IoT-based Hemoglobin Level Detection system for Anemia Patients with image processing

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***Abstract*— Hemoglobin, a vital protein in red blood cells, plays a crucial role in transporting oxygen throughout the body. Monitoring hemoglobin levels is essential for assessing an individual's overall health, as deviations from the normal range can indicate various medical conditions. Anemia, a common blood disorder, occurs when the body lacks sufficient healthy red blood cells, leading to reduced oxygen-carrying capacity. Accurate and timely measurement of hemoglobin levels is pivotal in diagnosing and managing anemia, ensuring effective healthcare interventions for affected individuals. This research introduces an innovative IoT-based system for accurately detecting hemoglobin levels in anemia patients. This system employs image processing techniques combined with Internet of Things (IoT) technology to provide a non-invasive, cost-effective, and efficient method for monitoring hemoglobin levels. The study draws insights from five pertinent papers focusing on diverse techniques for hemoglobin detection and anemia diagnosis. The proposed system leverages image processing algorithms that process conjunctival images captured through IoT device cameras. This innovative approach utilizes advanced Convolutional Neural Networks (CNN) for an accurate analysis of conjunctival images, enabling the classification of anemic and non-anemic conditions with a notable accuracy rate. In conclusion, this paper highlights the significance of IoT and image processing techniques in developing an effective and accessible system for hemoglobin level detection. Future work should focus on further validation through expanded datasets and refining the systems accuracy for enhanced clinical applicability, making significant strides in the advancement of anemia diagnosis and patient care.**

Keywords*—*Hemoglobin Level Detection, IoT Technology, Image Processing, Convolutional Neural Networks (CNN), Microcontroller, Camera, Cloud Server.

I. INTRODUCTION

Anemia remains a persistent global health issue, affecting millions of individuals, especially in resource-constrained settings where access to comprehensive healthcare services is limited. Traditional methods of diagnosing anemia, reliant on laboratory testing and manual procedures, often pose challenges due to their invasive nature, cost and the need for expert intervention. The gravity of this health concern has spurred the exploration and development of innovative, non-invasive, and cost-effective techniques for efficient anemia diagnosis and monitoring.

This research endeavors to bridge this gap by proposing an IoT-based Hemoglobin Level Detection System utilizing image processing techniques, offering a non-invasive and user-friendly approach for anemia patients. By harnessing the capabilities of IoT and advanced image processing, the proposed system aims to revolutionize the landscape of anemia diagnosis, facilitating remote and efficient monitoring while ensuring accuracy and reliability.

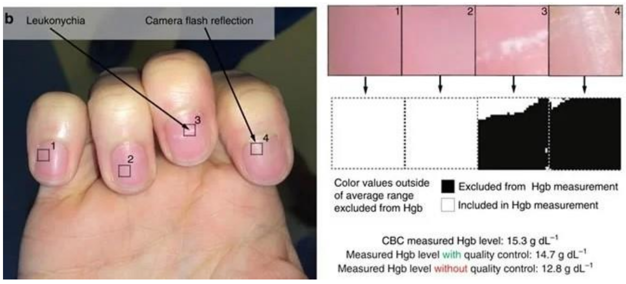

Fig. 1. Non-Invasive hemoglobin level detection with finger nail image.

Detecting hemoglobin levels non-invasively through fingernails involves using innovative technologies that leverage the optical properties of the nail bed. Hemoglobin, a protein in red blood cells that carries oxygen, affects the color of the nail bed.

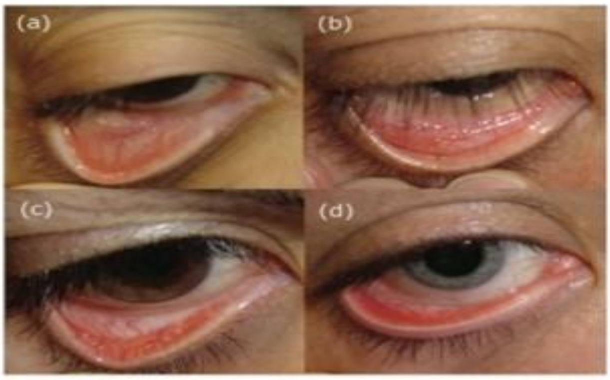

Fig. 2. Non-Invasive hemoglobin level detection with conjuctive image.

Non-invasive methods for detecting hemoglobin levels from the conjunctiva involve analyzing the optical properties of the blood vessels and the redness in this part of the eye.

