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Internet of Things (IoT) in Healthcare

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***Abstract*— The Internet of Things is a technology that promises to significantly change people's lives in today's world. In recent years, IoT has impacted every aspect of life, including healthcare, where it has become highly productive in improving the quality of medical services provided to patients. Using sensors, IoT is capable of continuously and in real-time monitoring the health status of patients. This is particularly helpful for patients with chronic illnesses as it can assist in preventing various complications. Below, we will discuss the theoretical context of IoT, explaining the concepts of IoE (Internet of Everything), IoT architecture, and the role of telemedicine. An analysis is then conducted on several IoT devices used for health monitoring. This includes the Helo Wristband for blood pressure monitoring, AliveCor for heart monitoring, Baby Check for infant health monitoring, and an analysis of the case study of the use of the Smart Sock. The results encompass demographic aspects, physiological norms, false-positive alarm cases, and clinical significance. Through this study, the aim is to provide a detailed overview of the impact of IoT on health monitoring, addressing challenges and advancements in this technology in the healthcare field.**

Keywords— Internet of Things, Healthcare, Smart Sock.

I. Introduction

The concept of the Internet of Things (IoT) dates back to 1832 when the first electromagnetic telegraph was configured. With this device, it was possible to establish direct communication between two machines using the transfer of electrical signals. However, the true history of the Internet of Things began to take shape with the invention of the internet in the late 1960s. The first IoT device was created at Carnegie Mellon University in the early 1980s. A group of students at the university installed microswitches in a Coca-Cola vending machine, allowing it to report how many cans were available and whether they were cold through a network.

It was in 1990 when John Romkey first connected a toaster to the internet. A year later, a group of students at the University of Cambridge came up with the idea of using an internet camera prototype to monitor the coffee supply in a coffee machine. They achieved this by programming the internet camera to take pictures of the coffee inside the machine three times a minute. These photos were then sent to a local computer where it could be checked if there was coffee available.

Despite the concept dating back to 1832, the term "Internet of Things" wasn't coined until 1999 by Kevin Ashton. He used the phrase "Internet of Things" as the title of his project presentation related to a sensor he was working on at Procter & Gamble. He included the word "internet" to draw attention, as the internet was a hot topic at the time. In the early 21st century, the Internet of Things became a common topic used by the media, and significant developments were made, paving the way for the future of IoT. In 2000, LG Electronics introduced the world's first smart refrigerator, enabling consumers to order food online. Following this innovation, in 2005, a rabbit-shaped robot capable of providing weather forecasts, the latest news, and stock market changes was created [1]. The Internet of Things encompasses a network of physical objects, or "things," that are integrated into this network through sensors, software, and various technologies. The purpose is to connect these devices and systems and exchange data among them via the internet. These devices can range from everyday household items to more sophisticated industrial objects. Now that everyday objects can be connected to the internet through integrated devices, physical things can collect data and transmit it with minimal human interaction [2].

The number of IoT-connected devices exceeds 27 billion today, and experts expect it to reach more than 100 billion devices by 2030. This is due to the continuous advancement of new technology in every sector. The adoption of the Internet of Things is happening in every industry, including healthcare [3].

II. Literature review

To conduct the literature review, studies published between 2018 and 2023 were considered. The studies were retrieved from Google Scholar, IEEE Xplore, Elsevier, and Research Gate.

Sivani, T., and Sushruta Mishra [4] in their work provided an overview of IoT applications in healthcare, including remote patient monitoring, smart wearable devices, and technological data analytics.

Albahri, et al. [5] in their research offered a summary of IoT technologies and their applications in healthcare environments. It covers remote monitoring, telemedicine, and the challenges and opportunities presented by IoT in healthcare.

Jamil, et al. [6] focused on healthcare monitoring systems, discussing IoT technologies used for monitoring vital signs and health parameters of patients. It reviews the hardware and software components of IoT-based healthcare systems.

Abdulmalek, et al. [7] explored the application of IoT in healthcare, emphasizing its role in improving patient care, monitoring chronic diseases, and enhancing healthcare object management. It also discusses privacy and security concerns.

