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Non-Invasive Hemoglobin Level Detector

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Abstract

Hemoglobin is essential for oxygen transport in the body, but traditional measurement methods require invasive blood sampling, which is often uncomfortable and impractical for frequent use. To overcome these limitations, there is a growing interest in non-invasive hemoglobin detection technologies that can measure hemoglobin levels without breaking the skin or drawing blood. These techniques are based on optical sensing principles, where light of specific wavelengths (typically in the red and infrared spectrum) is passed through body tissues like the fingertip or earlobe. The absorbed or scattered light by the blood and tissues provides measurable data that can be used to estimate hemoglobin concentration. This paper proposes a non-invasive hemoglobin level detector utilizes photoplethysmography (PPG) and spectrophotometry to collect optical signals from the user. These signals are then processed using embedded algorithms or machine learning models to calculate hemoglobin levels in real time. The system is powered by a microcontroller and includes a display or mobile interface for user-friendly output. This technology has the potential to revolutionize health monitoring, especially in resource-limited settings, rural healthcare, and home-based applications. It allows for safe, quick, and continuous hemoglobin assessment, making it suitable for pregnant women, children, elderly patients and individuals with chronic conditions who require regular monitoring.

Keywords

Hemoglobin Detection, Photoplethysmography, Microcontroller

Introduction

Hemoglobin transports oxygen from the lungs to the tissues and removing carbon dioxide from the body. Monitoring hemoglobin levels is essential for diagnosing various medical conditions, including anemia, nutritional deficiencies, blood loss and chronic diseases. Traditionally, hemoglobin measurement requires a blood sample and laboratory analysis using invasive techniques, such as a finger prick or venous blood draw. While accurate, these methods are often painful, require trained personnel, and are not ideal for frequent or large-scale screening. Non-

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invasive diagnostic devices have become an essential part of modern healthcare, offering painless and quick ways to monitor vital health parameters without the need for drawing blood. Among these, non-invasive hemoglobin and blood parameter detection tools are gaining importance due to their potential in real-time monitoring, reducing infection risk, and increasing patient comfort. These devices generally utilize optical sensors, PPG, and signal processing techniques to estimate levels of hemoglobin, oxygen saturation, glucose, or even detect tumors.

Pintavirooj et al. (2021) introduced a non-invasive hemoglobin monitoring system, gained significant attention due to its potential to provide rapid, painless and continuous assessment of hemoglobin concentration. The principle behind these systems is based on optical sensing, where light absorption characteristics of hemoglobin at specific wavelengths are analyzed. Hemoglobin exhibits distinct absorption peaks, with oxyhemoglobin absorbing strongly around 660 nm and deoxyhemoglobin around 880 nm. By exploiting these differences, optical sensors can estimate hemoglobin concentration without the need for invasive blood sampling. Ranjith et al. (2024) employs a photodiode placed between a red light-emitting diode (LED) at 630 nm and an infrared (IR) LED at 940 nm, along with associated signal conditioning circuits. In this approach, optical absorbance of arterial blood components is measured using the reflectance method, wherein visible and IR lights are alternately projected onto the fingertip of a subject. The photodiode detects the reflected light, and the resulting photocurrent is converted into voltage, followed by noise reduction and signal processing.

Das et al. (2023) proposed a novel system that integrates computational approaches with the traditional clinical practice of assessing hemoglobin levels by observing pallor in the palm. The method is based on inducing changes in palm pallor through controlled pressure application and release, followed by measurement of the rate of colour change. Time-domain analysis of these variations enables correlation with hemoglobin concentration. A customized device was employed to capture video recordings of palm colour changes using a smartphone camera, which were subsequently processed through a series of image processing and analysis techniques. The extracted parameters were then used as input features for ensemble-based prediction models, including regression and multi-layer perceptron networks. Experimental evaluation, conducted on palm pallor video samples from 131 participants, demonstrated a sensitivity of 93% with mean squared error (MSE) of 0.701 and root mean squared error (RMSE) of 0.698.

Kumar et al. (2022) proposed a non-invasive hemoglobin monitoring based on optical spectroscopy (reflectance or transmittance modes), digital photography, or spectroscopic imaging. These methods face challenges arising from factors such as varying ambient light conditions, motion artifacts, skin pigmentation (melanocytes) and the presence of other blood constituents, smoking habits, and the need for precise sensor placement. These limitations often affect measurement accuracy and reliability. Luangrat et al. (2013) explored novel hypotheses for non-invasive detection of hemoglobin concentration based on physiological signal variations. One such approach investigated the relationship between hemoglobin concentration and pulse amplitude. The underlying assumption was that individuals with elevated hemoglobin levels would exhibit differences in their average pulse amplitudes compared to normal conditions. To test this hypothesis, an experimental setup was designed in which the blood of normal subjects was diluted through controlled water intake. The findings revealed that approximately 80% of the participants demonstrated increased pulse amplitude following dilution, thereby supporting the hypothesis that pulse amplitude could serve as an indirect indicator of hemoglobin concentration.