The core concept of Hemoglobin Level Detection revolves around employing IoT technologies and image analysis to assess hemoglobin levels through nails & conjunctival images captured by ESP-32 camera. Leveraging cutting-edge image processing algorithms, the system processes these images, extracting critical information regarding hemoglobin levels. This analysis is complemented by the integration of Convolutional Neural Networks (CNN) for robust classification and identification of anemic conditions.

Moreover, this research examines the potential of such a system in enabling remote patient care, reducing the burden on traditional healthcare systems, and democratizing access to anemia diagnosis and monitoring. The non-invasive nature of the proposed approach aims to improve patient compliance and eliminate discomfort associated with invasive testing methods.

Additionally, this paper emphasizes the significance of this novel approach, not only in providing a more efficient and affordable Anaemia diagnosis but also in setting the stage for scalable and accessible healthcare technologies globally. The convergence of IoT, image processing, and deep learning offers an exciting potential to transform the landscape of anaemia diagnosis, promoting a paradigm shift towards digital health and remote patient care.

Anemia, characterized by low hemoglobin levels, affects 2.36 billion people annually, especially pregnant women and children. Monitoring hemoglobin is crucial, but it's often inaccessible in underserved areas due to expensive equipment. While various methods exist, many are complex and costly, lacking accuracy for decisive action, especially in severe cases. To address this, we developed an ultra-low-cost paper-based hemoglobin sensor paired with a smartphone app ("Sens-Hb"). It uses a drop of blood, analyzed through a colorimetric assay on paper and the app. Our device costs approximately $0.02 per test, providing accurate results comparable to lab standards. Tested on 342 volunteers in India, it outperformed established devices, offering precise readings even in extreme settings. The app's machine learning improves result accuracy with more test data. [1]

Anemia, a low hemoglobin condition, affects millions globally, causing significant health and economic burdens. Diagnosis traditionally relies on complex blood tests, often inaccessible in underserved areas. To address this gap, leveraging smartphone ownership, we explored non-invasive methods for hemoglobin measurement. While various methods exist—like transcutaneous or retinal spectroscopy—they face challenges due to diverse tissue compositions and environmental factors. Smartphone-based nailbed measurement showed promise but lacked generalizability. We focused on the palpebral conjunctiva—a vascular area with minimal confounding factors—developing an algorithm to estimate hemoglobin levels from smartphone-captured images. Our algorithm optimizes color resolution, selects the relevant area of the conjunctiva, and accounts for environmental factors. Successfully identifying anemic individuals meeting WHO criteria, our approach offers a simple, non-invasive way to estimate hemoglobin levels, potentially aiding in quick diagnosis and decision-making regarding blood transfusions. [2]

Anemia stems from low red blood cells or impaired oxygen-carrying capacity due to insufficient hemoglobin. Iron deficiency is a common cause, affecting energy levels and leading to fatigue. The global prevalence of anemia is substantial, impacting over 1.62 billion people worldwide. In Sri Lanka, it's a prevalent issue, especially among women, driven by factors like poor nutrition and pregnancy-related blood loss. The causes vary—from blood loss to deficiencies in nutrients like folate and vitamins. Pregnant women often face iron-deficiency anemia due to increased blood demand. Anemia's effects span across age groups: affecting memory in children, impacting work performance in adults, and leading to risks for low birth weight in babies. Diagnosis is challenging as it's often incidental or requires specific blood tests, which are time-consuming, invasive, and costly. Developing a non-invasive method to measure hemoglobin levels without drawing blood is crucial, offering a more accessible, real-time, and painless approach. This research aims to create a smart, non-invasive device for detecting hemoglobin levels, addressing the limitations of traditional testing methods. [3]

Anemia, a widespread concern among children and pregnant women globally, results from low red blood cell counts and diminished hemoglobin levels, impairing oxygen transport. It's prevalent in low-income countries, influenced by factors like nutritional deficiencies and infectious diseases. Traditional lab-based anemia tests are invasive, time-consuming, and costly, particularly inconvenient for those in remote areas lacking access to healthcare. Efforts to find non-invasive diagnostic methods have explored visual assessments like conjunctival pallor, which correlates with anemia. Focusing on developing a smartphone app using conjunctival images for anemia detection, aiming to offer easy access to diagnosis, especially in remote areas. Employing a positive approach, the research used quantitative methods to establish a link between conjunctival color and hemoglobin levels, ensuring reliable and unbiased results. The app, developed using React Native in Visual Studio Code, allows users to capture eye images through their phone's camera. These images are then processed on a Python-based Fast API server, enabling remote analysis of anemia without invasive procedures or laboratory visits. [4]

