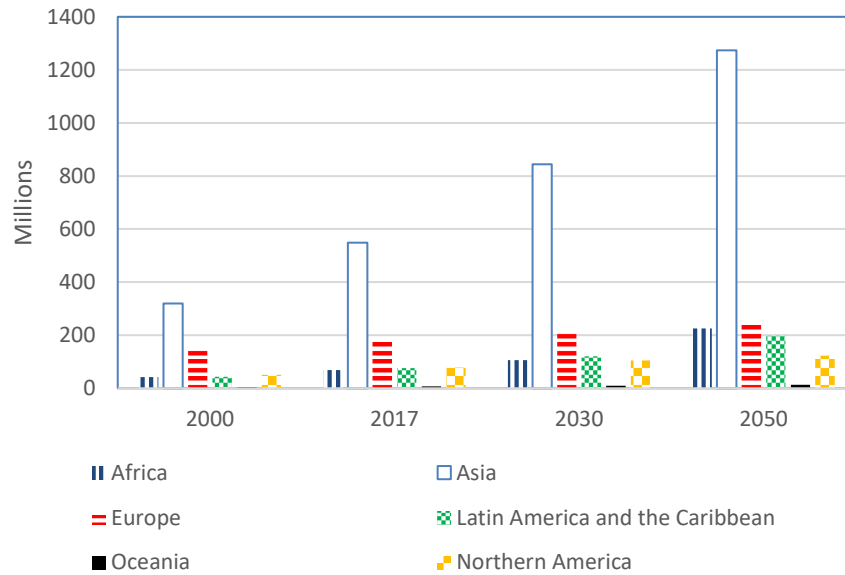


Figure 1. The population aged 60 years and older for various regions in the world [1] [2]

expense of long-term care. Therefore, many investigations around the world aim at developing new methods and technologies to provide continuous healthcare services to elderly people at a low cost, keeping them in better health and involving them socially so as to improve their sense of well-being [7].

Thanks to technological advancements, developments in miniaturization of electronic devices, sensing, camera and wireless communication technologies have made assistive living and environments possible [8]. Assistive living provides many healthcare solutions [9]. Hence, it is possible to build healthcare technologies that are comfortable, simple to use, unobtrusive, and also provide privacy and security. In addition to novel artificial intelligence techniques [10] and estimation methods [11], wearable sensors [12], exoskeletons [13], mobile phones, web cameras, and online social networks are all part of a future healthcare system.

In fact, the 'Future Health Index' report of 2016 [14] encouraged the adoption of rapidly-emerging digital technologies by the healthcare system. The adopted technology would enable the sharing of information amongst all parts of the healthcare system, including doctors, nurses, community workers, patients, hospitals, specialists, insurers, and the government. This transformation is already underway: 61% of U.S. healthcare organizations have already adopted

telemedicine solutions, such as electronic consultations and remote monitoring, as estimated in a study of the Healthcare Information Systems Society [15].

In summary, two main motivations lie behind the system proposed in this paper: Firstly, in many developed nations, the lifespan average has increased, resulting in growing elderly populations who need continuous healthcare services especially for those with chronic diseases; and secondly, from the cost perspective, it is necessary to move healthcare away from where it is most expensive (in the clinic, or emergency room) towards preventative measures and outpatient monitoring. In order to address these challenges, we propose a system named as Remote Smart Monitoring System for Patients (RSMSP), which is described in Fig. 2. RSMSP is an integrated system, which includes many parts (software and hardware) deployed together to create a smart healthcare system. This system has the ability to monitor a patient's status remotely and provide real-time support and interventions when they are required. For example, to send an alarm message to family members and caregivers in case of an emergency or give notification when a patient needs an assistance. The main contribution of this paper is an implementation of this system.

