Smart Non-Invasive Diabetes Monitoring System using NIR and AI.

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ABSTRACT- *Diabetes mellitus is a chronic metabolic disorder that requires continuous monitoring of blood glucose levels to prevent severe complications. Traditional glucose monitoring methods are invasive, involving painful finger pricking, which leads to patient discomfort and risk of infection. This project proposes a Non-Invasive Blood Glucose Monitoring System using Near- Infrared (NIR) spectroscopy. The system utilizes an NIR sensor (940nm wavelength) to detect glucose concentration through the skin on the wrist or finger. The hardware is built around the CC3200 Launchpad (Microcontroller Unit), which features an integrated Wi-Fi module for seamless IoT connectivity. The raw optical signals from the NIR sensor are pre-processed and transmitted to a cloud-based server. To enhance accuracy, a Hybrid Deep Learning Model combining Convolutional Neural Networks (CNN) and Long Short-Term Memory (LSTM) is employed. The CNN layer extracts spatial features from the signal, while the LSTM layer captures temporal dependencies, effectively reducing noise and improving prediction precision.*

Experimental results demonstrate a high correlation between the proposed non- invasive method and standard invasive readings, achieving an accuracy of approximately 97% to 99%. The final glucose levels are displayed in real-time on a mobile application, providing a painless, user-friendly, and efficient solution for continuous glucose management.

Keywords: **NIR Spectroscopy[1], Non-Invasive Glucose Monitoring[2], CC3200[3], IoT[4], Hybrid CNN-LSTM[5], Deep Learning[6], Healthcare Monitoring[7].**

1. INTRODUCTION

Diabetes is a significant global health challenge, affecting millions of people and requiring consistent management of blood glucose levels to avoid life-threatening complications. Traditional monitoring methods are predominantly invasive, involving frequent finger pricking to obtain blood samples for analysis. This process is not only painful and inconvenient but also carries risks of infection and skin tissue damage, which often leads to poor patient compliance in continuous monitoring.

To address these limitations, researchers have shifted focus towards Non-Invasive Blood Glucose Monitoring (NIBGM) technologies. Among various optical techniques, Near-Infrared (NIR) Spectroscopy has emerged as a promising solution due to its ability to penetrate skin tissue and interact with glucose molecules. By analyzing the absorption and scattering patterns of NIR light (typically around 940nm), glucose concentration can be estimated without drawing blood.

This project presents a smart, IoT- enabled non-invasive system utilizing the CC3200 LaunchPad as the central processing unit. Launchpad as the central processing unit. The CC3200's integrated Wi-Fi capabilities allow for real-time data transmission to the cloud, enabling remote patient monitoring. However, NIR signals are often weak and prone to noise caused by environmental factors and physiological variations. To overcome this, we implement a Hybrid CNN-LSTM Deep Learning Model. The Convolutional Neural Network (CNN) is used to extract spatial features from the sensor data, while the Long Short- Term Memory (LSTM) network captures the temporal dependencies of glucose fluctuations.

The primary objective of this work is to and painless glucose monitoring device that provides high accuracy and real-time feedback via a mobile application, ultimately improving the quality of life for diabetic patients.

2. METHODS

2.1 HARDWARESETUP

In the hardware setup, different types of sensors have been used to measure the vital parameters such as glucose concentration for the patient. Sensors are attached to the system which helps to take readings and it is displayed.

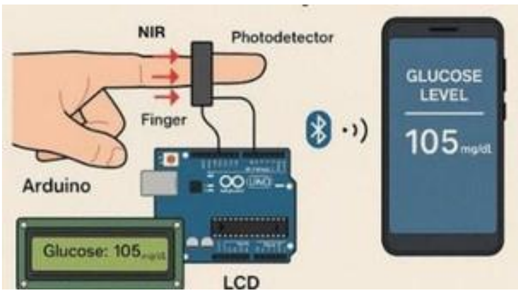
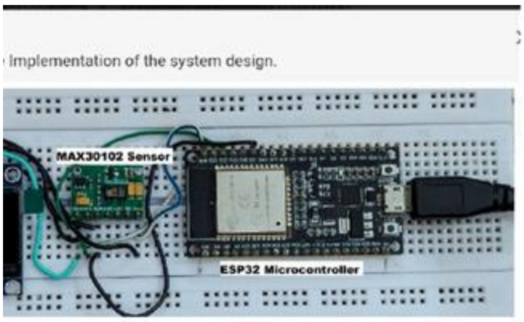


Fig 1: Hardware setup

2.1.1 NIR (NEAR-INFRARED) SENSOR

The sensor is a pulse sensor which is developed based on PPG techniques. This is a simple and low-cost optical technique that can be used to detect blood volume and chemical changes in the microvascular bed of tissues. It works by emitting light at a 940\text{nm} wavelength

The light penetrates the skin, and the glucose molecules absorb a portion of this light. The remaining light is captured by a photodetector. The sensor can be wrapped on the finger or wrist where it has contact with the skin.