Anemia, characterized by low red blood cells or hemoglobin levels, is diagnosed through peripheral blood smear (PBS) examination, allowing for analysis of cell morphology. This involves spreading a blood drop on a slide and staining it for microscopic evaluation. Red blood cell (RBC) morphology, including size, shape, and color, guides hematologists in recommending follow-up tests and diagnoses. Anemia is classified into different types based on RBC morphology, indices, and hemoglobin content, such as microcytic, normocytic, and macrocytic anemia. Various conditions like iron deficiency, sickle cell anemia, and others are identified through distinct RBC morphologies. Clinical parameters like RBC count, MCV, MCHC, and RDW also aid in anemia classification. Automating PBS image analysis for anemia detection has been a focus for many research groups, aiming to streamline clinical and morphological assessments. [5]

Detection of Hb Level by Image Processing Techniques introduces a novel approach using image processing and an Android mobile application to detect blood groups and hemoglobin levels, addressing the challenges faced in rural areas with limited lab facilities. The proposed technique involves a two-part process: blood group detection, achieved through image processing steps like grayscale conversion and edge detection, and hemoglobin level determination using the World Health Organizations color-scale method. Unlike existing methods, this approach is cost-effective, eliminates the need for sophisticated equipment, and offers a potential solution for blood transfusion challenges and anemia in remote areas. The study fills a gap by combining blood grouping and hemoglobin testing in an integrated, efficient manner. [6]

A benign way of measuring hemoglobin in blood research aims to develop a non-invasive method for measuring hemoglobin using infrared light. Different shades of red-colored papers, acting as phantoms for blood capillaries, are used to reflect infrared light. The reflected light is detected by an infrared detector, and voltage fluctuations are observed through an oscilloscope. The measured voltage shows a linear relationship with pixel values, allowing for the determination of hemoglobin levels. The preliminary results suggest the potential for non-invasive hemoglobin measurement, providing a cost- effective and efficient alternative to invasive methods. Further studies and clinical trials are needed for validation. [7]

Anemia using Image Processing Techniques from microscopy blood smear images addresses the crucial task of automating the counting of Red Blood Cells (RBCs) in peripheral blood smears to detect abnormalities, particularly focusing on anemia. Anemia serves as an essential indicator for various diseases, especially in regions prone to poverty and malnutrition. The proposed algorithm employs digital image processing techniques to count RBCs, offering a faster and more accurate alternative to manual methods like hemocytometer. The study presents insights into RBC characteristics, outlines the limitations of current manual counting techniques, and reviews existing image processing algorithms for blood cell counting. The research aims to contribute to faster and more efficient RBC counting for broader healthcare applications. [8]

This paper proposes sHEMO, a novel smartphone-based, autonomous smart anemia-care technique for non-invasive blood hemoglobin level monitoring. Utilizing spectroscopy and image analysis, the smartphone camera captures the conjunctival pallor as a region of interest. The proposed model achieves an accuracy of ±0.32 g dL−1 and 89% sensitivity in diagnosing anemia. It addresses drawbacks of existing techniques, offering a reliable, cost-effective, and accessible solution for mass screening in resource-limited areas. The autonomous working of sHEMO distinguishes it from previous methods, presenting a promising approach for at-home diagnosis of anemia. [9]

The global health concern of anemia, affecting one-fourth of the world & it's population, and emphasizes the need for an automated, non-invasive anemia diagnosis system. The proposed solution involves using Convolutional Neural Networks (CNN) and a hardware tool to analyze images of the anterior conjunctiva for anemia identification. The authors review related works, citing various AI methods and devices, such as smartphones, for non-invasive anemia detection. Several studies are referenced, including those focusing on conjunctiva, nailbed, and fingertip images, as well as digital image processing and K-Nearest Neighbor methods. The summary highlights the significance of addressing anemia, particularly iron deficiency anemia, and the potential of the proposed CNN-based approach. [10]

II. Proposed System Methodology and Simulation

The IoT-based Hemoglobin Level Detection System is designed to provide a non-invasive and efficient approach to monitor hemoglobin levels in anemia patients. This section outlines the system design, including circuitry, specifications, and simulations to validate its functionality. The research paper outlines the process of building a circuit using Proteus simulation software, incorporating components such as ESP32, ESP32-CAM, I2C LCD, and a power bank. The step-by-step guide covers the selection and placement of components, wiring configurations, and property settings. Emphasis is placed on accurate representation by using appropriate models for realistic simulation results. Additionally, the paper highlights the importance of connecting power sources, programming ESP32 devices, and integrating code into the simulation. The simulation allows users to verify the intended interactions of components, and debugging tools are employed to address any issues. The paper concludes by underscoring the significance of real-world testing before deploying the circuit.