This paper is structured as follows; Section 2 introduces the context behind this research while various health monitoring systems are reported in Section 3. The

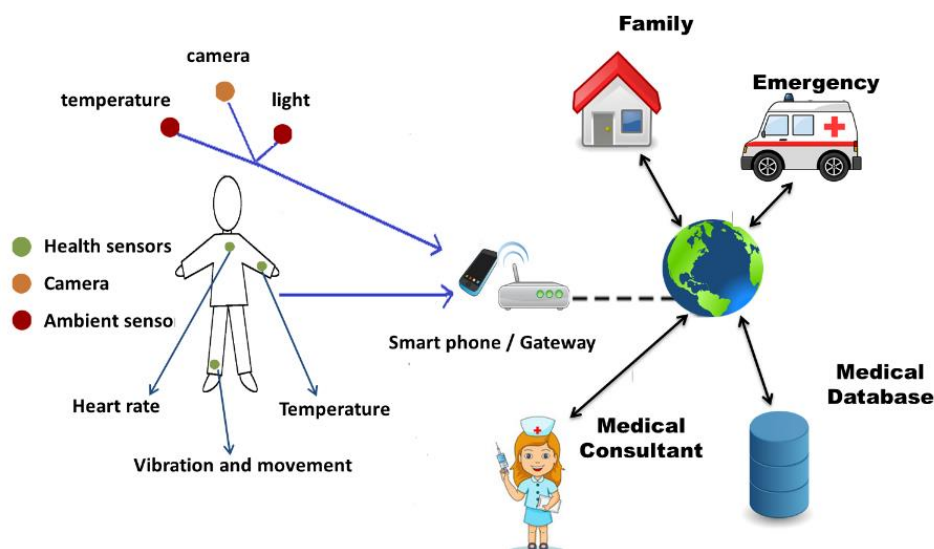


Figure 2. Remote Smart Monitoring System for Patients (RSMS)

proposed system is detailed in Section 4. Section 5 presents the realized simulation model. Finally, Section 8 concludes and expands on the potential of the proposed platform.

## 2. CONTEXT

Smartphone and tablet devices when connected to the Internet of Things (IoT), aside from their role in social networks and entertainment, are enablers of efficient communication in a clinical setting [16]. The widespread adoption and use of mobile technologies have the potential to provide new and innovative ways to improve healthcare outcomes and the health of individuals. For example, a survey conducted by the U.K.'s General Medical Council (GMC) demonstrated that in 2011, 30% of hospital junior doctors in the survey used a smartphone medical app on a daily basis for 1-10 min [17]. Medical and lifestyle apps provide a valuable way of sharing information, working more efficiently, and supporting diagnosis, treatment, and patient outcomes. Different types of healthcare apps will require a different approach to manage risk in both the development and use of the app.

In this paper, the heart rate (HR) is one of the principal life signs monitored. HR is considered as a practical guide to a patient's metabolic rate due to two reasons; firstly, it is generally a linear function of oxygen consumption (the primary expression of metabolic rate) [18]. Secondly, it is easy to measure this physiological response. The HR is vital in health monitoring because of its curative effect derived from exercise. However, as with sport and fitness [19], there is a risk of excessive activity. Thus, it is crucial to monitor the HR but also for a smart app to determine what benefits a particular person. Approximately 30–45 min of daily yet vigorous exercise can significantly reduce potential risks for many maladies including early death, Alzheimer's disease, CHD, diabetes, osteoporosis and

depression [20]. However, insufficient exercise will not result in the desired benefits, while excessive exercise can cause harm, and even death [19]. Physical activity offers significant advantages in preventing cancer, notably breast cancer and colon cancer, with the most active people at 30 per cent lower risk than the least fit [20]. Physical activity can also be of great benefit to those living with and beyond cancer, with positive effects on fatigue levels, body strength, mental health (for example, anxiety levels and self-esteem) and quality of life [21]. In the U.K., 'Macmillan Cancer Support's Move More' campaign is highlighting the benefits of exercise for cancer survivors [22].

Sports' training aids may, therefore, have lessons for elder and disabled care. MPTrain [23] is a mobile and personal system that users wear while exercising. It consists of a set of physiological sensors (HR and accelerometer) wirelessly connected to a mobile phone carried by the user. MPTrain's software allows the user to enter the desired workout in terms of desired HR stress over time. In this case, MPTrain determines whether the user needs to increase, decrease or keep the running pace, by comparing the user's average HR during a time window of the past  $N$  seconds (where  $N$  is typically 25) with the desired HR from the required workout for that day. There are many factors found to have a significant impact on the relationship between HR and energy expenditure included sitting HR in addition to age, weight and gender. The energy expenditure equation was then further validated on an independent sample of 97 individuals and found to have a correlation coefficient ( $r$ ) of 0.73.