III. Problem statement

The number of various health issues continues to rise, posing a constant risk to individuals. With the increase in health problems, we also see a rise in the number of patients, which in turn leads to a shortage of healthcare professionals. In these circumstances, IoT has become more applicable in healthcare and the healthcare field in general. Effective healthcare is characterized by speed and accuracy. The best way to achieve these characteristics is by relying on a wide range of IoT-connected healthcare systems. Through IoT, the digital identity of each patient is maintained.

One concerning issue is healthcare for newborn babies. Sudden Infant Death Syndrome (SIDS) is the primary fear for new parents today. The cause of SIDS is often a blockage of the airways. In most cases, this tragedy occurs while the infant is sleeping or crying unexpectedly, without any warning signs. An effective solution to this problem is seen in the use of IoT devices, which can monitor the health of newborns in real-time using smart sensors. The collected data can then be sent to their parents.

Research Questions:

1. How can IoT devices enrich traditional methods of newborn healthcare?

2. How can IoT devices collect data to improve newborn healthcare?

3. How effective can an IoT device be in preventing SIDS in newborns?

IV. IOT-Theoretical Background

Over time, the use of the internet has evolved in nature and complexity, going through several developmental phases. Web 1.0 allowed users to read content, while Web 2.0 introduced the capability to create and share content with others. Web 3.0 brought semantics, facilitating easier communication between humans and machines. Web 4.0 is characterized by the ubiquitous connection of the web with users at all times and in all places, offering personalized services enabled by continuous data collection. Amid this internet development, one of the standout themes is undoubtedly IoT, which signifies a single object with three characteristics: connectivity everywhere and with identity.

IoT has four features that address challenges for users. First, the system is complex and ubiquitous, leading to an increase in the generated data. Second, devices make autonomous decisions without user intervention, thus reducing user autonomy. The third feature or challenge is that ambiguity outweighs visibility. The decisions IoT devices make can be undesirable and difficult for users to manage and monitor, leaving users unaware of data collection and potential risks. The fourth challenge is that with the use of these devices, internet security and privacy threats will increase [8].

A. Internet of Eveything (IoE)

As a new technology, IoT represents a modern wireless telecommunication network. IoT can also be referred to as the Internet of Everything, as it consists of every web-enabled device that collects and transfers data gathered from their surrounding environments. These interconnected devices are considered intelligent since they can facilitate machine-to-machine (M2M) communication and take actions based on the information they exchange among themselves. Most of these devices operate autonomously without the need for human intervention, although human interaction with these devices is not excluded. Users can provide instructions to these devices and have access to the data collected by them. The 5G internet generation has the potential to unlock IoT and actualize the physical world, which is expected to transform our lives in the next 25 years. IoT has made significant strides in hospitals and other medical facilities in a relatively short time and is further evolving, revolutionizing the field of healthcare.

B. IoT Ecosystem

The IoT ecosystem is composed of various components that enable its integration into different fields. Among these components, we can mention sensors, connectivity methods, artificial intelligence (AI), and the user interface (Figure 1).

1) IoT Devices

IoT devices refer to hardware components such as sensors, various household devices, smart machines, and more. These devices are programmed for specific applications and collect, store, and transmit data using the internet. By integrating these hardware components into other devices such as smartphones, industrial equipment, and medical devices, they offer a wide range of applications. Their structure can be quite simple for some devices, while others are more complex and sophisticated. Thanks to cost-effective computer chips and wireless networks, these devices exchange data at high speeds.

2) Sensors

Another vital component of the IoT ecosystem is sensors. Sensors detect and monitor the external environment, collecting information. They then transform this information into readable and understandable signals for humans and machines. Sensors come in various types, some being active and others passive, and they can be analog or digital. Among the most well-known sensors used in IoT systems are optical sensors, temperature sensors, humidity sensors, pressure sensors, and more.