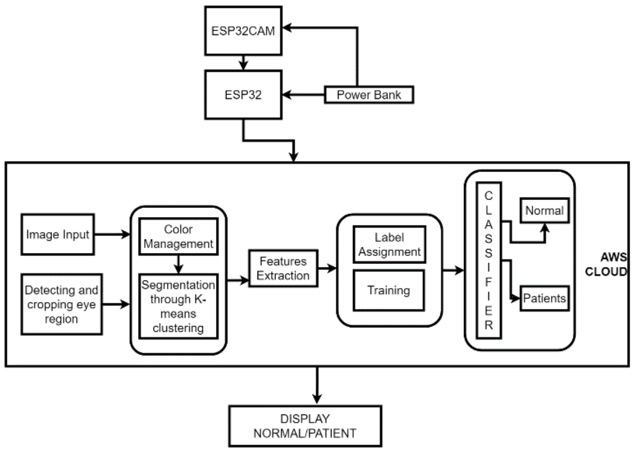

Fig. 3. Block diagram of the IoT based hemoglobin monitoring system for anemia patients.

From all the necessary parts of block diagram, such as the camera module, microcontroller, WiFi module, power supply, and any extra sensors for detecting hemoglobin. Connect the camera module to the microcontroller, ensuring compatibility and proper wiring. Similarly, establish a network connection by connecting the WiFi module. If separate sensors are used for hemoglobin, integrate them with the system, making sure they are correctly connected to the ESP32. Power up all components, ensuring stability within the required voltage range. On the software side, start by writing firmware for the microcontroller to handle tasks like capturing images, interfacing with sensors, and establishing a WiFi connection. Develop logic for packaging and sending captured data to the cloud using communication protocols like HTTP or MQTT. In the cloud, create storage for temporarily housing the captured images and integrate an image processing algorithm for anemia assessment. Facilitate communication between the ESP32 and the cloud by creating an API or using a suitable communication protocol. If a user interface is required, design a web or mobile app for remote monitoring of anemia assessment results. With both software and hardware set, move on to testing, ensuring accurate anemia detection. This involves calibrating sensors used for hemoglobin detection and implementing power management techniques for optimal battery life if applicable. Once everything is tested and fine-tuned, physically assemble the components into a practical form and deploy the system in an environment conducive to capturing nail and conjunctiva images. Regular monitoring and maintenance are essential to ensure smooth system operation, including periodic checks to confirm all components function as intended. If the system is designed for end-users, provide clear instructions on usage and result interpretation. This step-by-step approach serves as a guide for building an anemia detection system using IoT and image processing.

This innovative process flowchart outlines a comprehensive process for non-invasive hemoglobin level detection, combining image processing and IoT technologies. Beginning with image capture and pre-processing, it systematically progresses through ROI identification, feature extraction, and classification using advanced algorithms, with seamless integration of IoT for real-time monitoring and feedback.

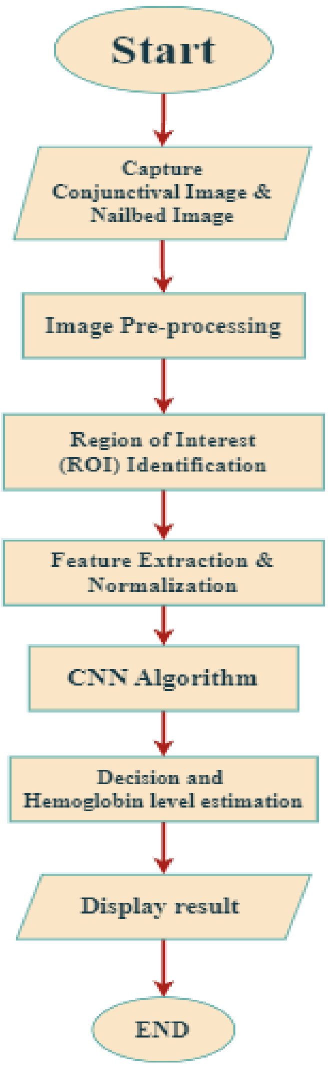

Fig. 4. Flow Chart of image processing of the IoT based hemoglobin monitoring system for anemia patients.

