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Smart Neonatal Guardian: AI-Driven Monitoring for Preterm Infants in NICU

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Abstract - Minimally designed, Neonatal Intensive Care Units (NICUs) are specialized medicinal settings that offer the highest level of care to preterm and ill infants requiring 24/7 assessment for pharmacological intervention. Monitoring of vital parameters (heart rate, oxygen saturation [SpO2], and body temperature) is crucial for providing safety and stability to these infants. Conventional NICU monitoring systems are costly and static components isolated within the hospital infrastructure, which cannot access real-time data outside clinical contexts.

Thesis synopsis: This study describes the design of a neonatal monitoring system based on machine learning and Internet of Things (IoT) that continuously measures vital signs in neonates. The proposed method consists of utilizing sensors to collect data including heart rate, blood oxygen saturation levels and body temperature that are attached to an ESP32 microcontroller for acquisition and processing. It is a device whose sensing data are collected and wirelessly transferred using Blynk platform to a mobile application.

These abnormal physiological value triggers alert the system through a built-in buzzer and mobile notifications, so that individuals can attend to patients who need medical care. The proposed system is cost-effective and portable solution which not only enhance traditional monitoring techniques but also provide a way for continuous monitoring of patient data with access from remote regions. This helps facilitate timely intervention and communication between healthcare providers and caregivers, ultimately improving neonatal health.

Keywords **-** IoT, ESP32, Neonatal Monitoring, Heart Rate Sensor, SpO_2 Sensor, Temperature Sensor, Remote Health Monitoring, NICU, Wireless Healthcare System, Real-Time Monitoring.

I.INTRODUCTION

Healthcare workers have to continually check their vital bodily parameters to ensure survival and adequate growth. Vital signs — heart rate, percentage of oxygen in your blood, body temperature and several others — are monitored Hubble-like because even the smallest changes from the norm can lead to complications that kill you. Constant monitoring allows medical professionals to catch potential issues early enough and act fast to remedy them.

Neonates are usually monitored in developed hospitals using these conventional neonatal monitoring systems. Even accurate and timely, these systems tend to be-wired devices stationary expensive specific to hospital environments. Moreover, these systems typically do not grant remote access to patient data, limiting monitoring to healthcare providers present in the NICU.

With the advancement of Internet of Things (IoT) technology, opportunities have arisen to enhance healthcare monitoring systems with wireless connectivity and real time data transmission. IoT allows for constant data collection and transmission of physiological information via medical devices and sensors, which healthcare professionals can access in off-site systems. Here, we propose an IoT-based neonatal health monitoring system which provides continuous measurement of vital signs of preterm infants through sensors connected to an ESP32 microcontroller. Using data integrated from sensors, the system records heart rate, oxygen saturation and body temperature and wirelessly transmits it to a mobile application for real-time monitoring. If

abnormal readings occur, alerts are generated to alert caregivers immediately.

The Noob monitor promises reduced healthcare costs while still providing systematic long-term monitoring, remote access to data provision, timely medical intervention and thus furthering neonatal healthcare quality.

II. LITERATURE REVIEW

The literature indicates significant advancements in monitoring newborns using new sensing and communication technologies. Standard NICU systems employ wired sensors to track heart rate, oxygen saturation and body temperature. While effective, these systems can limit the movement of infants, irritate their skin from electrodes and do not allow for remote tracking.

Based on the recent research, however, we are particularly concerned with wireless and real-time monitoring systems that can be applied in sensitive neonatal surrounding. These systems use low-cost microcontrollers such as Arduino or Wemos D1 Mini and physiological sensors to obtain the vital data. This data may be sent through IoT platforms like Blynk or Thing Speak, where doctors can monitor infant health remotely and will get notifications if the condition is abnormal.

2.1 Evaluation of Preterm Infant Care through Smart Monitoring Systems in NICU

Anthological assessment of necrogram monitoring technologies in NICUDOMAIN plays a vital role as a novel domain across the scopes of biomedical engineering and neonatal healthcare research. Note: Although several studies investigating preterm infant clinical outcomes are published in journals focused on neonatal medicine and pediatric health care, the requirements of reducing the length of clinical stay remain. Researches like this often discuss how continuous monitoring systems can improve patient safety, facilitate early detection of complications and help healthcare providers make timely medical decisions.