3) Connectivity

Since IoT operates through the internet, connectivity is a key aspect of the IoT ecosystem. Depending on the size and scope of the IoT system, these networking connections scale. The types of these connections include:

- LAN (Local Area Network): This represents a set of interconnected devices in a single physical location, such as an office, building, or home. If it's a home network with one user, it's called a small LAN, while a LAN in an enterprise or school with thousands of users and devices is called a large LAN [9].
- PAN (Personal Area Network): It is a network for personal zones through which information is exchanged between individuals in proximity.
- MAN (Metropolitan Area Network): This is a computer network that connects computers within a metropolitan area, typically a city or an area with many buildings.
- WAN (Wide Area Network): It's a network that collects connected local area networks (LANs). The WAN's reach is extensive, and in essence, it represents a network of networks. The internet is the widest-reaching WAN in the country.

4) Artificial Intelligence (AI)

When looked at individually, IoT and AI represent two technologies with significant potential, productivity, and high capability. However, when these two are combined, the effectiveness increases even further. If a system is capable of reading a list of tasks and performing them intelligently, it is known as an artificial intelligence system. If we create a device by blending IoT and AI technologies, the result will be a device capable of data analysis and making intelligent decisions without the need for human involvement, and this represents the essence of the Internet of Things concept [10].

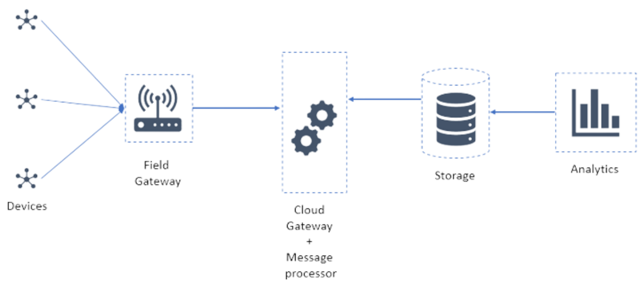

Figure 1. The basic structure of the IoT system.

5) IoT Architecture

IoT architecture refers to the use of sensors, actuators, processors, and transmitters. IoT represents a technology that operates by combining several other technologies that work together. IoT architecture involves a four-step process in which data flows from devices connected via sensors within a network. It then moves to the cloud to derive meaningful results, which need to be intelligently processed, analyzed, and stored. Various researchers have presented different versions of IoT architecture.

6) Three-layer architecture of IoT

One of the accepted models of IoT architecture is composed of three layers, which is generally acknowledged by academia and industry. Introduced since the early days of IoT technology, this architecture consists of the following layers: Perception, Network, and Application (Figure 2).

Perception Layer: It is responsible for perceiving the physical entities of things that surround us and are an integral part of the IoT ecosystem. This perception is enabled and based on sensing technologies such as RFID, WSN, GPS, NFC, medical sensors, etc. As a solution for objects that cannot be directly sensed, microchips are considered, which are attached to objects to provide sensing capabilities. Nanotechnologies and integrated intelligence play an essential role in creating small-sized chips that can be embedded within everyday objects, enabling them to have processing capabilities.

Network Layer: After collecting data from the Perception layer, the Network layer processes this data. After processing, this layer also transmits the data to the Application layer through network technologies such as Wi-Fi, LAN, 3G/4G, Bluetooth, and infra-red technologies. Due to the large amount of data being transmitted, it is necessary to implement a reliable program that handles the storage and processing of this data. Such a program is known as Cloud computing.

Application Layer: The data processed in the Network layer is used in the Application layer. This layer is also the front-end interface of the architecture, enabling the IoT device to reach its intended potential. By providing necessary tools such as actuators, this layer allows developers to realize the IoT perspective. Various applications can be developed, such as logistics management, identity verification, smart transportation, etc.

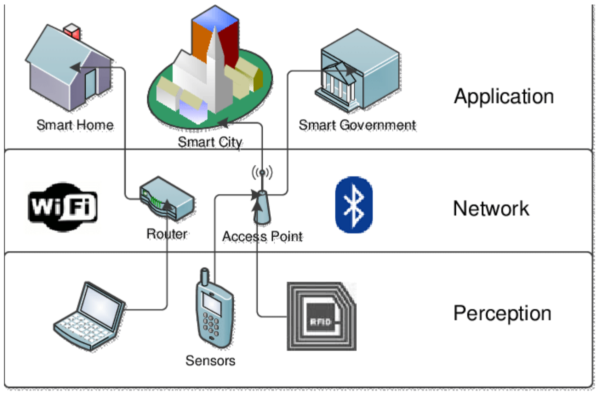

Figure 2. The three-layer architecture of IoT.