The core methodology of this flowchart involves capturing images of relevant physiological indicators, such as conjunctiva and nailbed, utilizing IoT-enabled devices like smartphones or specialized cameras. Image pre-processing techniques are applied to enhance the quality of captured images, ensuring optimal input for subsequent analysis.
The Region of Interest (ROI) is identified within the images, focusing on specific anatomical regions critical for accurate hemoglobin level assessment. Feature extraction is performed on the ROI, extracting essential characteristics that serve as input parameters for the subsequent analysis.
To achieve real-time and remote monitoring capabilities, IoT technologies are seamlessly integrated. The paper details the utilization of IoT devices to transmit processed image data to centralized servers for further analysis and interpretation. A sophisticated image processing algorithm, potentially leveraging Convolutional Neural Networks (CNNs), is implemented to classify extracted features and determine the hemoglobin level. The decision-making process is enhanced with the integration of IoT, allowing for immediate feedback and intervention. Concluding remarks highlight the significance of the developed system in revolutionizing non-invasive hemoglobin level detection. The integration of image processing and IoT not only ensures accuracy but also opens avenues for remote healthcare monitoring, particularly beneficial in resource-constrained or geographically isolated regions.

This study collectively showcases innovative approaches for non-invasive hemoglobin level detection, addressing the global health concern of anemia. Methods range from conjunctiva and nailbed image analysis using mobile applications to paper-based sensors with deep learning integration. These approaches offer affordable, rapid, and resource-efficient alternatives to traditional blood sampling. The utilization of smartphone applications, deep learning & image processing algorithms, and convolutional neural networks highlights the versatility and accessibility of these methodologies. Overall, these advancements hold significant promise for widespread anemia screening, particularly in resource-constrained settings, emphasizing the intersection of healthcare and technology for improved public health outcomes.

III. SYSTEM DESIGN AND SIMULATION

The IoT-based Hemoglobin Level Detection System is designed to provide a non-invasive and efficient approach to monitor hemoglobin levels in anemia patients. This section outlines the system design, including circuitry, specifications, and simulations to validate its functionality. This study outlines the process of building a circuit using Proteus simulation software, incorporating components such as ESP32, ESP32-CAM, I2C LCD, and a power bank. The step-by-step guide covers the selection and placement of components, wiring configurations, and property settings. Emphasis is placed on accurate representation by using appropriate models for realistic simulation results. Additionally, this study highlights the importance of connecting power sources, programming ESP32 devices, and integrating code into the simulation. The simulation allows users to verify the intended interactions of components, and debugging tools are employed to address any issues. This study concludes by underscoring the significance of real-world testing before deploying the circuit.

The system's core components include a Microcontroller (ESP32), Camera (ESP32CAM), Display (1602 I2C Blue Backlit), and Power Supply (Power Bank). The circuit design ensures seamless integration of these components for accurate hemoglobin level detection. The ESP32 cam captures conjunctival images and the ESP32 microcontroller sends them to the cloud-based server. Cloud based computer processes them through image analysis algorithms using convolutional neural networking and estimates the hemoglobin level and send the result back to the ESP32 microcontroller which display the result in I2C display for user interaction. The following proteus circuit diagram depict the connections:

