Master of Science in Electrical Engineering with emphasis on
Telecommunication Systems

Internet of Things in Healthcare

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ABSTRACT

Internet of Things (IoT) is becoming the most promising and life changing technology in todays world. It is a computing process in which the communication is made or aided with sensors. In the past few years, IoT has become most productive in the area of healthcare, to improve the quality of care to the patient's. As there is a rise in health issues, providing health assistance to each and every member is important. People nowadays are busy with their lives and even they forget about their health problems. Some people do not even take care of their health.

When the healthcare system has started communicating with IoT devices, it only started to maintain the digital identity of the patient. Today, IoT in healthcare has become more productive because the communication between doctor's and patients has been improved with mobile apps. These apps are developed by the companies so that the doctors can monitor the patient's health. If any problem has occurred to the patient, then the doctor approaches the patient and gives the appropriate treatment.

In this thesis, particular focus is given to infant healthcare, because the greatest fear of parents is that they would lose their infants at any time. Therefore, in this thesis, the traditional care methods for infants are reviewed first. Then, an experimental setup is proposed and implemented which is capable of monitoring the patient health. In this review a commercial device has been identified which monitors the real-time information about the infant's heart rate, oxygen levels, sleeping position, etc. If anything happens to the baby, the information will get to the mobile application which has already been developed by a company and is commercially available. Then, by doing an example field test for the baby, the information which is recorded is analyzed. The information that has been analyzed is sent to the mobile which is aided through a base station.

Keywords: Base Station, Healthcare, Infant Healthcare, IoT, Smart Sock.

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ABBREVIATIONS

IoT	Internet of Things
M2M	Machine to Machine
BP	Blood Pressure
WBANs	Wireless Body Area Networks
SIDS	Sudden Infant Death Syndrome
HR	Health Rate
HCPs	Health Care Professionals
BSN	Body Sensor Network
SHS	Smart Hospital System
RFID	Radio Frequency Identification
UID	Unique Identification
HSN	Hybrid Sensing Network
MA	Monitoring Application
GUI	Graphical User Interface
WSN	Wireless Sensor Network
UHF	Ultra-High Frequency
GPS	Global Positioning System
ECG	Electrocardiogram

CONTENTS

1 INTRODUCTION

1.1 Overview

The term “Internet of Things (IoT)” has recently become popular in communication technology. It has been developed in many ways and is called as the next frontier. IoT is set to transform many aspects of our lives, it changes our world. In the coming years, the number of IoT devices is expected to grow dramatically. The reach of IoT is more than 12 billion devices that can currently connect with Internet, but by 2020 it is estimated that there will be 26 times more connected things with the Internet than the people [1].

Today, everything around us from household lights and different home appliances to vending machines and cars has the ability to get online and interact with other machines. IoT refers to devices or objects that can interact with the Internet by making use of physical devices, sensors, microcontrollers, and network connectivity that enable these objects to collect and exchange data as shown in Figure 1. In order to collect the real time data consistently, each and every device has its unique identifier (UID), which makes the communication possible in an easy way like machine to machine (M2M) communication. A massive amount of data is collected from devices all over the world which is stored in the cloud. As a result, systems will become more efficient and smarter.

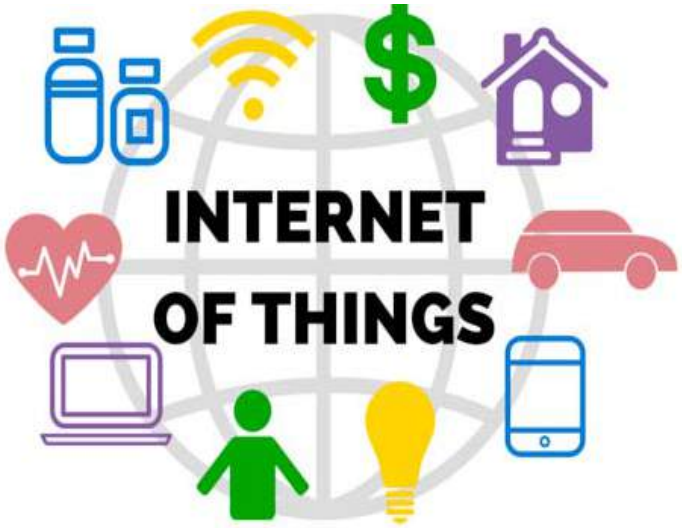

Figure 1: Internet of Things connected to many physical things and objects [2].

IoT creates smart objects which constitute eventual building blocks in the improvement of cyber-physical smart universal frameworks. It is intended for billions of physical things or objects that will be equipped with different kinds of sensors and actuators, that are joined by the Internet through diverse access networks assisted by different technologies such as wireless sensor networks (WSN), radio frequency identification (RFID), real time and semantic web services [1].

IoT which allows the people seamless interactions among different types of devices such as medical sensors, monitoring cameras, home appliances and so on [3]. By keeping all these things in view, we all know several applications which have been developed for IoT, in

which each and every physical object is connected through the Internet by employing sensor devices [4]. The communication is aided through the sensors installed into the participating devices. Sensors play a vital role in detecting signals. Sensors are now found in many applications, such as smart devices (mobile devices, tablets, etc.), automotive systems, climate monitoring, industrial control and healthcare.

Recently, IoT has become more productive in the area of healthcare systems. Specifically, IoT in the healthcare field combines sensors, microcontrollers etc., to analyze and send the sensor data to the cloud and then onwards to caregivers (doctors). Integrating the IoT features into medical devices improves the quality and service of care for elderly patients and also for kids. IoT in healthcare could maintain thousands of patient's data which is computerized and helps the patients to capture their data anytime. Many health sensing components have been developed more that are portable, this allows the patients to wear them for monitoring. The health monitoring device is connected to the patient such that the doctor can observe the patients condition at any-time. As IoT assisted patients can be accessed over the Internet, the health state of the patient can be detected at the right time so that proper action is taken [1].

The most of the developing countries have very poor healthcare infrastructure. If the health sensing device is made to communicate with portable devices like smart phones and tablets etc., communicating with the cloud is possible. People have access to these portable communication devices which are now becoming cheap [5]. The healthcare industry has made patient care more reliable. The real-time information of the patient data is analyzed and recorded, and the doctors/caregivers can monitor them by using handheld computers.

1.2 Motivation

Today, IoT has become the most powerful communication paradigm of the 21st century. Now, in the IoT environment, all objects which are in our daily life become a part of the Internet due to their communication and computing capabilities [3]. By 2020, 90 percent of all the healthcare organizations will have implemented IoT technology. Improving the efficiency of healthcare and the need of delivering quality care to patients is one of the challenging things of modern society [6]. Some healthcare organizations do not apply data from connected devices to other business processes. Effective healthcare depends on speed and accuracy, supporting many people and a huge range of devices which are connecting with IoT. Therefore, IoT has become more productive in the area of healthcare systems. In the past few years, many premature babies were dying or suffering with health complications. To solve this problem, IoT has developed a new technology in healthcare to improve the quality of care for infants.

1.3 Problem Statement

Health support of each individual should be considered as very important in todays world because of a rise in many health problems. If there is an increase in the number of patients, then this leads to a decrease in the relative number of doctors. As a result, the diagnostics are delayed or some patients are ignored. This makes patients more dependent on doctors for their check-up. Keeping all these issues in mind, healthcare systems have started connecting with IoT for maintaining the digital identity of each and every patient. Due to non-availability of doctors/caregivers and not being able to access the healthcare systems, many health problems are getting undetected in the healthcare system. On the other hand, these IoT based healthcare systems have helped the patients and doctors to continuously monitor and easily analyze the patient data [4].