Another study reported in [24] also considered the possibility of developing equations for estimating physical activity energy expenditure, from the HR-energy expenditure relationship in large, representing samples of



individuals with reasonable accuracy. Based on those results, we conclude that it is possible to estimate physical activity and energy expenditure from HR in a group of individuals with a great deal of accuracy, after adjusting for age, gender, body mass and fitness.

### 3. HEALTHCARE SYSTEMS

Technological advancements in minimizing the size of electronic devices, designing sensing devices, and improving wireless communications are the key driving factor behind emerging healthcare systems [25]. Researchers have investigated healthcare related technology in various ways. Yu et al. in [26] proposed a mental health monitoring system consisting of three components: the end nodes, the sink node and the data monitoring center. The 'end node' represents the sensors which are carried by elderly people. The sensor data is directed to and collected by a sink node, and then transmitted to the data monitoring center for recording, processing, and displaying results. Related mental health management software was developed to perform two functions for elderly people with mental illness. The principle of this system is based on analyzing the answers of elderly people about pre-recorded mini-mental-status examinations. The services of this system were limited to elderly people with mental illness and limited to one type of data which is audio data.

The system reported in [27] is a low-cost medical device that is able to sense, communicate, and analyze. The system enables real-time monitoring of patients' physiological conditions and at the same time is IoT-enabled. In that way, the device supports the active and real-time engagement of patient, care provider, hospital staff and doctors. The overall system comprises of three major modules: sensor module, data-analytic module and communications module. The study reported in [27] focused on the communication module and, through a network simulation, considered the impact of lost messages upon monitoring. In [28], Gaddam et al. presented a monitoring system for a care-home for the elderly. The proposal focused on detecting the usage of electrical devices, bed usage pattern, and the flow of water by means of an optimum number of cognitive wireless sensors. This system does not monitor the wellbeing of the elderly people, which would be based on reporting vital signs rather than the care-home activity actually tracked.

iCare [29] is another mobile health-monitoring system that used wireless body sensors and smart phones to monitor the critical health signs. This was achieved by four components: (i) body-sensors and other medical devices (ii) a smart phone (iii) a server and (iv) an alarm handling and ambulance calling protocol. In [30], Tapia et al. proposed a system for detecting activities in the home by means of a set of small and low-cost state-change sensors. The targeted activities were 'toileting', 'bathing', and 'grooming', which reflected the interests of medical professionals, according to the authors. The suggested system consisted of three components: environmental state-change sensors; the context-aware experience sampling tool and recognition and classification algorithms. The applied experiments employed sensors to monitor 'toileting', 'bathing', 'grooming', and 'doing laundry' activities in two homes. The authors' point was that medical professionals believe that changes in the activities of daily living are regarded as one of the most efficient ways to detect emerging medical conditions, which may later become critical. Other studies presenting patient health monitoring systems are reported in [31-33].

Another breakthrough dimension in healthcare systems is design and development of wheelchairs for mobility assistance of elderly and other people with disabilities. In [34], a low-cost wheel chair is presented which has the ability to navigate intelligently based on the local maps and speech processing techniques. The developed voice control commands in English language rely on Mel-frequency Cepstral Coefficients (MFCCs) and Mean Squared Error (MSE). The hardware design based on mechanical lever and gear box system and CAD of the intelligent and comfortable wheelchair is presented in [35]. Another notable research on power wheelchair based robot is reported in [36].

Most of the reported research did not provide an integrated solution for surveillance of the vital signs of elderly people but presented limited monitoring for specific physiological signs or home activities and also did not present practical modules. Hence, in order to meet such a requirement, the medical monitoring system must be reliable, comfortable, simple to use, provide privacy and advice to patients without disturbing a person's quality of life. In addition, it must enable elderly people's doctors, nurses, hospital staff, and/or other members of family to monitor and intervene when necessary. This research work presents such a system that provides a multitude of medical services.