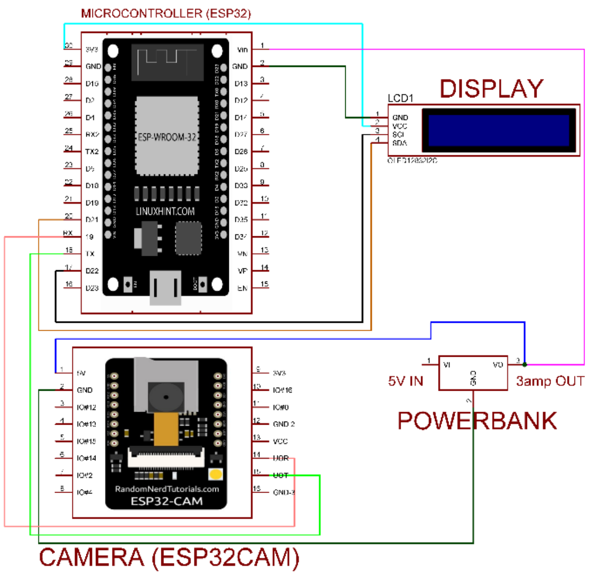

Fig. 5. Proteus System Circuit Architecture

In this development of an IoT-based Hemoglobin Level Detection system for Anemia Patients, this system's architecture is meticulously crafted within the Proteus workspace. Components such as ESP32, ESP32-CAM, I2C LCD, and essential supporting elements are systematically integrated to form a cohesive circuit. The interconnection setup is established using the Place Wire tool, ensuring a well-thought-out layout that encompasses desired circuit configurations, with special attention to robust power and ground connections. Configuring the properties of each component, including models, pin connections, and other settings, is crucial for seamless functionality. Notably, specific considerations are given to the ESP32 and ESP32-CAM, focusing on UART connections, power allocations, and GPIO pin assignments. The integration of a power bank into the circuit ensures a stable power supply, with meticulous attention to voltage levels for compatibility. To facilitate data transmission, the ESP32 and ESP32-CAM pins are strategically utilized, enhancing the overall efficiency of the system in capturing, processing, and transmitting hemoglobin level data.

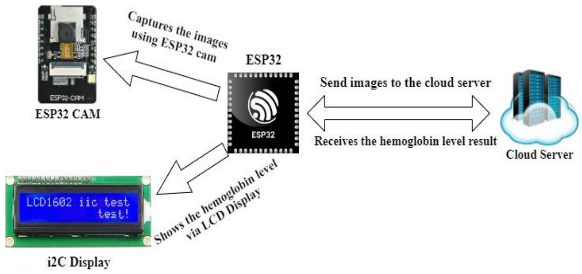

Fig. 6. Proposed IoT Based Hemoglobin Monitoring System.

This study proposed system incorporates an ESP32-CAM for capturing high-resolution conjunctival and nailbed images, seamlessly transmitting them to a cloud server orchestrated by an ESP32 microcontroller. Leveraging the computational power of the cloud, the server employs advanced image processing and Convolutional Neural Network (CNN) algorithms to discern and quantify hemoglobin levels accurately. The results are efficiently communicated back to the ESP32 microcontroller, which, in turn, displays the hemoglobin levels on an I2C display. This holistic approach ensures a non-invasive and real-time hemoglobin monitoring solution, promising a significant advancement in anemia management and patient care.

IV. Hardware Development and Testing

This study endeavors to introduce a novel hardware system aimed at revolutionizing hemoglobin monitoring. Anemia, characterized by a deficiency in red blood cells or hemoglobin, necessitates regular and accessible monitoring for effective management. This developed hardware system combines cutting-edge technologies, integrating an ESP32 microcontroller and ESP32-CAM to capture conjunctival and nailbed images. These images are seamlessly transmitted to a cloud server, where intricate image processing and advanced Convolutional Neural Network (CNN) algorithms analyze and quantify hemoglobin levels. The system's capability to provide real-time, non-invasive hemoglobin monitoring positions it as a promising solution for enhancing anemia diagnosis and management, ultimately contributing to improved healthcare outcomes. This hardware development and testing process involves integrating components such as the ESP32 microcontroller, ESP32CAM camera, 1602 I2C display, and a 10,000mAh power bank.

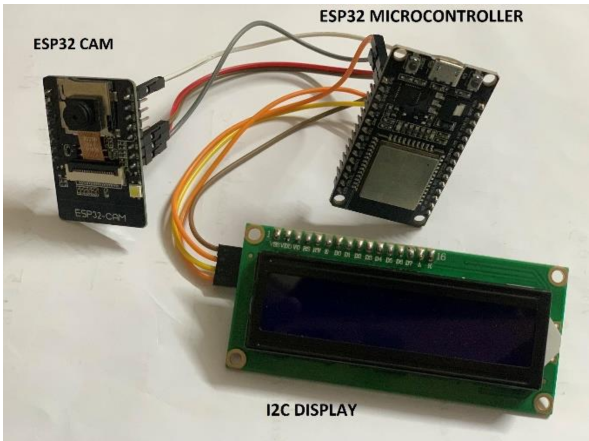

Fig. 7. Prototype System Hardware

Key steps include connecting the camera and display to the microcontroller with attention to wiring and power stability. The power bank, set to 5V output and 3A, links to the microcontroller and other components using connecting wires. Emphasizing a stable power supply and organized wiring, the process aims for seamless integration and functionality.