Infant healthcare is becoming a big problem today. The greatest fear of any parents is that they would lose their infant. Today the Sudden Infant Death Syndrome (SIDS) is a big problem. The most common reason for the sudden death of infants is that they are having trouble while they are breathing. This sudden death happens without giving any signs. It may happen when the infant is in deep sleep and also when the baby is crying or struggling with any other problem [14]. To avoid this problem, IoT has ensured the personalization of infant healthcare by maintaining the digital identity of infants each and every moment. By making use of IoT smart sensors, the infant health can be monitored, data can be collected, and real-time information of the infants each and every moment can be sent to their parents.

1.4 Research Questions

1. How can we utilize IoT to enrich the traditional methods of infant healthcare?

2. How can we utilize IoT to collect valuable data to improve the care provided to infants and babies?

3. How can IoT support healthcare staff to improve their work efficiency?

1.5 Aim and Objectives

IoT holds a great potential to meet the needs of healthcare.

1. The aim of this thesis is to develop an application/architecture, which is capable of monitoring the health of infants.
2. It is being applied to improve the access to care, to increase the quality of care, and to reduce the cost of care.
3. Monitor the health status of an infant by a sensor, which creates information that passes through a network so that it can be communicated or analyzed.

1.6 Method

Firstly, it has been started with analyzing the traditional care methods for infants and start looking into the devices that can be placed in the process of care to improve the accuracy of measurements and the response time for result analysis. An infant monitor can collect data and send real-time information of the infants breathing phase, heart beat, skin temperature, sleeping position and intestine activity level. Advances in sensor and connectivity technology are allowing devices to collect, record and analyze data that was not accessible before, this means being able to collect important data over time that can be used to help enable preventive care.

1.7 Outline of the Thesis

Chapter 1: It provides the introduction that deals with an overview and motivation for this thesis. It also contains problem statement, research questions, aim and objectives of this work, and method that has been used in this thesis work .

Chapter 2: It provides background for the general topic of IoT in healthcare, IoT for infants, challenges for IoT in healthcare and advantages of this work.

Chapter 3: Deals with previous research work related to this thesis.

Chapter 4: Presents the methodology using different IoT smart devices and sensors.

Chapter 5: Deals with the implementation. It illustrates the communication and connectivity of the experiment with a detailed account of the experiment setup.

Chapter 6: Deals with the example field test. It also presents the user experience and results of the example field test.

Chapter 7: Provides conclusions derived from the experiment, its results, and also points out future work.

2 BACKGROUND ON IOT IN HEALTHCARE

2.1 Healthcare and IoT

Technology which is now based on IoT has worked its way onto many consumer devices. Many people are expecting it to crossover to healthcare. IoT technology transforms the way we live and work. Also, it could change many aspects of our lives including healthcare. Nowadays, many healthcare applications are available which allows the patients to schedule their appointments through the applications on their mobile phones, smart devices etc. without any need to make a call to the hospital and wait for long time for an appointment.

2.1.1 General IoT in Healthcare

IoT transforms the medical data into insights for smarter patient care. Healthcare is now more technologically advanced and is all about connecting things together. Therefore, IoT is so important in healthcare. By leveraging devices like connected sensors and other types of things that people can wear all that information can be placed in the cloud, and doctor/caregiver can easily monitor the real-time information of the patient.

IoT can support potentially life saving applications within the healthcare industry by collecting data from the bedside devices, viewing patient information, and diagnosing in real-time the entire system of the patient care (see Figure 2). Today, many healthcare devices operate throughout the world which becomes an issue as it can cause data loss and mistakes in diagnosis. To overcome this the data which is collected will be stored in cloud.

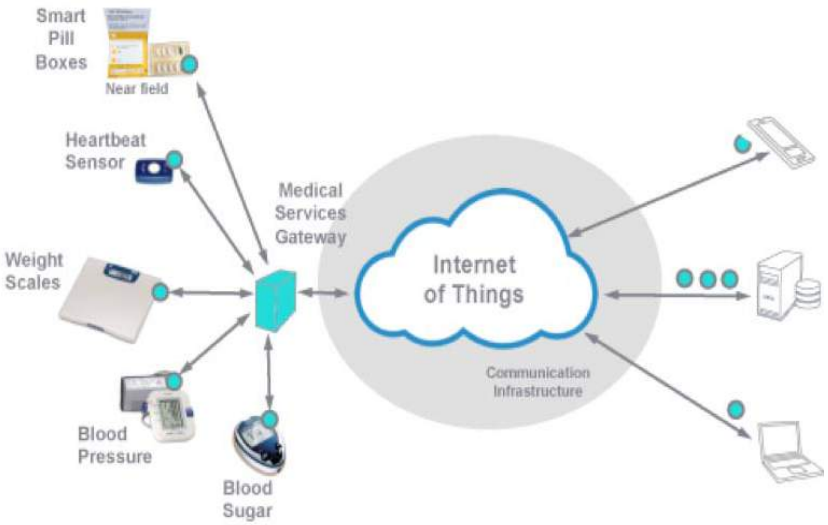

Figure 2: General IoT in healthcare [7].

The caregivers or doctors have the ability to easily monitor and manage the patient health and can save precious minutes everyday. Without having to manually visit each patient, the caregiver/expert or doctor can give a remote diagnosis and track the medical assets. Using the sensors and Wi-Fi, the right department in the hospital can be located while retrieving sensual information.

A. Clinical Care

Making use of IoT-driven sensor, the patient is continuously monitored. The patient requires close attention due to their physiological status, which is a noninvasive monitoring. The patient status is monitored by the sensor which collects the physiological information of the patient to be analyzed, making use of gateways. The obtained information will be stored in the cloud [8].

This information is then sent to the caregivers/doctors wirelessly for further analysis as shown in Figure 3. This improves the quality of care and also reduces the cost for the patient's [8].

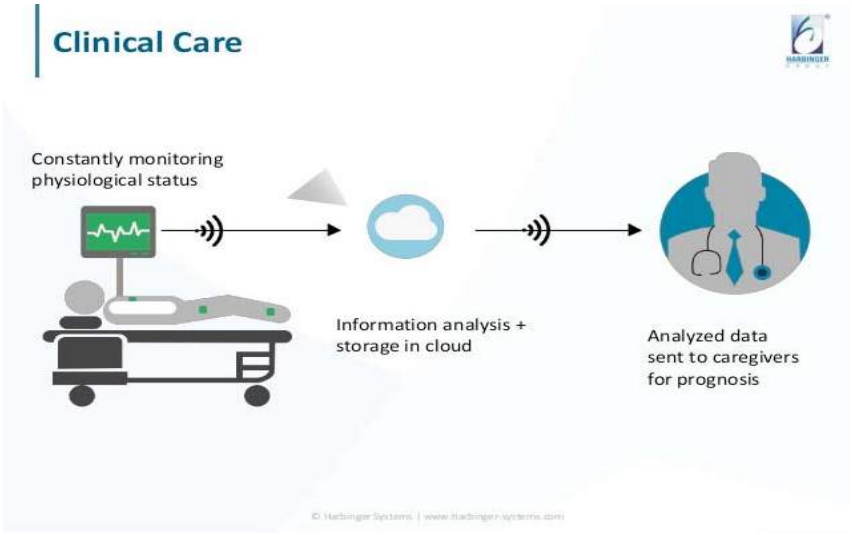

Figure 3: Clinical care system which constantly monitors the physiological status [9].

B. Remote Monitoring

The general IoT in a remote health monitoring systems tracks a patient's vital signals in real-time and responds if there is any problem in patient health. A device is attached to the patient as shown in Figure 4. It transmits the data about the vital signs from the place where the patient is located. The transmitter is connected through a telecom network to a hospital [8]. The hospital has a remote monitoring system that reads about the patient's vital signs. In the same way when the sensor is implanted into the patient's body, the data can be electronically transmitted. The information which is transmitted will be securely sent to healthcare providers/caregivers.