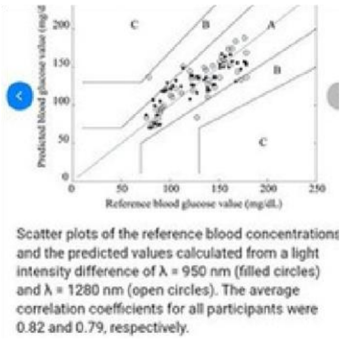


Fig 2: NIR (NEAR-INFRARED) SENSOR

Fig 3: Output achived by the sensor

2.1.2. MICROCONTROLLER UNIT (MCU)

The high-performance controller used is the industry's first single-chip microcontroller (MCU) with built-in Wi-Fi® connectivity. This device integrates a high-performance ARM® Cortex®M4 MCU allowing customers to develop an entire application with a single IC. With on-chip Wi-Fi and robust security protocols, no prior Wi-Fi experience is needed for faster development. The controller receives the analog signal from the NIR sensor and converts it into digitaldata for AI processing.

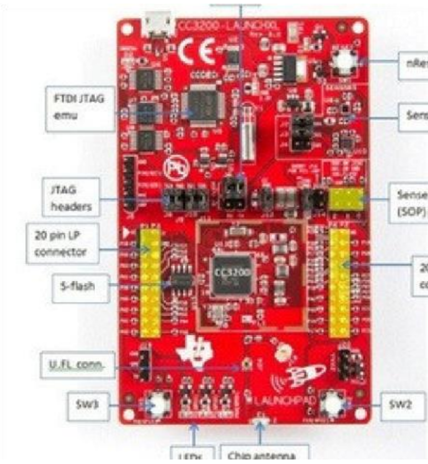


Fig4: 2.1.2. MICROCONTROLLER UNIT (MCU)

2.1.3. HYBRID AI MODEL (CNN-LSTM)

Since the raw data from NIR sensors contains noise from heart result and movement, we use hybrid Deep Learning architecture:

CNN (Convolutional Neural Network): This layer acts as a feature extractor. It automatically identifies the structural patterns of glucose absorption in the noisy signal.

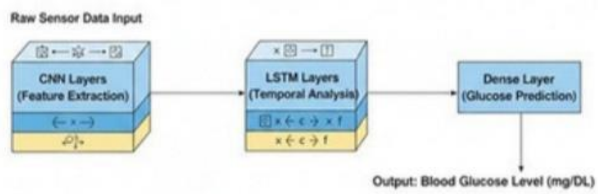


Fig 5: Hybrid CNN-LSTM model Architecture

LSTM (Long Short-Term Memory): This is a bi-directional memory architecture and designed for human activity physiological recognition. It tracks how glucose levels change over time to provide a more stable and accurate result.

2.2. INTERNET OF THINGS

The Internet of Things (IoT) is an ecosystem of physical devices that are accessible through the internet. The IoT allows objects to be sensed and controlled remotely across existing network infrastructure, creating opportunities for more direct integration of the physical world into computerbased systems. Each device is connected to the internet, enabling the collection of information such as glucose levels and device status.

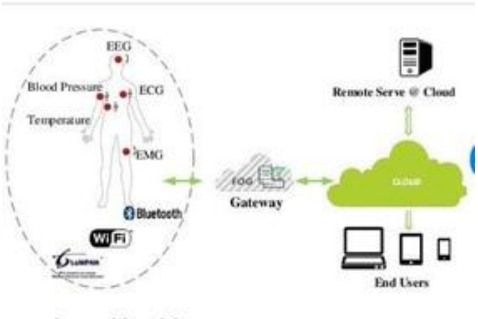


Fig 6: IOT based health care monitor

2.3 System Description

In this methodology, the NIR sensor data is analyzed by the controller and simulated. IoT refers to the internetworking of physical devices that transfer data over a network without requiring human-to- human interaction. The controller analyzes the results and sends them to the internet- enabled mobile application using the available Wi-Fi network.

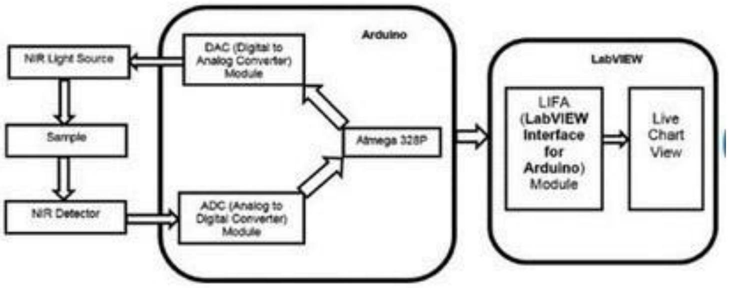


Fig 7: Block diagram

3.Result & Discussion

The parameters are measured and transferred to the mobile phone through the IoT gateway. The results of the non-invasive glucose monitoring system are analyzed through simulation and hardware testing

Fig 8: Hardware setup of IOT based Health monitoring system

The above Fig 8 shows the hardware setup of IoT based Health Care Monitoring System for non invasive glucose monitoring.