6)Five-Layer Architecture of IoT

With technological advancements over the years, IoT technology has progressed and improved. One of the changes within the IoT system is the addition of two layers to its architecture. The processing and business layers have been added, turning the three-layer architecture into a five-layer architecture (Figure 3). This version is considered a more comprehensive explanation of IoT architecture. The perception and application layers are the same as in the three-layer architecture, and below, we will discuss the other three layers.

Transport Layer: This layer is responsible for directing the data received from the sensor layer to the processing layer. This direction is achieved through networks such as Wi-Fi, Bluetooth, 3G, LAN, RFID, NFC, etc.

Processing Layer: Also known as the middle layer, this layer is responsible for acquiring, storing, analyzing, and processing large amounts of data from the transport layer. By using various technologies such as databases, cloud computing, and modules for processing large data sets, this layer manages and provides a range of services to the lower layers.

Business Layer: The entire IoT system is controlled by the business layer, ranging from applications, business models to user security and privacy. The way technology is distributed to the user, along with the technologies used by a device, determines the success of a device. The distribution of technology is a task handled by the business layer. By creating graphs and diagrams, this layer analyzes results and determines ways to improve the device [11].

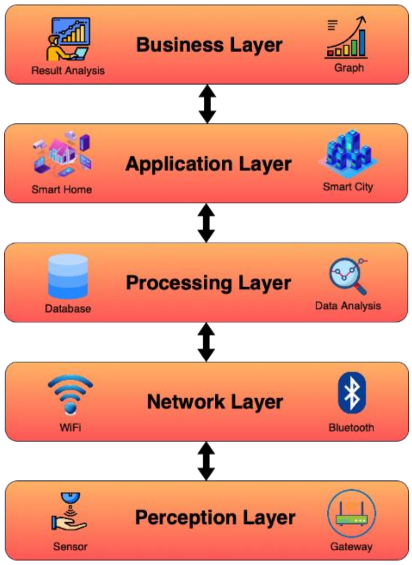

Figure 3. Five-Layer Architecture of IoT.

C. *IoT Architecture in Healthcare*

Continua is a healthcare alliance composed of more than 220 organizations. This organization has released an end-to-end (E2E) architecture that will be used for healthcare-related applications (Figure 4). The formation of this alliance is considered a historic achievement that is expected to create a sustainable environment with interoperability of connected healthcare systems. This E2E architecture provides an architectural overview of the ecosystem, including three network interfaces, four types of devices, and explains the limitations of the topology. With this architecture, data is transmitted from patient healthcare devices to hospitals or medical offices. Continua has created a design guide that specifies the core criteria. These criteria ensure interoperability among the components used in health monitoring and wellness applications [12].

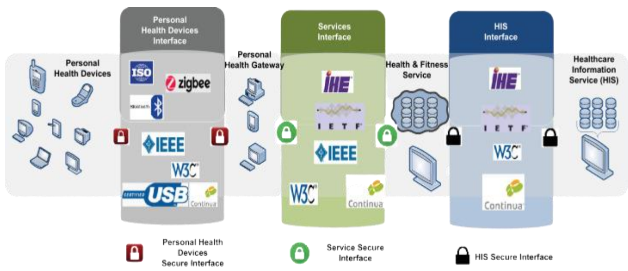

Figure 4. IoT Architecture for Healthcare Proposed by Continua.