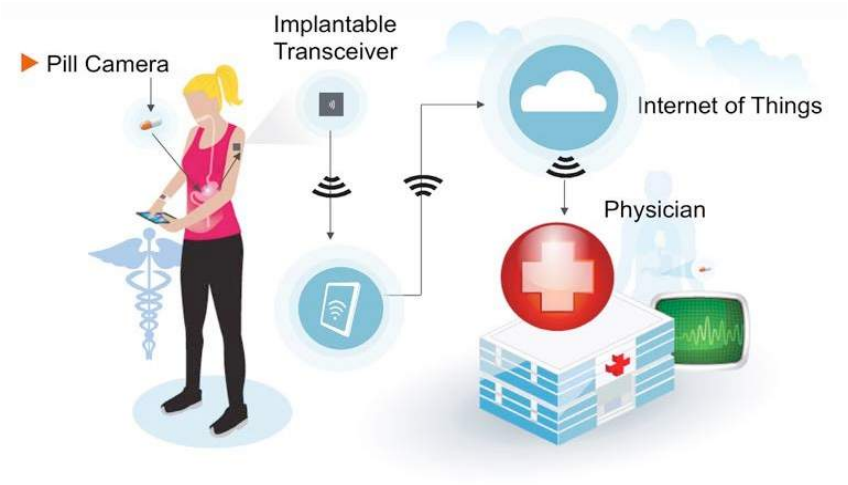

Figure 4: Remote health monitoring system [8].

2.1.2 Applications for IoT in Healthcare

Blood Pressure Monitoring

Blood pressure (BP) is one of the most important physiological parameters of the human body. Safe and simple to use blood pressure monitors have become common [10]. With the development in the healthcare system, the healthcare equipment/system is connected with an IoT device or sensors that makes an easy communication between the patient's and doctors/caregivers. An electronic blood pressure monitor is connected with the IoT sensor that collects the real-time information of the patient BP levels.

Rehabilitation System

A rehabilitation system can enhance and can restore the functional abilities and improves the quality of life for the people who are suffering with some disabilities in terms of mitigating problems that are linked with aging populations and when there is a shortage of health experts [10]. There is a community-based smart rehabilitation system that provides an effective treatment. A convenient adequate interaction and allocation of medical resources according to patient requirements can be done by an ontology-based automating designing method connected with IoT-based smart rehabilitation system [11].

Oxygen Saturation Monitoring

The pulse oximeter is a device which continuously monitors the blood oxygen saturation of the patient in a noninvasive way [10]. There are many advances in the communication technology, i.e., wireless networks, and medical sensors are booming at present days because of the low power consumption and low loss. The continuous monitoring pulse oximeters are used in many medical applications to know the oxygen levels in blood and also the heart rate (HR). The IoT sensor which is connected to the patient body will monitor and sense the patient's heart rate and oxygen levels, which can limit the patient activity [12].

Wheelchair Management

Wheelchairs are used by the people who are suffering with a physical illness and they cannot walk or any other physical disabilities. Wireless body area networks (WBANs) can connect smart objects with the Internet, to be used as a people-centric sensing (sensor) device for wheelchair users. There will be pressure cushion (which is a resistive pressure sensor) that will detect when the human body is falling down from the wheelchair. A smart wheelchair has another accelerator sensor which detects the falling of the wheelchair [13]. The doctor/caregiver can continuously monitor the patient's data from the hospital.

Healthcare Solutions Using Smartphones

Mobile devices and healthcare apps provide many benefits for health care professionals (HCPs). There are many medical healthcare applications which are now available in many ways and ready to access such as health record, information and time, communication and consulting with doctors, patient continuous monitoring and proper clinical decision making [15]. With the use of smartphone apps and sensors, the point of care and also the access to care has been increased and will support the improved patient outcomes.

General health care apps in smartphones

Table 1: General health care apps for smartphones (see in [10]).

Healthcare apps	Description
Calorie Counter	Keeps on tracking the food that we have consumed and calculates the fat and also the weight as well as cholesterol present in our body.
HeartRate Monitor	It continuously monitors the heart rate and collects the related real-time information.
Blood Pressure Monitor	It collects the blood pressure level of the patient, analyzes and records the data.
Body Temperature	It keeps tracking the body temperature and gives the information when the body temperature is increased.
Pedometer	Pedometer is available in many smartphones. It records the number of steps we have walked and gives the information of how many calories are burned per a unit of time.
Water Your Body	Many of us use this app because it reminds us to drink water every hour and tracks our body water drinking habits.
OnTrack Diabetes	It keeps on monitoring the blood glucose level and gives proper medication to manage diabetes.
Skin Vision	It keeps on tracking the skin condition which enables us to identify early if any skin disorder occurs.

EyeCare Plus	It monitors the eyes vision and then which is analyzed and tested.
Asthama Trackers and Log	It monitors real-time information of the patients asthama.
Cardiomobile	It monitors the cardiac rehabilitation which is done remotely on a real-time basis and collects the data.
Pill Remainder	If the patient forgets to take a pill it reminds the patient medication times.
Fall Detector	It continuously monitors the humans activity levels and if any issues occur, it alerts us on falling.

2.1.3 IoT in Healthcare for Babies and Infants

For parents, nothing is more important than keeping their baby happy and healthy. Babies cannot speak and tell if they are hungry or if it feels like hot, cold, sleepy. Now, IoT wearables can make all the difference. IoT has now been developed for babies and infants to help their parents. Parents can monitor their infant's health wirelessly (for example via Bluetooth technology), there are many IoT wearables, devices and smart sensors which can continuously monitor the baby's/infants vital signs and send that data directly to a mobile device. An infant monitor can collect data and send real-time information of the infants each and every moment.

2.2 Challenges for IoT in Healthcare

- Security and privacy: There could me many potential implications, so that the devices which are connected (connected devices like smartphones, sensors etc.) [2] can be at a risk from hackers or hacking [2]. Whenever there is transmission of data from one device to another it must be encrypted.
- Integration: Integrating multiple devices and protocols within the network is another challenging task for implementing successful IoT in healthcare. There are many smartphones that are connected to the network which actively collect data. There are also different communication protocols that complicates the process of aggregating the information.
- Technology adoption: Creating a new app with innovative ideas that helps doctors and patient's, this is not enough to pay for a new technology. The product which is developed should also be monetized in the healthcare system.

2.2.1 Advantages of IoT in Healthcare

- Treatment for diseases are done before they get out of hand, because the patients are continuously monitored and the caregivers or providers can access the real-time data and improve the disease management [16].

- The automated data and the smart monitoring which are controlled by the devices connected with the IoT and the decisions are made easily based on deep analytics which reduces errors.
- Patient monitoring is done on a real-time basis, which significantly cuts down the unnecessary doctor visits and also cuts down the hospital stays. This can reduce the cost for patients [16].
- Connected healthcare enables the caregivers to get access to real-time information when the patient is continuously monitored and the decisions are taken properly. This can help and provide timely care that improves the treatment outcomes.

2.2.2 Disadvantages of IoT in Healthcare

- There is a compatibility problem for the IoT in healthcare, because currently there is no standard for tagging and monitoring with the sensors.
- Privacy and security is one of the big issue with IoT in healthcare, i.e., all the patient-doctor data must be encrypted.
- The software can be hacked by other users and the personal information is misused. These possibilities are endless in IoT.

3 RELATED WORK

Recent advances in healthcare systems have opened up great opportunities for the implementation of smart environments and smart healthcare. Especially in the health and medical field, several sensors have been developed to evaluate different types of vital signs such as heartbeat, body pressure, temperature and oxygen levels. Researchers have addressed several issues in healthcare and IoT in healthcare. This section describes about research on healthcare system using different sensor networks.

In [1], a comprehensive review on usage of IoT in healthcare system has been discussed. In this paper, they have addressed several methods and things that are used in IoT in healthcare systems, challenges of IoT in healthcare. A methodology for the prediction of chronic disorders from the wearable healthcare devices have been discussed to bring the smart healthcare solutions anywhere, which makes the methodology useful for decision making.