Research focusing on technology development (such as sensor integration, physiological signal monitoring, and medical device design) generally gets reported in biomedical engineering journals. This includes developing reliable monitoring devices, data acquisition systems, and communication frameworks for the continuous observation of infant health parameters [16]. Research device-centric paradigm has enabled this transition of conventional laboratory-based monitoring technologies to highly sensitive, small-sized and portable devices for in situ implementation in extreme NICU settings. The appropriate venue to publish such work often depends on whether the research is based around clinical outcomes, technological advance or both.

2.2 Smart Biomedical Systems for Neonatal Care in Intensive Units

Neonatology is known to be one of the most challenging aspects of healthcare, as premature infants are vulnerable and require constant surveillance with increased environmental responsiveness. Contemporary biomedical systems intend to assist clinicians through persistent perception of physiological variations, including but not limited to heart rate, respiratory rate, oxygen saturation and body temperature. These systems use sensors to acquire physiological data and analyze the information collected for possible detection of health issues in newborn babies.

Monitoring continuously can alert clinicians early to a medical complication such as respiratory distress, cardiovascular instability or infection. These systems provide valuable information by modeling the trajectory of physiological data over time and can guide decisions on how to treat and care for patients. Hence, intelligent biomedical technologies are developed as an essential component of current NICU framework.

2.3 IoT-Based Monitoring for Preterm Infant Surveillance in NICU

Recent years have seen much effort devoted to the incorporation of Internet of Things (IoT) technologies in neonatal monitoring systems. IoT frameworks allow sensors inside medical devices or incubators to continuously capture physiological metrics like heart rate, oxygen saturation and body temperature. This data is then shared wirelessly with cloud platforms from which it can be monitored and examined by medical professionals.

The studies of this kind advance smart incubator systems with the integration of several sensors and network interactivity. These systems perform real-

time observation of neonatal health status, and allow health information to be accessed remotely. Despite evidence suggesting the benefits that IoT-based systems for monitoring provide, a complete solution dedicated to the continuous observation of preterm infants is still something that needs more research and development.

2.4 Non-Invasive Monitoring of Preterm Infants Utilizing Smart Neonatal Monitoring Systems

Contact-based sensors have certain disadvantages, which can be addressed by non-invasive monitoring methods. Also, they have very thin skin (for which wires glued to the body can cause trauma) and distally positioned organs that needs time to develop. Consequently, some researchers have investigated alternative monitoring methods that require less extensive body contact with the infant.

These have included camera based monitoring, thermal sensing, radar-based respiration detection and environmental sensors within incubators. These systems can measure fis of physiological parameters like heart rate, respiration and motion without physical contact being maintained. Hence, non-invasive monitoring modalities can significantly improve infant comfort without compromising the fidelity of health data made available to healthcare providers.

2.5 Current Smart Neonatal Monitoring

Contemporary neonatal monitoring systems incorporate a combination of sensor technologies, wireless communication and digital platforms to allow for continuous monitoring of the health status of premature infants. Such systems can be in the form of smart incubators, imaging or wearables and act like eyes that can measure heart rate, respiration, temperature and oxygen levels.

In such a way, these systems provide active signaling to healthcare providers for real-time detection of even minor physiological abnormalities. Alert notifications allows the medical personnel to respond quickly when health parameters are out of normal limits. The benefits of such technologies, however (i.e. their data quality and dependability, system security and clinical acquisition), have thus far failed to translate into regular introduction or implementation within surgical NICUs.

Limitations of Conventional Neonatal Monitoring Methods in NICU

Neonatal monitoring has key limitations in the context of premature infants.

Skin Irritation and Discomfort: Contact-based sensors affixed to the skin of the infant may result in irritation or infection since premature infants have very sensitive skin.

Conventional wired monitors can irritate the skin and limit movements of neonates, however newer technologies using wireless monitoring systems allow for easy observation of neonatal vitals from a distance, as shown in ***Fig 1.***

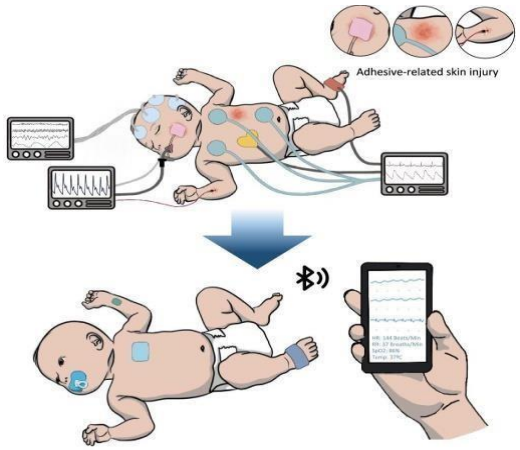

Fig 1: Comparison between Conventional Wired Monitoring and Wireless IoT-Based Neonatal Monitoring System

Restricted Movement: The use of multiple wires and electrodes that are connected to monitoring equipment restrict the infant's movement which could interrupt daily caregiving activities.