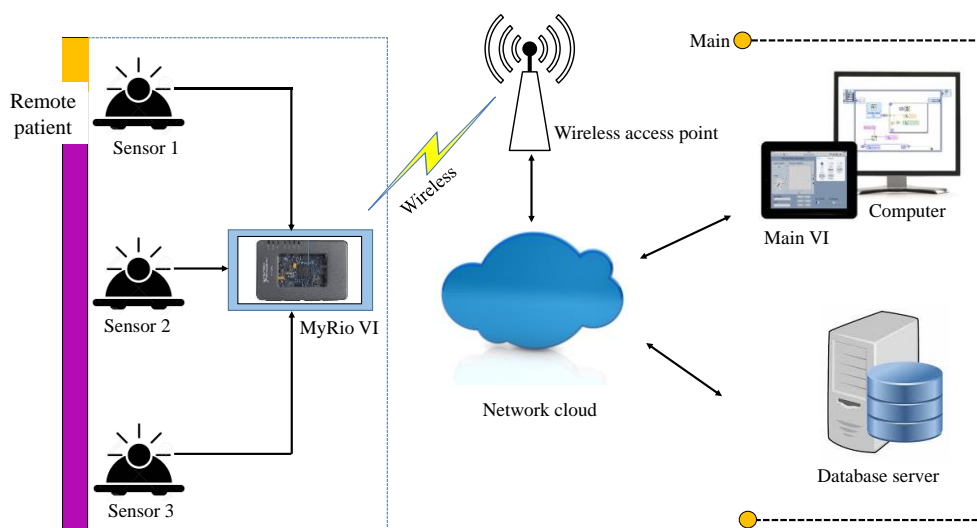


Figure 3. Operating principle of RSMSP health monitoring

#### 4. PROPOSED SYSTEM

The proposed system named as Remote Smart Monitoring System for Patient (RSMSP) was introduced in Section 1. Its components are:

- The area health sensors with cameras are used to gather HR, temperature, vibration and movement data of a patient along with camera data. Further, ambient sensors observe the home or make measurements of the surrounding environments. These facilities are provided in hardware.
- Wireless communication, which is a mixture of hardware and software, is relied upon to transmit a patient's sensor data and camera data to a mobile phone and to a gateway. Data arriving at a gateway relayed to a remote center via IoT. The wireless communication component provides active and real-time engagement between all the entities of the system.
- The remote center is essentially an application software which needs to access a medical database containing a patient's medical records. This center includes control applications that receive data from the sensors and camera, analyzes them and consequently takes the necessary action based upon the results of the analysis.

RSMSP has potentially many benefits to patients and care providers:

- Remote monitoring of patients' status by passively or actively collecting data from patients wherever they are.
- Enabling long-term continuous patient monitoring.
- Improving health outcomes and quality of life for each patient.
- Real-time support and interventions.
- Extension of care to the home after discharge, helping in the prevention of emergencies and re-admissions.
- Reduced hospital stays.
- Creating low-cost healthcare technologies.
- Accessing to a patient's health data with increased frequency.
- Support an increased level of accuracy for clinical monitoring readings, particularly the readings that would otherwise be provided by the patients themselves.
- Increase the level of trust and reliance that physicians place in data. This is pertinent especially when there are a few outlying readings, which could potentially be indicative of an underlying problem, but could also be attributed to errors in measurement.



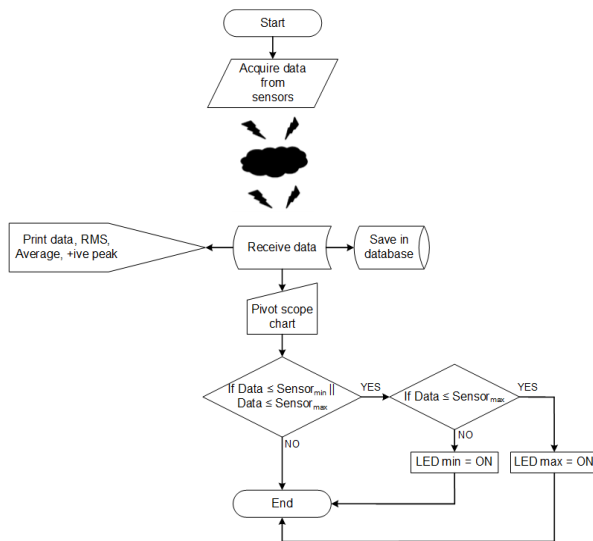


Figure 4. Example processing cycle

- Create a complete database that may be used for research purpose in future.