In [5], an interference aware scheduling of sensors in an IoT enabled healthcare monitoring system for a real-time smart health monitoring system has been proposed. There are many sensors connected to a local data processing unit with a shared channel that has a fixed bandwidth. There are many sensors which have a wide variety of channel access requirements. The access provided to the channel should be discrete, so that the sensors which are used by smart health monitoring system should make use of the required bandwidth and also delay in the shared channel. To solve this problem, a scheduling technique for a IoT based system has been implemented that nullifies the interference among the different sensors and reduces data loss.

In [6], an IoT-aware architecture for smart healthcare systems is proposed. Implementing an IoT-aware smart architecture for automatic monitoring and tracking of patient's personal, and biomedical data within hospitals and nursing institutes. A smart hospital system (SHS) is developed, which relies on different technologies, specifically RFID, WSN. Smart mobiles are interoperating with each other through a constrained application protocol (CoAP)/IPv6 over low-power wireless personal area network (6LoWPAN)/REST infrastructure. SHS can collect, in real-time both environmental conditions and patient's physiological parameters through an ultra-low-power hybrid sensing network (HSN) which is composed of 6LoWPAN nodes integrating the UHF RFID functionalities. The data which is sensed, is delivered to a control center where an advanced monitoring application (MA) makes these things easily accessible by both the local and remote users via REST web service.

In [11], an IoT-based smart rehabilitation system has been introduced. In this research, an ontology based automating design methodology for the smart rehabilitation system using IoT technology is introduced. The rehabilitation system is established through Wi-Fi and other technologies such as RFID-based short-distance radio communication technology, unique identifier (UID) based identification technology, and global positioning system (GPS) technology. A service-oriented architecture is developed which is used for designing, implementing, managing and other kinds of healthcare services. After designing and implementation of the IoT rehabilitation system, each and every patient will get good treatment and they are well diagnosed with the two rehabilitation strategies. This system takes care of more than one patient.

In [12], a wireless system for remote monitoring of oxygen saturation and heart rate has been proposed and described. In this research, making use of the pulse oximeters, the level of oxygen in the blood and also the heart rate of the patient is measured. Then, this measured data is transferred to a central monitoring station through a WSN. The patient will be

continuously monitored and the central monitoring station receives the information of the patient's oxygen saturation level and heart rate through the WSN. If any problem occurs, an alarm will be activated automatically. A graphical user interface (GUI) is developed to display the results and measurements (data) of the patients.

In [17], a secured IoT-based healthcare system with body sensor networks has been proposed. It operates through BSN architecture to achieve system efficiency and robustness of transmission within public IoT-based communication networks. The utilization of robust crypto-primitive to construct two communication mechanisms, one is for ensuring transmission confidentially and another is for providing the authentication among the smart objects, the local processing unit and the backend sensor. The healthcare system is implemented with the Raspberry PI platform to demonstrate the practicality and also the feasibility of the mechanisms.

In [18], building an IoT-aware healthcare monitoring system is introduced. A prototype is presented for the implementation of an IoT-aware healthcare monitoring system, which will reduce the cost of healthcare and will increase the need of specialized care. It alerts about the patient's health condition in real-time, if any problem is experienced, and if the patient needs any medical attention or hospitalization. In this paper, the authors also focused and discussed about how to build an ad-hoc extensible healthcare monitoring system during runtime by using low cost wireless sensors and already existent IoT technology as a communication platform.

In [27], design of Infant health condition check solution based on a wearable device with attitude heading reference system has been proposed. The authors had proposed a design for infant condition check solution to decrease infant mortality and accident rate by using a wearable device and camera. This design has utilized the AHRS to measure the infant's attitude, and they have used various biometric sensors to the information. Based on this, parents can observe the infant's health condition.

4 USING SMART SENSORS AND DEVICES

4.1 Smart Devices and Sensors and their Methodology

Smart healthcare technology is one of the most emerging technology in the present healthcare system. By making use of smart wearable devices, the patient generated data can be sent to electronic devices or any health records so that the doctors/caregivers can directly monitor the patient activity in real-time. These can reduce the healthcare costs. There are several connected smart devices that have been developed in the healthcare industry.

In old days' patient's had come to the doctor in order to talk about their breathing problem, sugar levels etc. Today, patient's have access to wearable devices, smartphone apps, sensors that they can use at home can gather all the data and sends that data to the doctor, so, that the doctor can monitor the patient and gives a proper medication if any problem occurs. There are some developed wearable devices, smartphone apps and sensors. We discuss about some of them which mostly are used.

Helo Wristband

A real-time health monitoring device which monitors the patient's health 24/7 with a disease prediction shown in Figure 5. It can monitor each and every moment in the body like exercise, emotions, blood pressure, heart rate and electrocardiogram (ECG). This wristband has active sensors that can sense your human body. If you have any problem, you can send signal to your family members, and they can automatically trace the GPS position of the patient. This will keep us in contact with smartphones [19].

Figure 5: Helo wristband to monitor the patient in real-time [20].

Wireless Blood Pressure Monitor

This device is used when the patient is suspected to have high blood pressure like hypertension. This wireless blood pressure monitor is wirelessly connected to a smartphone app through Bluetooth. It monitors the patient health in real-time and also alerts the patient to take proper medication [21]. The device is shown in Figure 6.

Figure 6: Wireless blood pressure monitor [21].

AliveCor Heart Monitor

This smart sensor is attached to the phone case as shown in Figure 7., It is wirelessly connected to the smartphone app, it collects the ECG recording, and analyzes the data. If there is any difference in your ECG level, you should contact the physician [21].

Figure 7: Smart phone case sensor [21].

4.2 Smart Devices and Sensors for Babies and Infants

Today, many babies are born premature in the world, some of them may die or some of them will suffer from physiological problems with loss of body water. The fear of the parents is about their infant's health condition. Now, technology has been developed to improve the quality of healthcare. Smart wearable devices and sensors are booming in the present emerging technology. There are some smart devices and sensors that would help the parents about not to worry about their infants.

Baby Check

The baby check is a wearable baby monitor, it straps on to the babies arm easily and tracks the baby's body temperature and movement (see Figure 8). This baby check wearable device will sync with the parent's smartphone app via Bluetooth technology. The data of the baby can be monitored in the app and notifies you if anything happens.

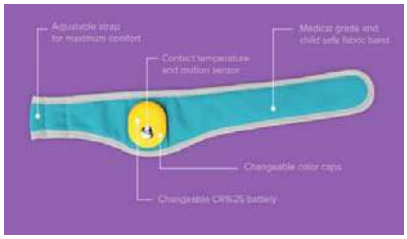

Figure 8: Smart wearable baby monitor [25].

Allb Baby Monitor

It is a wearable smart device shown in below Figure 9. It should be clipped onto the two layers' of the diaper or to the clothes of the baby. The device is wirelessly connected to the smartphone app via Bluetooth technology. It can monitor the body temperature and breathing phase of the baby and the reading will be displayed on the smartphone app. It alerts you when ever the readings are too low or too high.

Figure 9: Smart device to track the baby temperature and breathing levels [25].

Smart Clothing

The smart clothing sensor technology is shown in Figure 10. It tracks the baby when sleeping. The sensor is connected to a home Wi-Fi network wirelessly. It is connected to the smartphone app through Bluetooth. If there are any changes in the baby's activity, it will be updated to their parents through the mobile via Bluetooth technology [22].

Figure 10: Smart clothing tracker when baby is sleeping [22].

Smart Sock:

This Owlet Smart Sock 2 sensor monitors the baby heart rate and oxygen levels in real-time when the baby is sleeping. It notifies the parents through a smartphone app, if the heart rate and oxygen levels goes out of preset zones. In this thesis, this Smart Sock 2 sensor is used because it is one of the finest sock sensors for the new parents to feel happy about their baby (see Figure 11).

Figure 11: Smart sock 2 for babies [23].