Telemedicine, Healthcare, and Medical IoT

Telemedicine and Medical IoT are two terms where the difference between them is small, and this difference is related to how they use IoT. Telemedicine refers to the use of medical data transmitted from one location to another using electronic communications. This communication aims to improve and preserve the patient's health condition. Telemedicine is closely related to the term telehealth, which is used more broadly to refer to remote healthcare (Figure 5), excluding clinical services. Components of telemedicine and telehealth include remote monitoring of vital signs, ongoing medical education, video conferences, telehealth call centers, and the transmission of medical images. In short, telemedicine is the use of IoT for medical purposes and describes the modernization of healthcare through the use of information technology.

Healthcare, as a type of medical care, aims to monitor and support chronic conditions and implement preventive measures to ensure a healthy lifestyle. IoT in healthcare describes a range of devices and technologies used to support personal health. These systems and devices provide personalized services designed for an individual. Personal healthcare systems that use IoT include glucose level monitors, heart rate pacemakers, various cloud computing services, and devices for monitoring children and infants [13].

Figure 5. Telemedicine - Providing medical consultations with patients remotely.

V. IOT DEVICES AND THEIR METHODOLOGY

One of the most recent advancements in healthcare is smart healthcare. Traditional healthcare methods involved patients visiting doctors to report issues such as breathing problems, blood sugar levels, and more. Now, with the help of sensors, smartphone applications, and other IoT devices, data can be collected and sent to the doctor, allowing remote monitoring of the patient's condition. There are many devices used for health monitoring, and below, we will discuss some of the most widely used.

A. Helo Wristband

An intelligent device for real-time 24/7 health monitoring, with disease prediction capabilities as shown in Figure 6. This device has active sensors that monitor the human body. It monitors blood pressure, heart rate, ECG/EKG, sleep quality, emotions, steps, calories, fatigue, and more. It also has an SOS function where, if the person wearing the wristband encounters a problem, signals are sent to their family members, who can track their GPS location. Other features expected to be added to this device include monitoring blood sugar, blood oxygen levels, temperature, alcohol levels, and serving as a mosquito repellent [14].

Figure 6. Helo-Health Monitoring Wristband.

B. Pajisja për monitorim të presionit të gjakut me valë

In Figure 7, an intelligent device is presented, which is used by the patient in cases when they suspect they have high blood pressure, such as hypertension. It has been developed with the assistance of cardiologists and subsequently clinically tested to provide accurate results. It offers easy usage, with just a press of a button and Wi-Fi connectivity to the application, you can measure and monitor blood pressure accurately. The application also offers the possibility of creating a health diary that the patient can share with their doctor [15].

Figure 7. Device for blood pressure monitoring with waves.

C. AliveCor Heart Monitor

This device has the shape of a phone case, as seen in Figure 8, but it can also be a peripheral device that attaches to the back of the phone. It is used to monitor and record the user's EKG. Through waves, it connects to the phone's application, where the collected recordings can be viewed and analyzed [16].

Figure 8. Sensor for EKG monitoring in the form of a phone case.

D. Smart Devices for Infant Health Monitoring

There are many cases where a small device is attached to the baby's arm, tracking the temperature and the baby's body position (Figure 9). It transmits the baby's statistics to the smartphone application. In cases where it detects a significant increase or decrease in temperature, an alarm is triggered as a warning sign. The device is made up of hospital-grade fabric and is safe to wear for extended periods [17].

Figure 9. Baby Check - a temperature and body position monitor.

1)Smart Sock

The Owlet Smart Sock sensor (Figure 10) is used to monitor the heart rate and oxygen levels of infants. The infant is monitored in real-time while sleeping. This device is also connected to a smartphone application, through which the parent will be notified if the heart rate and oxygen level are outside the normal range. Below, we will discuss this sensor in more detail, as it is considered one of the best sensors for infant monitoring.

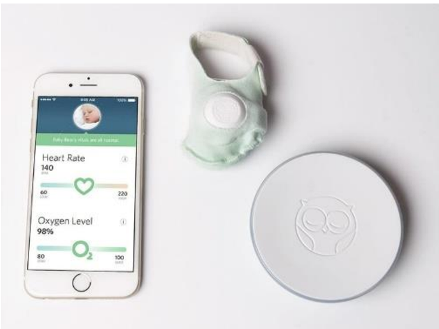

Figure 10. Owlet Smart Sock 2.