## 5. SIMULATION MODEL

MyRio Virtual Interface (VI) from National Instruments was employed to implement the simulated model. It is an embedded hardware device which is designed specifically to assist in the rapid design of engineering systems. In addition, LabVIEW was used as a system-design platform. LabVIEW is a development environment which can use the G-Programming language to take full advantage of the processor in MyRio. In the implemented simulated model, MyRio acted as the remote sensor server to acquire all the raw data. Data are transmitted wirelessly over a network and stored at a database server located somewhere in the network. This should employ a backup system such as in a RAID 0 /1 mirroring. Fig. 3 is an overview of this system, showing the sensor server connected to three sensors, which directly monitor a patient. In turn, the MyRio implemented server connects to a wireless access point that ultimately communicates over the internet as part of an IoT. Within the IoT is a database server, in practice, possibly provisioned within a cloud data center. The user interface to this data was implemented by means of LabVIEW.

The flowchart of Fig. 4 describes an example processing cycle, as implemented. Multiple sensor's data are acquired, with the ability to store that data or possibly print it out. After updating a graphical display showing ongoing measurements, should newly-acquired data exceed previous maximum or minimum values, an alarm light is set. In the monitoring process, the sensors deployed will vary based on a patient's status. For example, a patient who suffers from severe heart disease needs particular observation of their heartbeat, while a paralyzed patient

needs monitoring to be focused on the movement and vibration of their body.

Fig. 5 shows an implementation of the graphical display. The data from three sensors are plotted on the display, with alarm lights also present, along with statistical reporting. A log. is also shown, which indicates the state of the connection to a patient's sensors. Fig. 6 shows the Main VI with database G-Programming. It describes the connection of the three sensors with database. Fig. 7 presents the acceleration profile the sensors during a typical set of measurements.

## 6. CONCLUSION

Continuing healthcare represents an economic burden for national governments. In addition to the psychological impact upon a patient, the need to be monitored by other people may be hard to accept. Furthermore, forcing a patient to leave home and stay in a residential care-home or nursing home may badly impact upon their condition. These obstacles and issues can be overcome by implementing a healthcare monitoring system such as the proposed RSMSP. Providing continuous monitoring and services to a patient has many benefits in terms of quality of service and psychological support, apart from RSMSP's low cost and ease of setting up in a person's home. The proposal consists of three main components health and ambient sensors with camera, wireless communication and remote center (including raw sensor readings database and graphical display application). All the collected data are transmitted via wireless communication to be recorded in that database. The health staff can display the recorded data from this database through the graphical display. To maintain a patient's information securely, only authorized health staff are allowed to access the database.

MyRio instrumentation and the LabVIEW programming platform were used to implement the system. The results of realizing the proposed system show many advantages including minimization of the continuous care cost, facilitation of health services at any location, availability of the real-time response to a patient's condition, achieving patient's independence and creating a complete database to save observed data that may be used in future research. Furthermore, RSMSP may be used by any person desiring to monitor his/her health.

Future directions for extending the research on RSMSP are wide and concrete and are primarily intended to address limitations of the proposed study. For instance, we plan to develop a prototype and conduct trials of RSMSP with elderly patients in a real scenario to further