Reason Behind choosing the particular Smart Sock 2

The reason behind choosing this particular Smart Sock 2 is because of SIDS. The sudden death happens when the baby is suffering with breathing problem and if the heart rate goes down. By using this Smart Sock 2, real-time information of the baby can be monitored and we can observe the heart rate and oxygen levels of the baby when the baby is asleep, and also it notifies when the baby is wiggling and feeding. This device gives the readings when the baby is feeding also. Most of the other devices will not notify the parents while the baby is feeding and the metrics like heart rate and oxygen levels both are not tracked using only one smart device or sensor.

This Smart Sock 2 is wirelessly connected to the base station, and the base station will notify the parents through lights and sounds (discussed in section 5.2). It also communicates with the smartphone app in the way that the base station wirelessly connects to the smartphone app, and the app will alert the parents by giving notifications.

5 TESTBED IMPLEMENTATION

5.1 Experimental Setup

Firstly, the Owlet Smart Sock 2 is introduced which is a smart reliable sensor. The Smart Sock electronic is plugged into the base station by making use of a micro USB. The base station has two cable slots in which one is used by the sock electronics to charge the smart sock and the other slot is for the Power USB block as shown in Figure 12.

Block Diagram

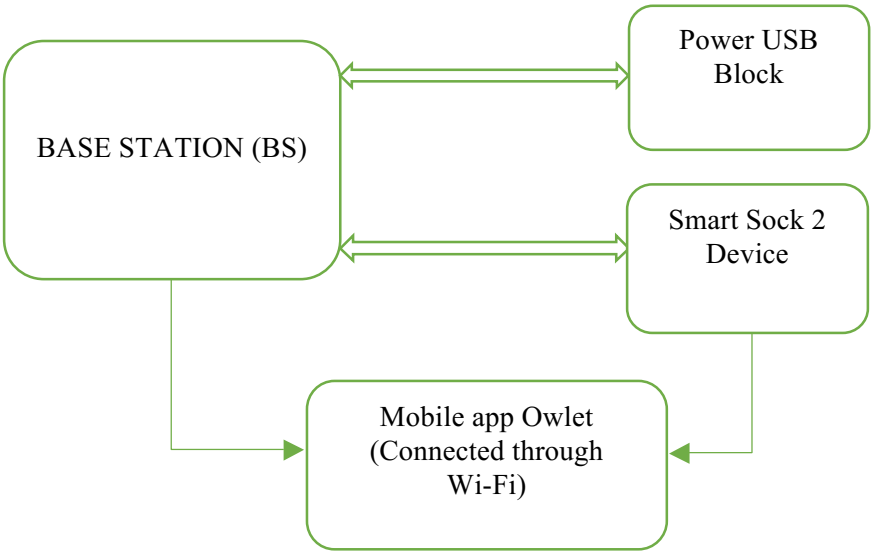

Figure 12: IoT healthcare for infant's architecture.

To set up the Smart Sock 2 the parents should connect the sock to the base station which then connects to any home wireless network. Then, the parents should install the Owlet app in their mobile phone. After the installation process is done, the base station will ask to register for the home's wireless network as shown in the Figure 13.

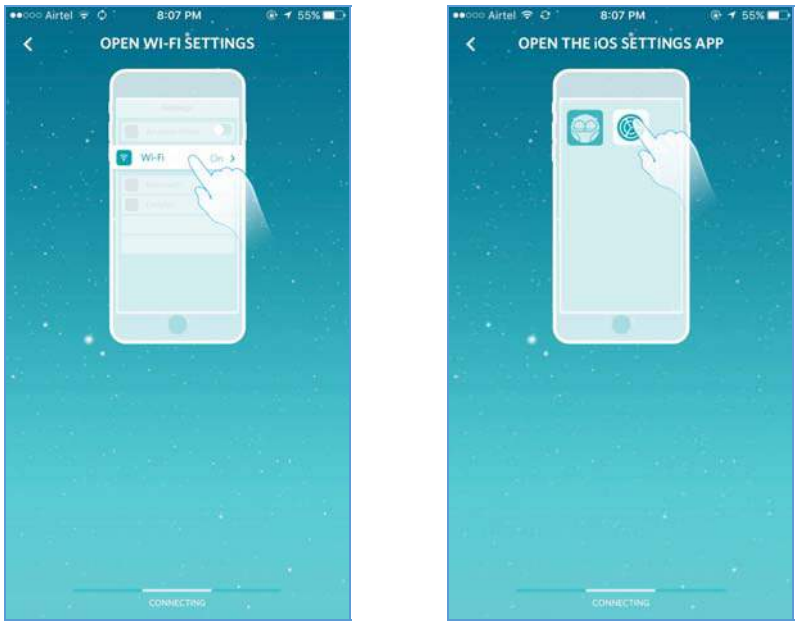

Figure 13: Connecting to wireless network (Screenshots).

Then, by opening the settings in the smartphone, the base station should get registered by connecting it to the Owlet sock (Owlet Wi-Fi) as shown in the Figure 14. After connecting to the Owlet network, it will redirect to Wi-Fi the setup in the app which has been installed. Then, the profile should be completely filled with the baby's information, the app gives certain instructions about the sock that has to be fitted to the baby's foot. After that, parents can plug in the base station near to them and observe their baby.

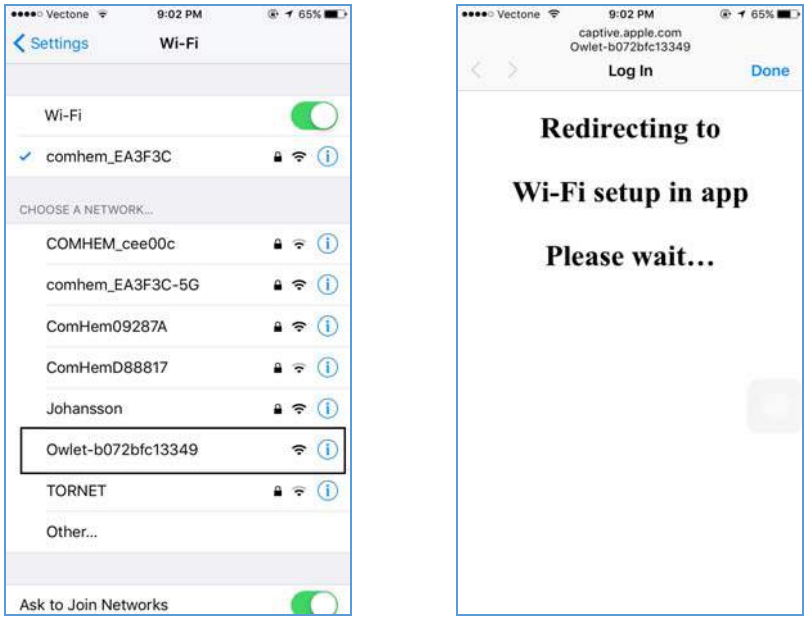

Figure 14: Redirecting to setup the Wi-Fi in app (Screenshots).

In Figure 15, the mobile app connects with the base station wirelessly to display the real time information of the infant's heart and oxygen levels. To check whether the base station is working, press and hold the small button which will be in between the Wi-Fi and the sock under the base station for 6 seconds and one can hear the red notification sound.