E. The Motive for Using Smart Sock

The motive behind proposing the use of Smart Sock is the reduction of sudden infant deaths (SIDS). Sudden Infant Death Syndrome can have several causes, but difficulties in breathing are considered the main reason. SIDS can occur in any healthy infant and often happens when the baby is asleep [18].

F. Configuration and Operation of Smart Sock

This intelligent and reliable device consists of the base station, which has two micro-USB ports. One port is used for charging the base station, while the other is used for charging the sensor that will be placed on the sock (Figure 11). Through this sensor, the sock communicates with the base station via a wireless connection.

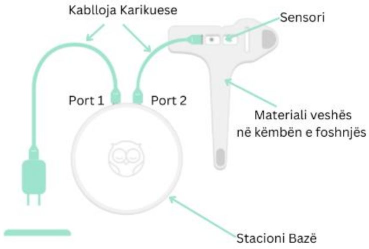

Figure 11. Parts of Owlet Smart Sock 2.

The Base Station should also connect to the mobile application via Wi-Fi. From there, the parent receives information about the baby's heart rate and oxygen levels (Figure 12). The application will send notifications in the form of alarms when these heart rates and oxygen levels in the baby are outside the normal range. Through the application, the parent understands the reason for the alarm trigger. The sensor's battery can last up to 18 hours without needing charging. The Base Station serves as a basic informant by issuing visual and auditory signals in cases where there are abnormal changes in heart rate or oxygen levels.

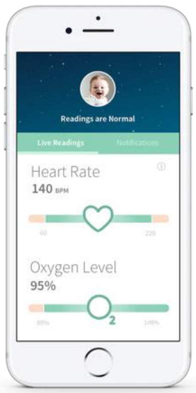

Figure 12. Reading heart rates and oxygen levels from the application.

The base station changes color depending on the information it provides. There are 5 types of notifications, and each has a specific color (Figure 13). The white color indicates that the device is charging properly, the yellow color indicates that the sock is not properly placed on the baby's foot. The blue color indicates that the sock is out of range and cannot communicate with the base. The red color, the most alarming one, indicates that the heart rate or oxygen levels are outside normal levels. The green color signals that the device is receiving data properly, and there are no issues with the baby [19]. The collected data will be stored in a reliable Cloud-based database. Even if there is a Wi-Fi or power interruption, monitoring of the baby continues for up to 18 hours, keeping vital data at the local level, and as soon as the connection is restored, the data is uploaded to the Cloud.

Figure 13. Different signaling colors of the Base.

VI. OSS USE CASE STUDY AND RESULTS

A study conducted by [20] has reported the initial experience of monitoring the cardiorespiratory system at home in 47,495 newborn infants using OSS. The study period started in October 2015 and lasted until May 2017. Due to the extended study duration, the collection of demographic data for OSS users was only conducted for active users in May 2017. The number of these users was 5,125 or 24.2% of all participants (Table 1).

A. Demographic Results

15% of the monitored infants were preterm babies, while 85% were full-term healthy infants. The majority of users were individuals who had become parents for the first time and were in their 30s. The primary reason for using OSS was to ease their peace of mind, while other reasons included the infant being diagnosed with breathing or heart problems. According to the responses received, approximately 8% of users had a history of SIDS in the past, and about 15% of infants had just been discharged from the neonatal intensive care unit (NICU).

Table 1. Demographic data of active OSS users.

The demographic survey data group (n = 5125)	Percentage
Newborn Profile	
Full-term newborns	85%
Preterm newborns	15%
Parent Profile	
Parent Age Category	
• 30-39 years	61%
• 21-29 years	31%
• 40+years	7%
College-educated families	70%
Families with at least 1 healthcare industry professional	37%
Families at or below average income	28%
Reasons for Using OSS	
History of SIDS (parent or close relative)	8%
Infant diagnosed with breathing or heart problems	12%
Post NICU for newborns	13%
First-time parent	30%
Sense of "peace of mind"	44%
Parental Outcome of Using OSS	
Following safe sleep guidelines	82%
Improved sleep quality for parents	94%
Reduced anxiety	96%

B. Physiological Normative Results

Gestational age in prematurely born infants was difficult to verify, so the physiological normative findings only include full-term infants. The normal average heart rate for these infants was 136 bpm in the first month and 106 bpm in the 12th month, while the average blood oxygen level (SpO2) in the first month of life was 96%, and 97% in the 12th month. Table 2 presents the averages of heart rate and SpO2 for 39,326 infants.