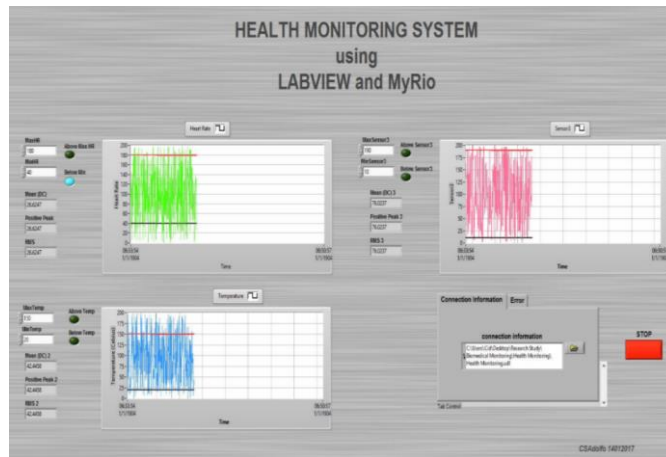
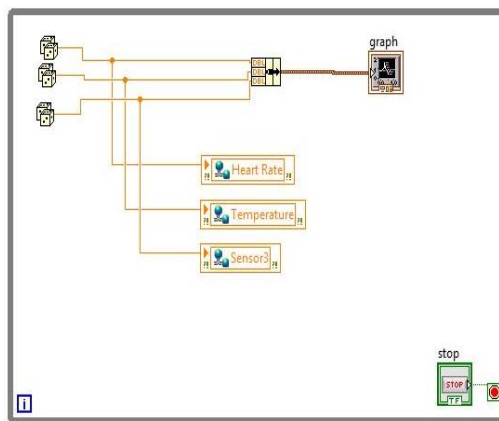
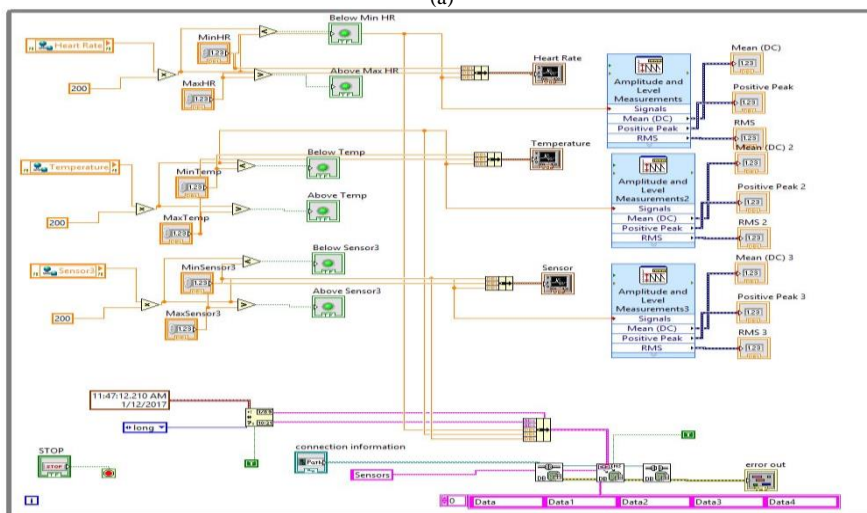


Figure 5. The implemented health-monitoring display



(a)



(b)

Figure 6. Connections of the three sensors shown through G-Programming (a) Higher-level diagram (b) Detailed diagram showing actual implementation

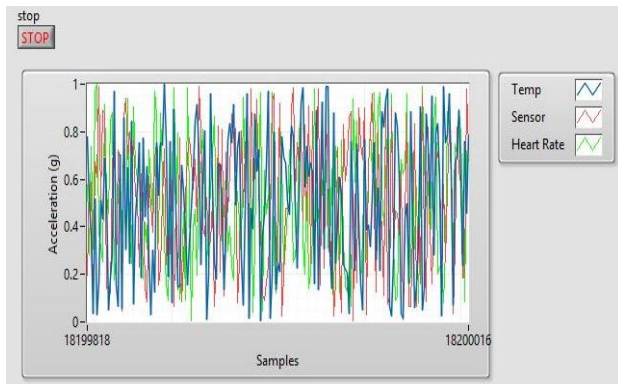


Figure 7. Example processing cycle

characterize the performance and efficacy of the proposed system. Also, RSMSP will be integrated with blockchain network to enhance scalability, reliability and authenticity of the proposed system. To help in timely prediction of life-threatening diseases, another possible extension in the system can be application of machine learning and/or artificial intelligence-based learning techniques. Moreover, considerations arising due to limitations of IoT are envisaged to be taken into account in near future e.g. Fog computing can improve data acquisition and manipulation which ultimately improves the network infrastructure in terms of packets loses.

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