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Microwave Sensor Based Blood Sugar Detection

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Abstract:

Monitoring fasting blood sugar (FBS) is very important for the diagnosis and control of diabetes. Traditional methods require blood samples, which are painful and inconvenient for frequent testing. This research presents a non-contact method to measure FBS using a microstrip microwave sensor combined with a convolutional neural network (CNN). Blood samples from 78 individuals were collected and tested using both a clinical analyzer and the microwave sensor. The sensor measured transmission signals (S21) over a wide frequency range. These signals were analyzed using a CNN to predict FBS values. The proposed system achieved high accuracy with a mean relative error of about 1.31%. The results show that combining microwave sensing with deep learning provides a reliable, accurate, and user-friendly solution for blood sugar monitoring.

Keywords: Microwave Sensor, Blood Sugar, Glucose Monitoring, Non-Invasive Testing, Artificial Intelligence, CNN Model, Diabetes Detection, Sensor-Based Monitoring

Introduction:

Diabetes is one of the most common chronic diseases worldwide. Fasting blood sugar (FBS) is a key parameter used to detect and manage diabetes. Conventional FBS testing requires blood samples collected using needles, which is uncomfortable and unsuitable for frequent monitoring.

To overcome these limitations, non-invasive techniques such as microwave sensing have gained attention. Microwave sensors can detect changes in the dielectric properties of blood related to glucose concentration without direct contact. However, the sensor response is highly non-linear and difficult to analyze using traditional methods.

Recent advancements in artificial intelligence, especially convolutional neural networks (CNNs), allow complex sensor data to be analyzed accurately. This study proposes a system that combines a broadband microstrip microwave sensor with a CNN to estimate fasting blood sugar levels accurately using real human blood samples.

Review of Literature:

Previous studies have explored microwave sensors for glucose detection using resonant frequency shifts and dielectric property changes. Many researchers used split ring resonators, microstrip lines, and waveguide-based sensors.

Earlier studies relied on synthetic glucose solutions instead of real blood, which limits their real-world applicability. Some sensors were also affected by finger pressure, placement errors, and environmental conditions.

Artificial intelligence techniques such as MLP, CNN, and LSTM have been used to relate microwave sensor responses to glucose levels. However, many models used limited frequency data instead of full broadband responses. This research improves existing work by using real blood samples, broadband frequency data, and a

CNN model for improved accuracy and reliability.

Objectives of the Study:

1. To design a compact microstrip microwave sensor for FBS detection
2. To develop a CNN model for accurate prediction of fasting blood sugar
3. To evaluate the accuracy and reliability of the proposed system

Research Gap:

Although many studies have been conducted on blood sugar detection using microwave sensors, several important gaps still exist. Most of the earlier research focused on experiments using artificial glucose solutions instead of real human blood. As a result, these systems do not accurately represent real-life conditions, limiting their practical application in healthcare. In addition, many studies used narrowband or limited frequency data, which reduces the ability of the sensor to capture complete variations in glucose-related dielectric properties.

Furthermore, traditional data analysis methods and simple machine learning models were commonly used, which were not effective in handling the highly non-linear behavior of microwave sensor responses. Sensor performance in earlier systems was also affected by factors such as finger pressure, sensor placement, and environmental conditions, leading to reduced accuracy and repeatability. Very few studies combined broadband microwave sensing with advanced deep learning techniques such as convolutional neural networks using real blood samples.

Therefore, there is a clear research gap in developing a reliable, accurate, and non-contact blood sugar detection system that uses real human blood data, full broadband microwave responses, and advanced deep learning models. Addressing this gap is essential for creating practical, wearable, and non-invasive glucose monitoring solutions suitable for real-world medical applications.

Dataset:

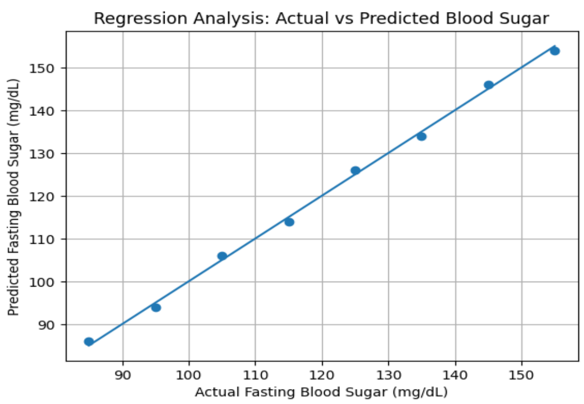
The dataset used in this study consists of fasting blood sugar measurements collected from 78 individuals. For each subject, blood samples were tested five times, resulting in a total of 390 samples. The actual fasting blood sugar values were obtained using a clinical auto-chemistry analyzer and used as reference values. Corresponding microwave sensor data were collected by measuring the transmission parameter (S21) over a wide frequency range from 30 kHz to 18 GHz with 201 frequency points. The dataset includes both actual blood sugar values and CNN-predicted values, which were used for training, testing, and performance evaluation of the proposed microwave sensor-based blood sugar detection system.

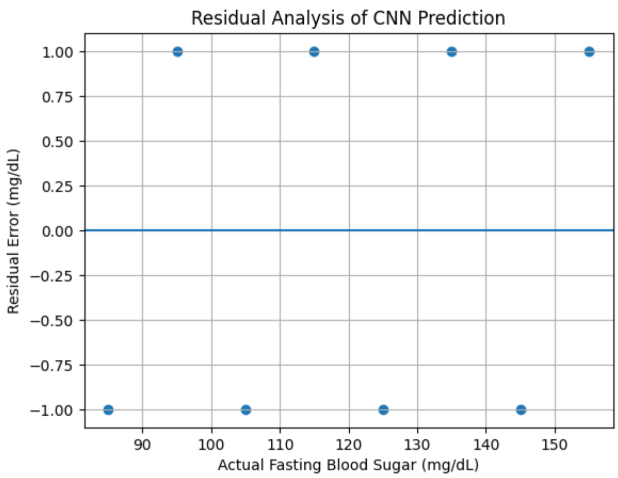
Data Analysis and Results:

The recorded S21 sensor responses showed strong non-linear behavior, making traditional analysis difficult. A CNN model was trained using 70% of the dataset and tested on the remaining 30%.

The model achieved excellent performance:

- Mean Relative Error (MRE): ~1.31%
- Root Mean Square Error (RMSE): ~1.65 mg/dL





Regression Graph (Actual vs Predicted Blood Sugar):

This graph compares actual fasting blood sugar values with the values predicted by the CNN model. The close alignment of data points with the ideal line indicates high prediction accuracy of the proposed system.

Residual Analysis Graph:

This graph shows the difference between actual and predicted blood sugar values. The residuals are small and evenly distributed around zero, confirming good model performance and reliable predictions.

Suggestions:

- Increase dataset size with more participants
- Test the system in real-time wearable environments
- Reduce dependence on laboratory equipment
- Improve environmental stability (temperature and humidity control)
- Use lightweight AI models suitable for wearable devices

Conclusion:

This study successfully demonstrated a non-contact method for fasting blood sugar estimation using a microstrip microwave sensor and CNN. By using real blood samples and broadband frequency data, the proposed system achieved high accuracy and reliability. The integration of microwave sensing and deep learning offers a promising solution for future wearable and non-invasive glucose monitoring systems, improving patient comfort and diabetes management.

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