Table 2. Average by age for the long-term monitored newborns (n = 39,626).

Age after birth (n)	Heart rate frequency ± DS	SpO_2 (%) ± DS
1 month (15 372)	136 ± 9,0	96 ± 1,7
2 months (19 729)	131 ± 8,2	97 ± 1,6
3 months (20 443)	122 ± 7,5	97 ± 1,6
4 months (20 168)	116 ± 7,4	97 ± 1,6
5 months (19 357)	114 ± 7,5	97 ± 1,9
6 months (18 103)	112 ± 7,2	97 ± 1,5
7 months (16 268)	111 ± 7.1	97 ± 1,4
8 months (13 806)	110 ± 7.1	97 ± 1,4

9 months (10 917)	109 ± 7.2	98 ± 1,4
10 months (8357)	108 ± 7.2	98 ± 1,4
11 months (6166)	107 ± 7.2	98 ± 1,4
12 months (4459)	106 ± 7,6	97 ± 1,4

C. False-Positive Alarms and Clinical Significance

The most frequent alerts (Red Alerts) were for low oxygen levels (71%). For high or low heart rates, the alerts were relatively few, around 18% and 10%, respectively. From the use of the OSS, it was observed that clinically significant alerts were constantly accumulating and repeating. For example, a monitored infant had no alarms for 6 months, but then alarms started occurring up to 10 times a day. Through a medical review analyzing the data collected by the device, it was discovered that the infant had been infected with respiratory syncytial virus (RSV).

Users were asked to report alarms that were clinically significant. From the data collected until October 2015, a total of 80 cases were reported where OSS alerts had either prevented a critical event or assisted in diagnosing a disease the infant had but had been overlooked. Out of these cases, 49 or 61%, upon verification by a doctor, were found to be clinically significant. The other 31 cases, or 39%, were clinically insignificant, meaning the alarm might have been triggered by excessive movement of the infant or improper device placement.

From the clinically significant cases, it was possible to diagnose 23 infants with respiratory syncytial virus (RSV), 7 infants with supraventricular tachycardia (SVT), 7 infants with breathing difficulties, 5 infants with airway obstructions due to poor sleeping positions, 3 infants with congenital heart defects, and 3 other infants with apnea.

VII. CONCLUSION AND DISCUSSION

More than 27 billion devices are connected to IoT today, and this number is expected to reach 100 billion by 2030. IoT is a continuously growing technology that is touching every aspect of life, especially healthcare. Healthcare becomes more effective when characterized by accuracy and speed. The best way to achieve these characteristics is by relying on a wide range of healthcare systems connected to IoT. Through IoT, the digital identity of all patients can be preserved. The benefits of applying IoT in healthcare are numerous, ranging from providing remote medical assistance, real-time health monitoring, to collecting and processing patient data.

IoT devices are ideal for measuring vital signs such as pulse, heart rate, body temperature, oxygen levels in the blood, blood pressure, glucose levels, and more. These devices collect data from the surrounding environment through various sensors. These devices are user-friendly, so even patients can use them from home to monitor physiological values if they have adequate values.

This thesis also discussed neonatal healthcare, especially finding a monitoring method for the prevention of SIDS (sudden infant death syndrome). A solution proposed is the use of an IoT device called the Owlet Smart Sock. This device provides information about a baby's heart rate and oxygen levels in real-time. A study was conducted to assess the effectiveness of this device, which showed that it had reported a total of 80 cases. Thanks to its alerts, critical events were prevented or assisted in diagnosing any diseases the baby might have had, but which would have otherwise been overlooked.

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