Danger of Disconnection: Because wired sensors are still attached, they can sometimes be disconnected when the system is moved or even handled, resulting in faulty readings or false alarms.

Limited Predictive Capability: Conventional monitoring systems simply offer real-time readings but lack advanced analytics which could help in predicting potential health complications.

2.6 Progress in Smart Neonatal Monitoring Systems

Newer neonatal healthcare technology innovations include better nursery monitoring systems with more sophisticated sensors and communication networks. These systems enable non-invasive monitoring of key

infant health parameters, thus reducing the requirement for invasive monitoring procedures.

Most Modern monitoring devices uses wireless communication technologies to send data in real-time on mobile application or cloud platforms. It enables Paramedics & HCPs to access patient data remotely and enable early intervention in normal conditions. Also, advances in sensor technology have improved the accuracy and reliability of physiological records.

Both these technologies have very encouraging results, yet many of the systems are still being clinically tested and they need to be validated further before applying them widely in hospital environment or settings.

2.7 Summary and Research Gap

Although several studies have investigated complex neonatal monitoring approaches, several critical challenges remain before reliable and clinically applicable solutions can be developed.

- ***No Clinical Validation:*** These systems are often poorly validated clinically, and fail to generalize in a real NICU environment.
- ***Lack of Standards:*** There is no established framework or standard that guides the integration of multiple sensors and their interoperability with hospital monitoring systems.
- ***System Reliability:*** Monitoring systems should be able to provide stable performance in presence of noise from the environment and changes in infant physiological conditions.

This study presents an IoT-based Smart Neonatal Guardian system to continuously monitor vital signs of preterm infants at home and sort out abovementioned problems. It uses various sensors to listen to heart rate, oxygen level, and body temperature by wirelessly sending the test results into a computer for monitoring or alerts.

III.METHODOLOGY

We use IoT technology for continuous health tracking of NICU babies. It starts out with a step- down transformer to change 230V AC to 12V AC. Then AC power is transformed to 12V DC with a bridge rectifier. Finally, in order to have a stable power supply, there are a capacitor that filters fluctuations and noise, and a voltage regulator that provides regulated 12V and 5V outputs if needed for the system components. The system incorporates various important sensors, including a heart rate sensor to monitor the baby's heart rate, an SPO2 sensor for tracking oxygen levels, and a temperature sensor.

3.1 Overview of the Current System

Smart Neonatal Guardian system is an AI-enabled monitoring framework that provides real-time, noninvasive, intelligent surveillance of preterm neonates in the NICU.

3.2 Overview of the Proposed System

This new IOT based smart band resolves all these limitations, as inbuilt advanced sensors and is connected through wireless medium for uninterrupted progress tracking. This method ensures continuous observation of preterm newborns in the NICU

Temperature Sensor (LM35): To detect infection or inflammation of the infants by monitoring body temperature.

Heart Rate sensor (MAX30100): For continuous monitoring of preterm infants. Heart Rate: a key indicator of physiological stability

Oxygen sensor (MAX30100): Used for long-term monitoring of the oxygen saturation level in a preterm infant's blood, which reflects their respiratory or cardiovascular health

A buzzer for aural indication supports to provide alerts on Thursday product conditions.

Rehabilitation and allows immediate alerts and remote data access to enhance patient safety.

3.2.1 Principal Attributes of the Proposed System:

Multiple Sensor Integration: Heart rate, body temperature and oxygen level of the infants are monitored.

- Alerts in an Instant: As soon as any reading seems abnormal, the alarm gets triggered and messages get sent via mobile app.
- Remote Monitoring: The data is transmitted remotely using ESP32 microcontroller that enable care takers to monitor their patients from anywhere.
- Use of Blynk IoT Platform: Both the patients and healthcare practitioners can remotely access both

real-time and previous history data through the Blynk IoT platform.