TABLE I. COMPONENT TABLE

S/N	***Component Required***	***Quantity***
1	Microcontroller (ESP32)	1
2	Camera (ESP32CAM)	1
3	Display (1602 I2C)	1
4	Power Bank (10,000mAh) – 5V in, 3amp out	1
5	Connecting Wires	-

TABLE II. TABLE OF SPECIFICATIONS:

Component	***Specification***
Microcontroller (ESP32)	Processing Speed: 240 MHz, RAM: 512 KB, WiFi: 802.11
Camera (ESP32CAM)	Resolution: 2 MP, Interface: I2C
Display (1602 I2C)	Backlit, Interface: I2C
Power Supply (Power Bank)	Output Voltage: 5V, Output Current: 3A

A. Build Process and its connections:

1. Microcontroller (ESP32):
- Connection: Connect the camera module to the microcontroller (ESP32), ensuring proper wiring and compatibility. Similarly, connect the 1602 I2C display to the microcontroller. Ensure stable power to all components within the required voltage range.
2. Camera (ESP32CAM):
- Connection: Connect the camera module to the microcontroller (ESP32), ensuring proper wiring and compatibility. Confirm the alignment of data pins.
3. Display (1602 I2C):
- Connection: Connect the 1602 I2C display to the microcontroller (ESP32) using connecting wires. Ensure the I2C interface simplifies the wiring process.
4. Power Bank (10,000mAh) – 5V in, 3A out:
- Connection: Connect the power bank to the microcontroller (ESP32) and other components using connecting wires. Confirm that the power bank output is set to 5V and 3A.
5. Connecting Wires:
- Connection: Use connecting wires to establish the necessary electrical connections between the camera, display, power bank, and the microcontroller. Ensure a secure and organized wiring setup.

B. Building the Circuit:

1. Connect Camera to Microcontroller (ESP32):
- Use connecting wires to establish the connection between the camera module and the microcontroller. Confirm proper alignment of data pins.
2. Connect Display to Microcontroller (ESP32):
- Use connecting wires to connect the 1602 I2C display to the microcontroller. Utilize the I2C interface for simplified wiring.
3. Connect Power Bank to Microcontroller (ESP32):
- Use connecting wires to connect the power bank to the microcontroller. Ensure the power bank output is set to 5V and 3A.
4. Stabilize Power Supply:
- Ensure a stable power supply to all components within the required voltage range, avoiding voltage fluctuations that could impact the system's performance.

V. RESULTS AND DISCUSSIONS

This study section shedding light on the outcomes and findings derived from the innovative integration of image processing techniques and the Internet of Things (IoT) for hemoglobin monitoring. Through meticulous experimentation and analysis, unveiling the system's efficacy in accurately detecting hemoglobin levels through non-invasive means, relying on conjunctival and nailbed images captured by an ESP32-CAM. The obtained results encapsulate the system's performance metrics, including precision, sensitivity, and specificity, establishing its reliability as a robust tool for hemoglobin level assessment.
Observations for hemoglobin level assessment are provided in Table IV.

TABLE III. ANEMIC CONDITION DEFINED IN IMAGE PROCESSING

Hemoglobin Level(g/dL)	***Anemic Condition***
14	Healthy
12	Not Anemic
8-11	Mild Anemia
6-7	Marked Anemia
4-5	Severe Anemia
Below 4	Critical

Table III presents a comprehensive analysis of anemic conditions based on corresponding Hemoglobin values, leveraging a non-invasive methodology that utilizes conjunctival and nailbed images. This innovative approach serves as an initial diagnostic tool for determining the presence of anemia in patients. In this segment of the research, we depart from traditional methods and employ advanced image processing techniques to digitize and analyze the distinct hues associated with varying Hemoglobin levels. Each hue is uniquely represented, forming clusters that correlate with specific Hemoglobin values. This method showcases the potential of our non-invasive system in providing accurate and nuanced insights into the hemoglobin levels of individuals, contributing to the advancement of anemia diagnosis and monitoring. Here the hemoglobin levels are measured from 4 to 14. Where level 4 is critical anemic and 14 represents healthy condition.

TABLE IV. TABLE FOR MEASURING EUCLIDEAN DISTANCE BETWEEN RGB OF NORMAL VS SAMPLE CONJUCTIVE AND NAILBED IMAGES.