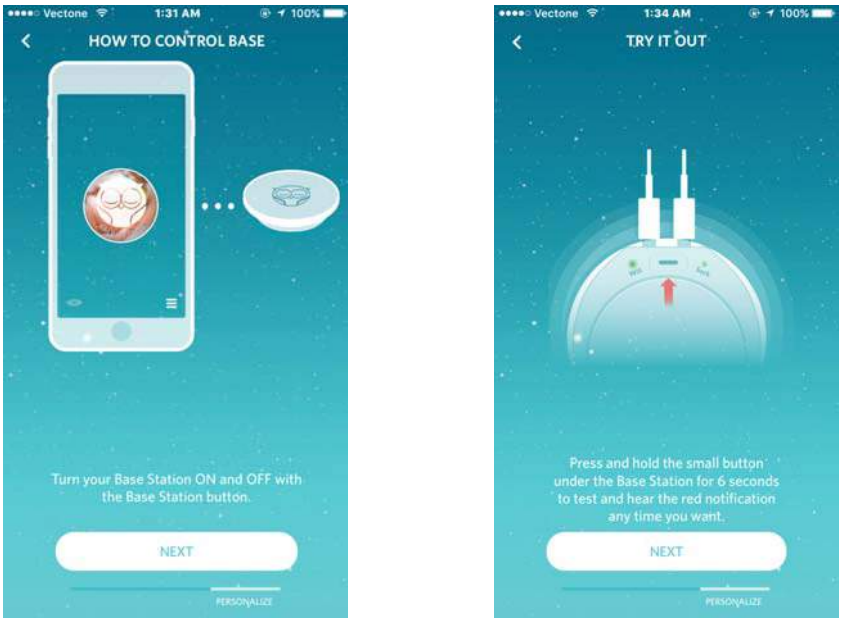

Figure 15: Smartphone app wirelessly connected to base station (Screenshots).

SMART SOCK: The Owlet Smart Sock 2 helps the parents to check their babies by monitoring the heart rate and oxygen levels in real time. The smart sock comes with three sock sizes to fit for babies from new born to up to 18 months old.

Figure 16: The mobile app is wirelessly connected to the base station [26].

BASE STATION: The base station is wirelessly connected to the home Wi-Fi network and it wirelessly collects the baby's data from the smart sock which is a reliable sensor. The Smart Sock 2 connects with the Bluetooth to the base station and gives the signal if anything happens or something goes wrong.

MOBILE APP: The Owlet smartphone app helps you to get the real time information of the baby's heart rate, oxygen levels and if the baby is wiggling and also it notifies you if it goes out of range (see Figure 16).

5.2 Communication and Connectivity

The connectivity between the base station to smart sensor and base station to smartphone app is connected via Wi-Fi technology. The base station will broadcast only through open Wi-Fi network. If the wireless network has username and password, then the smart sensor and the base station are not allowed to register. It has been connected in two ways, one way is that it is connected to the home wireless network and the other is through Hotspot from another open wireless network. We can add to multiple Wi-Fi networks if needed by selecting the option add Wi-Fi network in the smartphone app as shown in Figure 17.

Figure 17: Connecting to Wi-Fi (Screenshot).

The base station is the primary alert that communicates with parents through lights and sounds. The Owlet Smart Sock 2 will monitor when the baby is sleeping or baby is alone otherwise it may give false alerts. When the sock monitor is in use, the base station should be plugged in otherwise the base station will be turned off and the sock cannot monitor the baby in real-time. As such, the base station cannot notify the parents if any problem has occurred. The communication between the smart sock and base station is supported, when the base station is turned on.

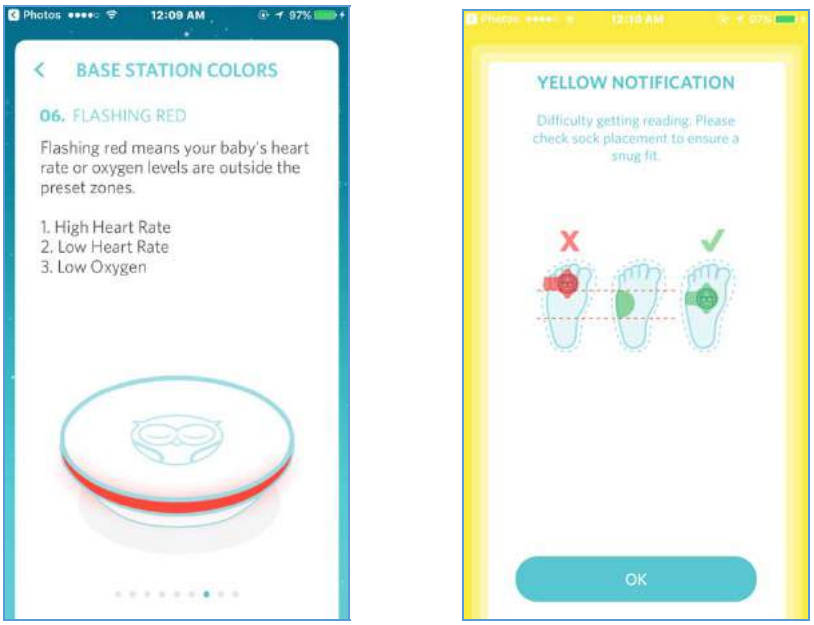

Figure 18: Alerts when the sock is not placed properly (Screenshots).

If the Smart Sock sensor is not placed in right way on the baby, then we will get a lot of false alarms like yellow and red lights. In Figure 18, the yellow light notifies you through mobile app, when the sock is not placed properly and the red alert notifies you if the baby is far way from base station or when low oxygen levels are detected. So, make sure the smart sensor touches the skin snuggly.

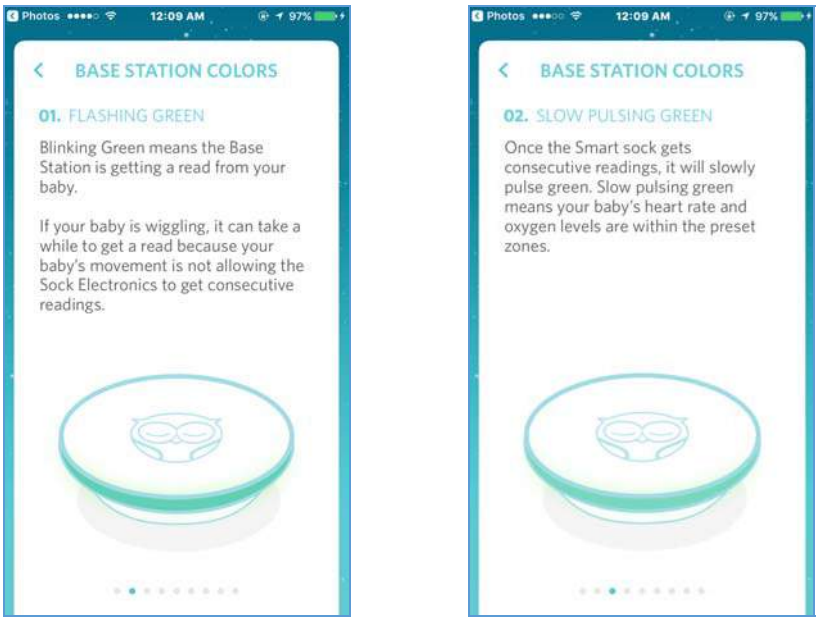

Figure 19: When smart sock shows different lights (Screenshots).

If the base station starts blinking green the there is nothing to worry about, because it starts and tries to get the readings of the baby but it will take some time to get the readings. If there is slow pulsing green light showing on the base station, this means the readings are normal as shown in Figure 19, i.e. heart rate and oxygen levels are normal.

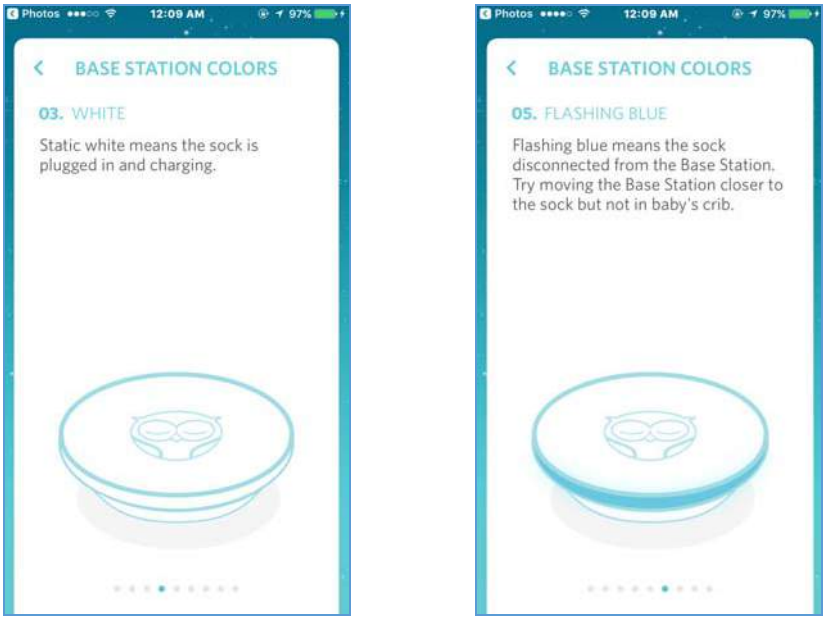

Figure 20: When the sock is charging and when disconnected from base station(Screenshots).