3.3 System Architecture

The system includes three primary modules, namely the hardware module, communication module and software module. Hardware module collects infant physiological data using several sensors. In order to ensure the connectivity and transferring of this data through IoT technology, we have the communication module. This software module will process the data it has collected and output it in a format that can still be understood by healthcare professionals and caregivers, with user-friendly methods of monitoring that infants conditions.

Fig 2: Overall System Architecture of the Proposed Infant Monitoring System

3.3.1 Hardware Implementation

The intelligent band includes the following core components:

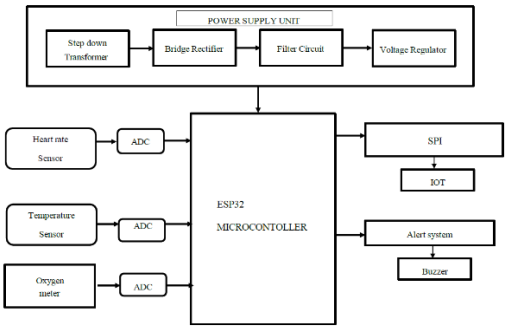

Fig 3: Block Diagram of the Proposed IoT-Based NICU Monitoring System

ESP32 Microcontroller: A cost- effective, energy-efficient microcontroller that manages the collection of sensor data, and its wireless transmission.

Capacitor: This is used in the power supply circuit to filter voltage fluctuations and provide DC output.

Power Supply Unit: Ensures even power supply to all the components using regulated power supply (IC7805 and IC7812).

3.3.2 Software Development

Embedded C Programming: Get sand analyses sensor data with the ESP32 microcontroller. Algorithms to detect abnormal measurements and trigger alarms
Arduino IDE: Used to write and upload code onto the ESP32microcontroller.
Blynk for IoT Communication: sensor's data gets forwarded to a Blynk IoT platform this allows the idea of near real-time observation.

3.3.3 System Workflow

Data Acquisition: The sensors continuously monitor the patient vital parameters and physical activities.

Data Processing: ESP32 microcontroller analyzes sensor values and identifies outliers to the expected range.

Alert: In case of any aberration in situation (e.g Irregular heart rate, hypo-oxygenation condition, abnormal body temperature) buzzer is switched ON and a notification will be sent into mobile application.

Remote Monitoring: Data is sent to Blynk platform, so caregivers can access information on patients instantly.

3.3.4 Benefits of the Proposed System

Improved Patient Safety: Ongoing surveillance quickly uncovers problems before they cause challenges

Remote Access: Caregivers can monitor patients without in-person visits, thereby reducing hospital readmissions.

Extensive Information: Multi-sensor integration provides rich context for many aspects of infant monitoring.

Intuitive Interface: Mobile application aids in ease of use by providing live data. Caretakers are notified and updated with the anomalous situations through push notifications.

Economically Efficient: IoT technology reduces long-term health care problems by enabling remote treatment. The design and implementation of smart bracelet based on IoT could be an alternative solution to monitor the health conditions of abnormal heart rate patients. By using advanced sensors, real-time data processing, and remote access this system is designed to enhance post-surgery care by improving patient safety and accessibility of immediate medical assistance.

IV.RESULTS

This method of chronic patient monitoring system for NICU babies in real-time provides inexpensive, reliable, and non-invasive continuous health tracking. With the use of IoT sensor, which integrating heart rate, SPO2 and temperature sensors, the system will determine vital signs ensuring that any variation in normal values leads to immediate notifications Integrating a microcontroller and transferring data in real- time via the Blynk app aids healthcare providers, along with this system enhances ninety-nine vulnerable NICU babies' safety and care by providing an excellent support tool that enables early detection of potential victims to criticality.

4.1 Sensor Efficacy and Data Accuracy

The smart band is a multi-sensor capable of collecting real-time physiological and motion information. All sensors were tested for precision and calibration in controlled environments that suggested reliable or consistent operation.

Table1: Multiple sensors in smart band record physiological and movement data in real-time.

Sensor	**Measured Parameter**	**Expected Range**	**Observed Accuracy**
Heart rate Sensor	Infants Heart Rate (beats per minute)	100-160 bpm(Normal Neonatal Range)	±2 bpm
Temperature Sensor	Body Temperature (°C)	36.5–37.5°C (Normal Range)	±0.2°C
Oxygen Sensor	Blood Oxygen Saturation (%)	90-100% (Normal Range)	±1°

Note: The sensors provided real-time measurements that all fell within acceptable error margins, validating the reliability of the system.