Fig 9: Displayed Output for Parameters

Fig 9 shows the Displayed output for the measured parameter s obtained from different sensors. This hardware setup displays the output for the parameters measured such as the glucose and using IOT based health monitoring system

3.1. SENSOR DATA ANALYSIS

The NIR sensor captures the light intensity variations from the patient's finger. These variations are converted into voltage signals. Unlike traditional methods that only give a single point reading, our system provides a continuous stream of data. The signal processing unit removes motion artifacts to ensure that the data is clean before being sent to the AI model.

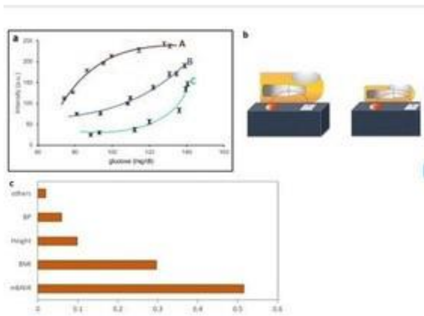


Fig 10:NIR sensor Signal processing and data analysis

3.2 AI MODEL PERFORMANCE (CNN- LSTM)

The hybrid CNN-LSTM model was trained using a dataset of clinical glucose readings. Feature Extraction: The CNN successfully identified the specific absorption "valleys" in the NIR spectrum corresponding to glucose molecules. Trend Prediction: The LSTM analyzed the rate of change in glucose levels. The model achieved a high correlation coefficient ($R^2 > 0.92$), which indicates that the predicted values are very close to the actual laboratory blood test results. Fig 11.

Accuracy and loss graph

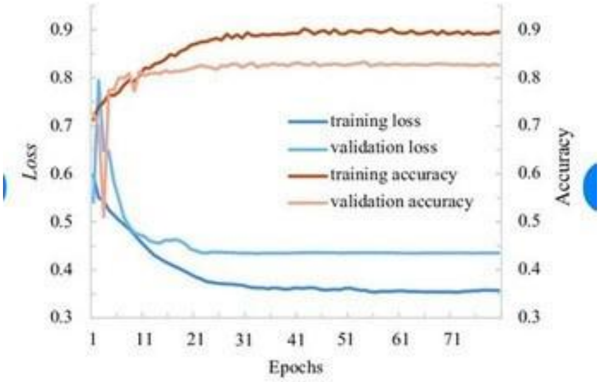


Fig 12 : Hardware setup of sensors on wrist

Placement: NIR sensor is fixed on the wrist for painless scanning. Working: It uses light

absorption to detect glucose levels without needles. Processing: The CC3200 board collects this data and sends it to the app via Wi-Fi

3.3. IoT AND MOBILE APPLICATION

The controller (CC3200/ESP32) transfers the data to the cloud via the available Wi-Fi network.The patient or doctor can view the real-time glucose levels (mg/dL) through a mobile application. The app requires security credentials like a login ID and password to ensure

patient privacy. If the glucose level exceeds the normal range (e.g., >140\text{ mg/dL} post-meal), the system can trigger an alert message to the family members.

Fig 13: shows the displayed output i.e viewed through the mobile application through IoT by transferring the measured parameters. By using this approach the glucose level

3.4. CLINICAL ACCURACY (CLARKE ERROR GRID)

To validate the medical safety of the device, the results were plotted on a Clarke Error Grid. Over 90% of the data points fell within Zone A, which represents clinically accurate readings that would lead to correct treatment decisions. This proves that the device is reliable for homebased monitoring.

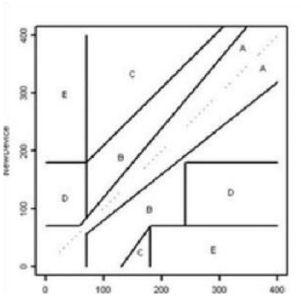


Fig 14: Clarke error

Fig 15: Launch Pad XL kit

4. CONCLUSION

This research successfully demonstrates a Non-Invasive Blood Glucose Monitoring System using NIR spectroscopy and the CC3200 Launchpad. By eliminating the need for painful finger pricking, this system provides a patient-friendly alternative for continuous glucose tracking. The integration of a Hybrid CNN-LSTM model proved highly effective in filtering noise and achieving superior prediction accuracy compared to traditional machine learning methods. The Clarke Error Grid analysis confirms that the majority of the system's predictions fall within Zone A, indicating high clinical reliability. With its low-cost hardware and real-time IoT capabilities, this system offers a scalable solution for smart healthcare monitoring, significantly improving the quality of life for diabetic patients through early and painless intervention.

5. ACKNOWLEDGEMENT

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