If the base station is blinking in white color then the smart sock electronics is charging, this means that the sock is plugged into the base station. If the base station is flashing blue, this means that the sock is disconnected from the base station as shown in Figure 20. The flashing blue alerts you when the sock is far away from the base station.

6 EXAMPLE FIELD TEST AND RESULTS

The Smart Sock 2 sensor is placed on the infant in the process of care to improve the accuracy of measurements and the response time for result analysis. The Smart Sock 2 acts as an infant monitor or baby monitor that can collect the data and send real-time information of the infants breathing phase, heart beat, wiggling and activity level. The advance in sensor and connectivity technology are allowing the devices to collect, record and analyze the data that was not accessible before. This means, it can collect the important data over time, which can be analyzed easily and then used to enable preventive care. In particular, this device can help to prevent SIDS.

6.1 Example Field Test

An example field test has been conducted based on a parent volunteering with its baby to participate in this test. The Owlet baby monitor Smart Sock 2 is placed on the baby's foot of age 14 months. We had setup the environment at the home of this family. The test subject baby is of Chinese origin. The data is collected when the baby is sleeping or when the baby is feeding. By doing this example field test, we have collected some results, which have been recorded and analyzed, as shown in the Figure 21.

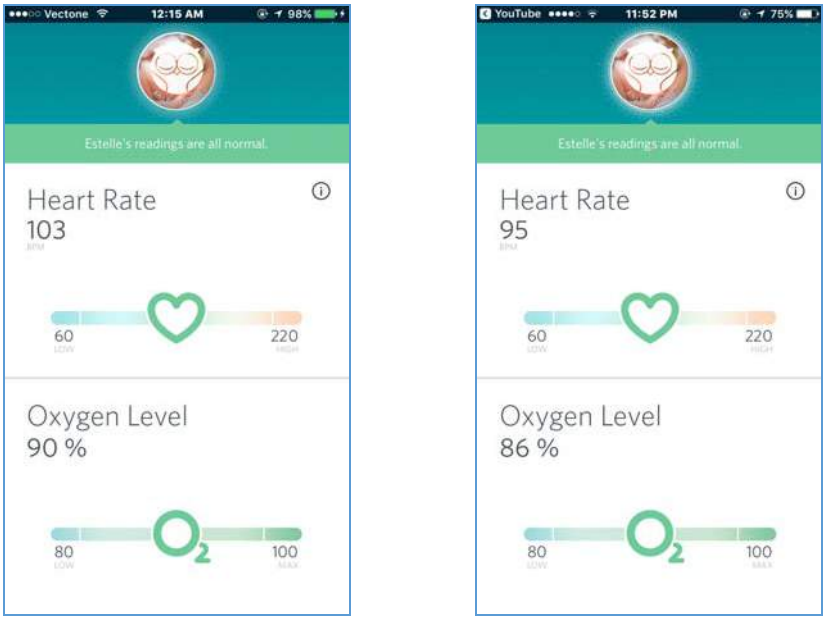

Figure 21: Readings of day 1 and day 2 (Screenshots).

The data is collected from the baby "Estelle". Day 1, Estelle's readings are normal with the heart rate 103 BPM and the oxygen levels are 90% as shown in Figure 21. On day 2, the readings are normal but the heart rates and oxygen levels goes down to 95 BPM and 86%, as shown in the Figure 21. The readings being normal when the heart rate goes down also. The Owlet baby care app can notify us if the heart rate and oxygen levels are low.

The data which is shown in Figure 22, is about the baby's information that is collected and recorded on day 3 and day 4. The heart rate and oxygen levels are normal on day 3, i.e. 106 BPM and 89%. On day 4, there is a slight difference in the readings heart rate i.e. 105 BPM and oxygen level is 91%.

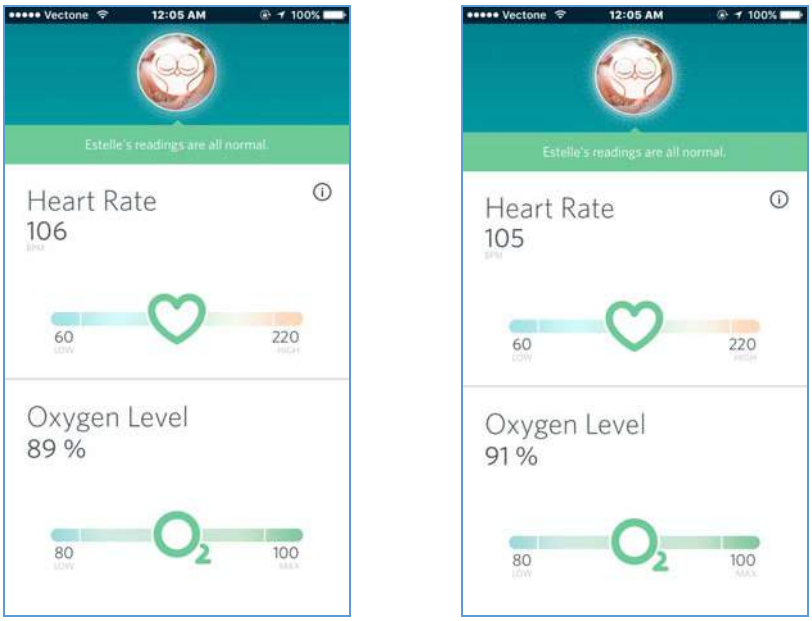

Figure 22: Readings of day 3 and day 4 (Screenshots).

When the baby is asleep, low oxygen level is detected. The low oxygen levels were detected in two ways. One case is when the baby's oxygen level is indeed low and the other case is due to false alarms. When low oxygen levels are detected, it notifies by showing a red notification an alert message as shown in Figure 23. It is also designed to notify the parents if the heart rate and oxygen levels are going out of the preset zones.

Figure 23: When it shows a red notification alert (Screenshot).

The baby started wiggling when she is asleep. In this situation, the base station will notify the parents through the mobile/smartphone app when the baby starts wiggling as shown in Figure 24. The smart sock will stop sensing the baby or pause the information if the baby movement is continuous.

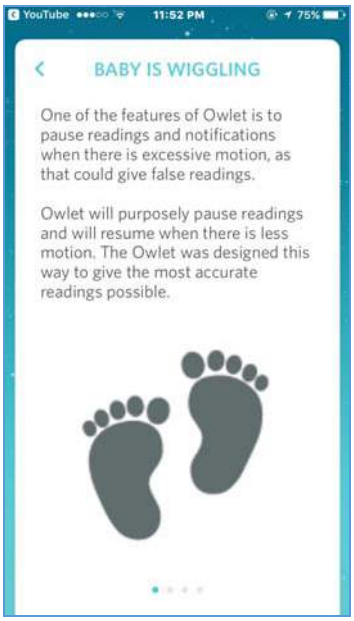

Figure 24: When the baby is wiggling (Screenshot).