This research work introduces a non-invasive hemoglobin level detector using optical sensing technology to estimate hemoglobin without blood samples. The integration of IoT and wearable technology also supports telemedicine and continuous health tracking. This affordable, user-friendly solution enhances proactive care and early anemia detection.

Methodology

This paper proposes a non-invasive hemoglobin detector by passing red and infrared light through a body part (e.g., fingertip) and analyzing light absorption via photoplethysmography (PPG) and spectrophotometry, the system estimates hemoglobin levels painlessly and accurately. The device uses red (660 nm) and infrared (940 nm) LEDs along with a photodiode to measure light absorption through a fingertip or earlobe. A microcontroller processes the optical signals and displays real-time hemoglobin level on an LCD screen and transmits them wirelessly to mobile devices. Designed to be portable, battery-powered, and cost-effective, the device is suitable for clinical and home use. IoT integration enables remote monitoring via ThingSpeak, and future improvements may include machine learning for enhanced accuracy across diverse users. Figure 1 shows the block diagram of non-invasive hemoglobin detector.

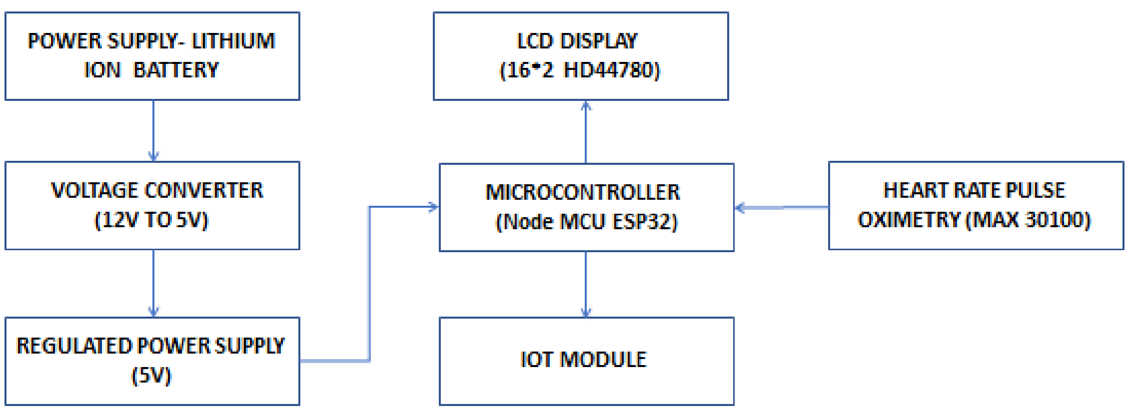

Figure 1. Block diagram of non-invasive hemoglobin detector

A lithium-ion battery is used as the primary power source, offering high energy density and portability, making the device suitable for wearable or point-of-care use. The 12V output from the battery is stepped down to 5V using a voltage converter to ensure compatibility with the operating voltage of electronic components like the micro-controller and sensors. A regulated 5V supply ensures stable and consistent voltage to the micro-controller and sensor modules. The NodeMCU or ESP32 micro-controller acts as the brain of the system. It receives raw data from the hemoglobin sensor, processes it using appropriate algorithms, and outputs the Hb level in real-time. It also handles communication with the display and optional IoT functions. The MAX30100, although primarily a pulse oximeter, is used in this system to estimate hemoglobin levels based on light absorption at different wavelengths. The sensor uses red and infrared LED's and a photodetector to capture reflected light from blood capillaries non-invasively. The LCD module is used to show the calculated hemoglobin level and its health status such as low, normal, or high. The 16×2 display is simple, cost-effective, and user-friendly for real-time feedback. Integrated with the ESP32, the IoT module allows remote transmission of Hb data to a cloud platform or smartphone application for continuous monitoring and data analysis.