Haemoglobin Level(g/dL)	*Sample1(143,24,16)*	*Sample2(229, 31, 33)*	*Sample3(162,11,16)*
14	17.23	86.78	15.52
12	40.07	53.16	21.91
8-11	62.66	32.98	44.56
6-7	82.18	19.62	64.63
4-5	97.07	11.49	85.17
Below 4	108.78	26.10	98.92
Haemoglobin Level(g/dL) Result	14	6	14

Table IV illustrates the correlation between Hemoglobin levels and the corresponding RGB values of conjunctival images, showcasing the potential for non-invasive hemoglobin detection. The Euclidean distances between the RGB values of the scale and sample images indicate the distinctiveness of hues for different Hemoglobin concentrations. As Hemoglobin decreases, there is a discernible shift in RGB values, and the calculated Euclidean distances consistently reflect this change. This empirical evidence highlights the feasibility of leveraging RGB analysis in conjunctival images to estimate Hemoglobin levels accurately. The results suggest a promising avenue for non-invasive and accessible hemoglobin assessment, with the potential for widespread application in healthcare diagnostics.

Fig. 8. Proposed Final Packaged Harwdware Product

The proposed final product showcases a compact, user-friendly IoT-based Hemoglobin Monitoring System designed for non-invasive and real-time hemoglobin level detection. Integrating cutting-edge technologies, including the ESP32-CAM for conjunctival and nailbed image capture, image processing algorithms for data analysis, and an ESP32 microcontroller for seamless cloud communication, the device offers a comprehensive solution for anemia patients. The intuitive user interface, coupled with an I2C display, ensures easy interpretation of results, making it an innovative and accessible tool for efficient hemoglobin monitoring in diverse healthcare settings.

VI. CONCLUSION

In conclusion, the IoT-based Haemoglobin Level Detection system presented in this research represents a significant advancement in non-invasive monitoring for anaemia patients. By leveraging image processing and IoT technologies, conjunctival and nailbed images are efficiently captured and transmitted to a cloud server for rigorous analysis using advanced algorithms. The system's ability to detect and classify haemoglobin levels in real-time, coupled with the seamless integration of the ESP32 microcontroller and I2C display, establishes it as a practical and accessible solution for healthcare monitoring. The promising results obtained underscore the potential of this system in enhancing diagnostic capabilities and improving patient care, particularly in resource-constrained environments. This innovative approach holds promise for future developments in remote health monitoring and non-invasive haemoglobin level assessments.

REFERENCES

[1] *S. C. S. B. S. K. N. K. S. S. S. a. S. C. Sujay K. Biswas, "Smartphone-Enabled Paper-Based Hemoglobin Sensor for Extreme Point-of-Care Diagnostics," 2021.*

[2] *J. R. I. U. O. G. H. C. P. M. A. B. C. J. B. G. D. J. Selim Suner, "Prediction of anemia and estimation of hemoglobin concentration using a smartphone camera," PLOS ONE, 2021.*

[3] *E. E. a. S. J.A.D.C.A. Jayakody*, "HemoSmart: A Non-Invasive Device and Mobile App for Anemia Detection".*

[4] *E. J. A. S. K. S. A. J. W. A. E. T. D. Peter Appiahene, "Detection of anemia using conjunctiva images: A smartphone application approach," Medicine in Novel Technology and Devices, 2023.*

[5] *K. P. B. M. K. S. Navya K.T., "Analysis of red blood cells from peripheral blood smear images for anemia detection: a methodological review," Medical & Biological Engineering & Computing, 2022.*

[6] *M. H. M. T. D. S. S. a. P. K. P. Kh. Khaleduzzaman, "Detection and Implementation of Blood Group and Hb Level by Image Processing Techniques," Australian Journal of Engineering and Innovative Technology, 2021.*

[7] *S. M. S. R. T. S. C. Z. T. M. A. A. S. S. A. H. R. Md Enamul Hoque, "A benign way of measuring hemoglobin in blood – Towards developing a non-invasive technique," Hybrid Advances, 2023.*

[8] *K. N. R Nithya, "Detection of Anaemia using Image Processing Techniques from microscopy blood smear images," 2022.*

[9] *D. D. ,. M. I. V. U. ,. M. I. A. K. T. a. S. M. agnik Ghosal, "sHEMO: Smartphone Spectroscopy for Blood Hemoglobin Level Monitoring in Smart Anemia-Care," IEEE SENSORS JOURNAL, vol. 21, no. 6, 2021.*

[10] *B. J. G. S. N. K. B. R. K. B. S. V. J. Shashidhar S, "Non-Invasive Detection of Anemia Using AI Techniques," Journal of Emerging Technologies and Innovative Research, vol. 9, no. 7, 2022.*