6.2 User Experience

The Owlet Smart Sock 2 helps to do checking for the parents by monitoring real-time information of the baby's (0 – 18 months) heart rate and oxygen levels. Eventually, the mobile app takes a few minutes to get the readings. However, the user baby is 14 months old and sometimes not allowed to place the smart sock on her foot. When she is in deep sleep, parents are placing the Smart Sock 2 to her foot. Some times, we got false alarms because the baby is moving more and trying to remove the sock. We think this Smart Sock 2 will be more useful for babies below 12 months and for new parents.

ADVANTAGES:

There are some advantages of finest Smart Sock 2.

- It is better for small babies.
- Informs if the oxygen levels and heart rate goes out preset zones.
- Reduced cost and gives quality of care.

DISADVANTAGES:

There are some problems the test user has experienced while doing the example field test.

- Several false alarms when the baby is moving.
- Smart Sock 2 battery life is an another problem.

6.3 Results

There are some results we got from the baby by doing the example field test. We can observe the heart rate and oxygen levels are changing everyday. We can see on day 5 the oxygen level is 83%, if it goes below 80% then the low oxygen levels are detected for the baby. In this thesis, heart rate and oxygen levels are selected as metrics because most of the premature babies may have complications with this, and many sudden deaths happen because of low oxygen levels. The peak readings of the baby's heart rate and oxygen levels are calculated (see Table 2).

Table 2: Baby's heart rate and oxygen levels observed for 7 days.

DAY	HEART RATE	OXYGEN LEVELS
Day 1	103	90%
Day 2	95	86%
Day 3	106	89%
Day 4	105	91%
Day 5	97	83%
Day 6	100	83%
Day 7	120	88%

Figure 25, shows us that the heart rate is fluctuating and it is not constant. From day 1 to day 6 we can see that there is slight change in the rate, on day 7 again the heart rate is increased to 120 bpm. If the heart rate goes below 60 bpm, it notifies the parents by giving the red notification. Here, we can observe the heart rate which we have checked by doing example field test for 7 days are normal.

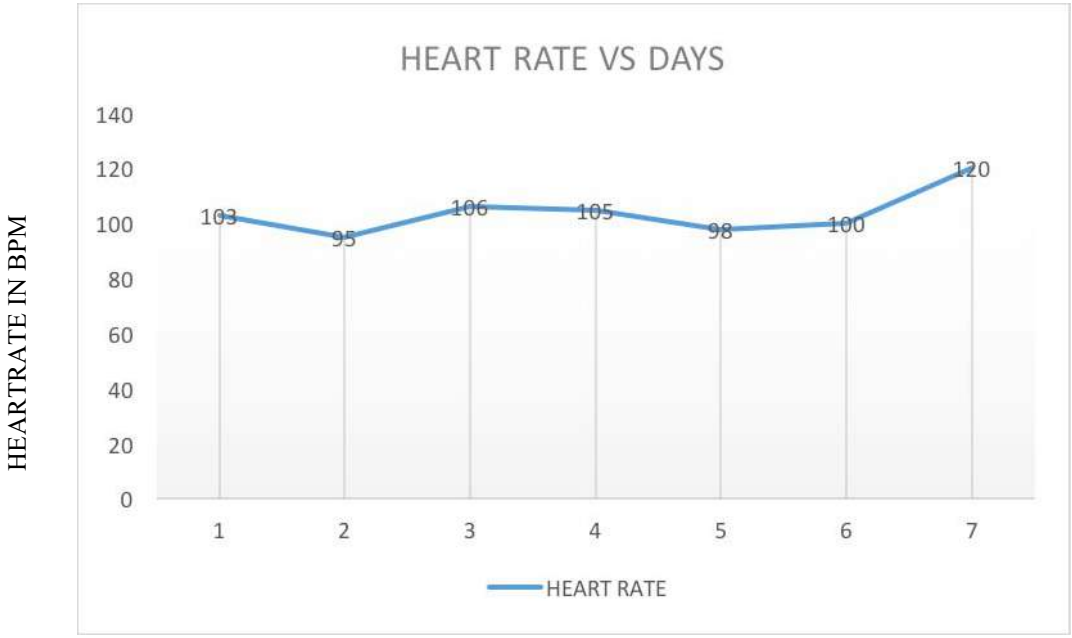

Figure 25: Represents a graph between heart rate versus days.

Similarly, the Smart Sock 2 also tracks the oxygen level. Here, we can see the oxygen levels are also fluctuating but they are normal. For the first 4 days the oxygen levels are in between 88% to 90%, but, on day 5 and day 6 it went to 83% of oxygen level. It is not constant on everyday, it keeps on changing. The low oxygen levels are detected if it goes below 80%.

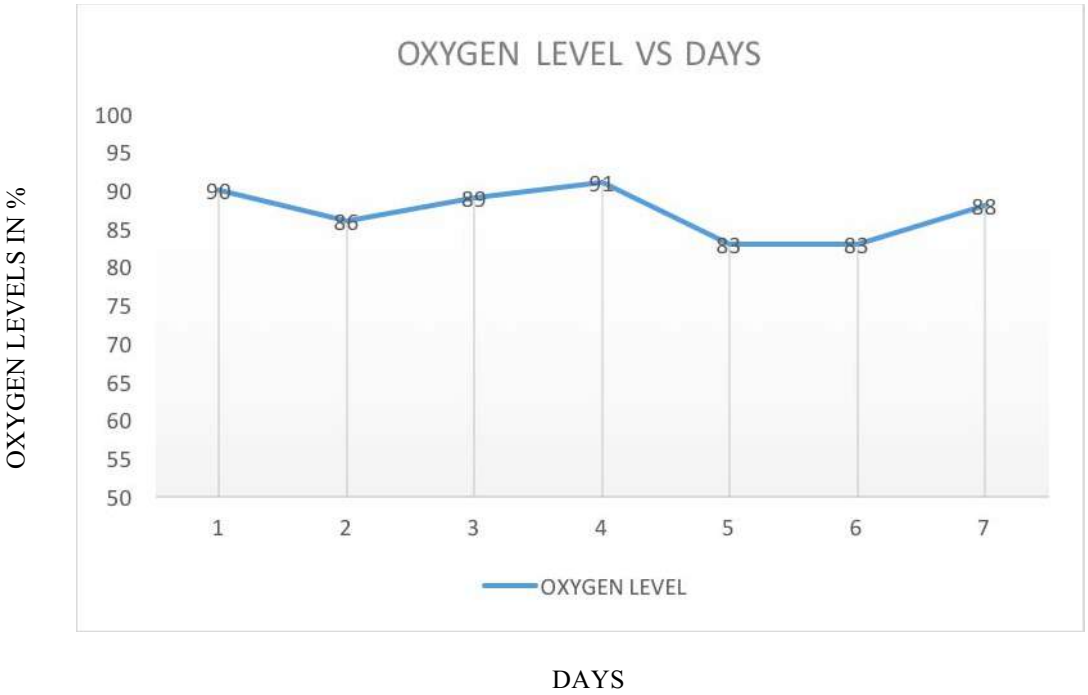

Figure 26: Represents graph between oxygen levels versus days.

7 CONCLUSION AND FUTURE WORK

Firstly, it has been started by studying and finding different sensors and devices for healthcare in IoT. The proposed solution for infant healthcare is based on the Owlet Smart Sock 2 (wearable device). This device is unique because it is working actively in any situation. It gives real-time information of the infant's heart rate and oxygen levels and notifies to the parents if readings go out of range. The reason behind choosing the metrics heart rate and oxygen levels are due to SIDS, because the sudden death happens mostly in the case where oxygen levels are low and when the heart rate goes down. The system is implemented using the Smart Sock 2, base station, smartphone, and open Wi-Fi network.

However, there are some problems we need to solve. If we go in another area, which is not a home Wi-Fi network or business Wi-Fi network, it is getting trouble while connecting. It is quite difficult when getting to security matters. Also, the battery life time of the Smart Sock 2 sensor should be improved. The base station should come with a battery instead of plugging in all the time.

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