4.2 Comparison of Sensor Accuracy

The following graph shows the error for every sensor in the system. All sensors performed within acceptable limits. The resulting accuracy rate for the heart of factorial data was +-2 bpm, however, the step-down accuracy for temperature was up to +-0.2degC (smallest), as shown in Fig 2.

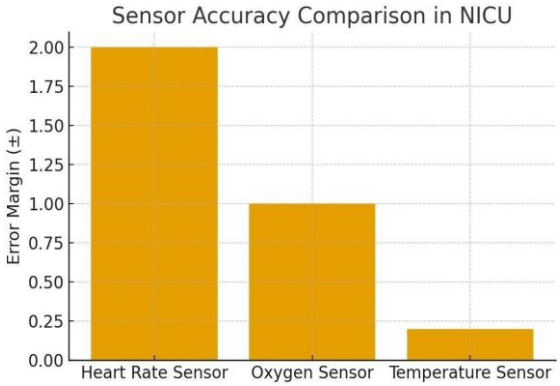

Fig 4: Sensor Accuracy Comparison for NICU Monitoring System

4.3 Real Time Alert Mechanism

Aggregated data can be continuously analyzed for real-time anomalies such as bradycardia or hypoxemia, or abnormal temperature fluctuations. This means that as soon as a critical condition is identified alerts are sent, allowing either nurse stations or mobile devices to take immediate action. All alerts include important information (senor readings and time stamps) needed for further processing by the healthcare staff who must acknowledge these alerts for continuity of monitoring and record keeping.

Table 2: Alert Notifications Generated by the Buzzer and Blynk Smartphone Application for Abnormal Conditions

Abnormal Condition	**Trigger Point**	**Alert Method**	**Response Time**
Brady cardia / Tachycardia (Heart Rate	<100 bpm or >160 bpm	Audio-Visual Alert + mobile	1.8 seconds

sensor)		notification	
Hypoxemia (Oxygen Sensor)	SpO2<90%	Audio-Visual Alert + mobile notification	2.0 seconds
Hypothermia (Temperature sensor)	Temperature>38°C	Audio-Visual Alert + mobile notification	2.2 seconds

Note: The alert system had a consistent ability to detect abnormal conditions and send text notifications to caregivers in under 3 seconds, thus promoting rapid intervention.

4.4 Remote IoT Monitoring

The Blynk IoT platform serves as an efficient solution for real-time display of patient data and storage of historical records for analysis. Design Considerations: The mobile user interface would allow caregivers and healthcare professional's access to sensor data as well as notifications in the event of an emergency. Here are the key observations:

Data Usage: Patients' data may be accessed anywhere in the world using the Blynk application with internet accessibility, this dynamic monitoring refers to heart rate and temperature.

Data Logging: This data is stored in the cloud for later analysis, as we want to be able to make detailed evaluations of a patient's state.

Observation: Remote monitoring aspires to eliminate the necessity for close face-to-face observation while still allowing regular assessment of a patient's health.

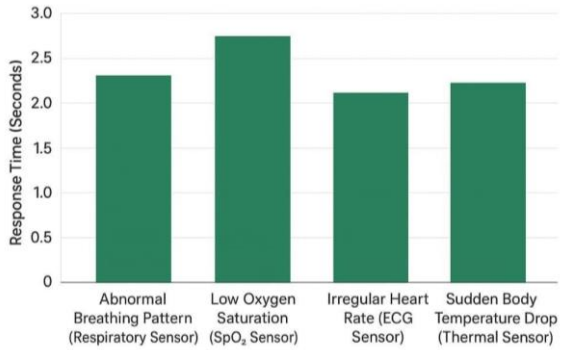

Fig 5: Real-Time Remote Monitoring of Infant Vital Signs Using the Blynk IoT Platform.

4.5 Validation and Testing of Prototypes

The Smart Neonatal Guardian prototype went through several stages of validation and verification tests to confirm its safety, accuracy, and reliability for use in monitoring preterm infants while admitted to the NICU. First of all, testing was carried out for individual components in order to verify the sensor calibration and accuracy of the measurements (heart rate, oxygen saturation (SpO2), body temperature). This was succeeded by system integration and bench testing with simulated neonatal data, to verify continuous data flow, accurate alert generation and system stability during prolonged operation.

The next phase of assessment was evaluating the system's capability to identify abnormal physiological states (eg, bradycardia, hypoxemia, and temperature deviations). We also performed usability testing to ensure that the alert notification and monitoring interface was easy for health professionals to interpret. Lastly, a pilot testing was performed to assess system performance and response time with respect to its feasibility for implementing continuous monitoring in neonatal care settings. In conclusion, the results showed that this proposed monitoring system has demonstrated reliable performance giving accurate real time assessment with very low false alerts making a perfect fit for neonatal healthcare applications.

As it is IoT supported, hence the system continuously tracks the NICU infants. It is used in a power supply circuit, here the step-down transformer steps down 230V AC to 12V AC. A bridge rectifier is used to convert this voltage into 12V DC. The function of a capacitor is to filter voltage fluctuations and keep it stable, also the voltage regulators are used to obtain a regulated output of 12V and 5V which several system components would require. The monitoring unit consists of a combination of several sensors including heart rate sensor, SpO2 sensor, temperature sensor that continuously measure the infant's vital parameters.

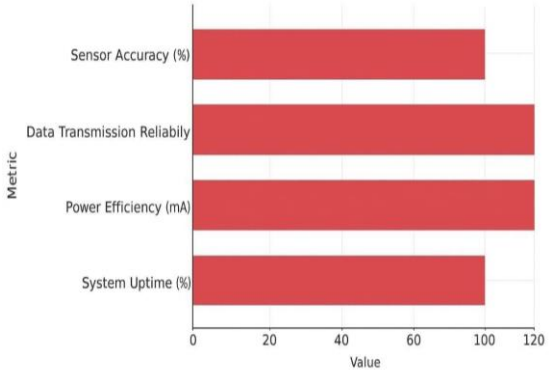

Fig.6: Performance Metrics of the Proposed IoT-Based NICU Monitoring System.

V. CONCLUSION

A real-time patient monitoring system for NICU infants that has been presented offers a reliable and non-invasive solution for continuous health monitoring. Using integrated heart rate, SpO2, and temperature sensors built on IoT technology, the system provides daily monitoring of these vital parameters and produces alerts in real-time if any abnormal conditions are noted. Here, the use of microcontroller and real-time transmission via Blynk application enables health care professionals and caregivers to directly glean information in an instant, enhancing response time and supporting better clinical outcomes. Overall, the system improves care and ensures that vulnerable NICU infants receive immediate treatment by timely diagnosis of serious health-related conditions.

REFERENCES

[1] B. Olmi, L. Frassineti, A. Lanata and C. Manfredi, “Automatic Detection of Epileptic Seizures in Neonatal Intensive Care Units through EEG ECG and Video Recordings: A Survey,” IEEE Access, vol. 9, pp. 138174-138191, 2021.

[2] Mijsters, F. Video-based infant monitoring: Recognizing appetite, pain and sleep in preterm infants (Master's thesis). Utrecht University, Utrecht, The Netherlands (2022).

[3] E. De Groot et al., “Developing the best observational sleep stage scoring system for very and extreme preterm infants,” Sleep Medicine, vol. 90, pp. 167-175, 2022.

[4] A. Bik et al., “A scoping review of behavioral sleep stage classification methods for preterm infants,” Sleep Medicine, vol. 90, pp. 74-82, 2022.

[5] T. Sentner et al., “The Sleep Well Baby Project: An automated real-time sleep-wake state prediction algorithm in preterm infants,” Sleep, vol. 45, 2022, Art. no. zsac143.

[6] S. Cabon et al., "Voxyvi: A system for long-term audio and video acquisition in neonatal intensive care units," Early Human Development, vol. 153, 2021, Art. No. 105303.

[7] A. M. Rahman, M. S. Hossain, G. Muhammad, IEEE Internet of Things Journal, vol. 6, no. 2 (2019): 3263-3271.

[8] Gope, P.; Hwang, T., BSN-Care: A secure IoT-based modern healthcare system using body sensor network. IEEE Sensors Journal 2016, {WOS}:000368522800019. 16, no. 5 (2016): 1368-1376.

[9] S. Patel and H. Park, “A review of wearable sensors and systems with application in rehabilitation,” Journal of NeuroEngineering and Rehabilitation, vol. 9, no. 21, 2012.

[10]M. R. Yuce, Implementation of wireless body area networks for healthcare systems, Sensors and Actuators A: Physical Vol. 162, 1, pp. 116–129 (2010).