The system consists of a SpO_2 and heart rate sensor. This sensor non- invasively measures blood oxygen saturation (SpO_2) and heart rate by analyzing the light absorption characteristics of blood. These readings are crucial indicators of cardiovascular and respiratory health, especially in patients with chronic conditions. The microcontroller- ESP32, serves as the control hub of the device and receives signals from the sensor. Specialized filters integrated into the circuit help stabilize the sensor outputs, ensuring accurate and reliable readings. The processed data is then displayed on a 16x2 LCD screen, providing real-time feedback to users with clear, easy-to-read outputs such as heart rate in beats per minute and SpO_2 percentage. An IoT module connected to the ESP32 enables wireless transmission of real-time health data to a cloud server or mobile application, supporting remote monitoring by healthcare professionals or caregivers. This functionality is particularly beneficial for continuous health tracking outside of hospital settings, promoting early detection of anomalies. A Battery Management System (BMS) safeguards the lithium-ion battery during operation, protecting against overcharging and short circuits, thereby enhancing the safety and durability of the device. A manual power ON/OFF switch is included for user control, allowing convenient activation or deactivation when needed. Figure 2 depicts the schematic diagram of non-invasive hemoglobin detector. The developer designed a flowchart to demonstrate how the proposed system operates on ThingSpeak is an open-source Internet of Things (IoT) platform.

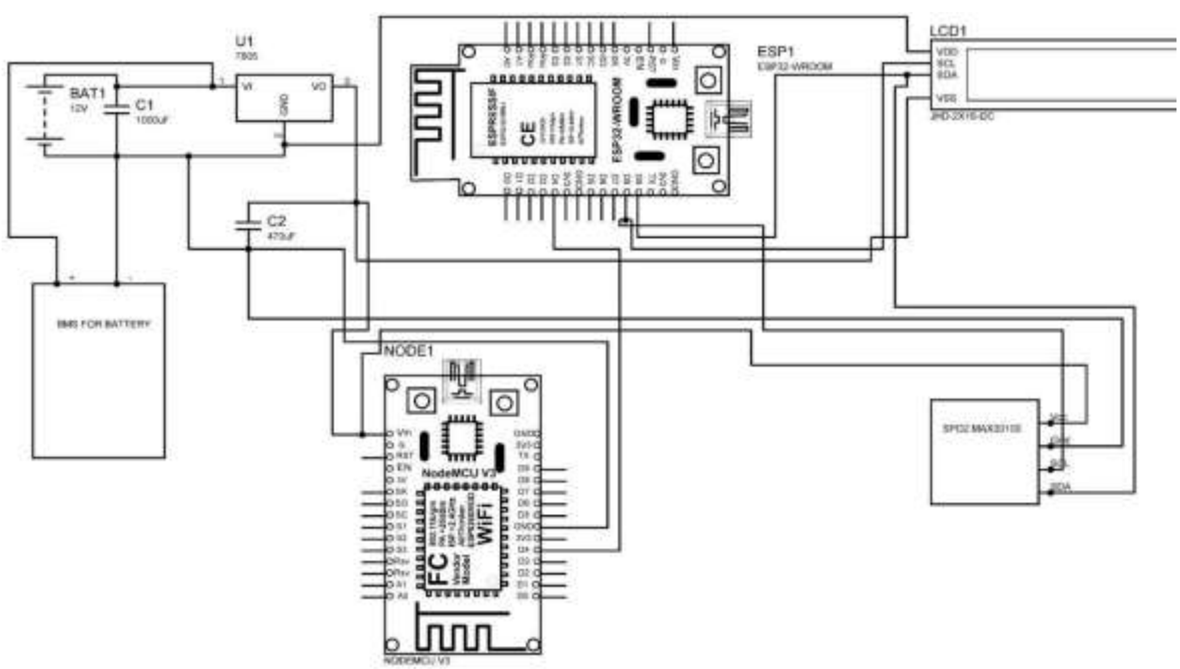

Figure 2. Schematic diagram of non-invasive hemoglobin detector

ThingSpeak is an open-source platform designed to enable users to collect, analyze, and visualize data from connected devices and sensors. Data can be sent to ThingSpeak using its API, where it is stored in channels. Additionally, based on specific data conditions ThingSpeak allows users to send notifications to doctors or caretakers.

The system consists of ESP32, heart rate pulse oximetry (MAX30100) sensor and LCD display. A heart rate pulse oximeter sensor is a non-invasive electronic device used to measure two vital physiological parameters: heart rate (measured in beats per minute) and blood oxygen saturation level (SpO_2, expressed as a percentage). These two indicators are essential for assessing a person's respiratory and cardiovascular health. One of the most commonly used sensors for this purpose is the MAX30100, a compact and efficient module that combines pulse oximetry and heart rate monitoring into a single unit. The sensor operates based on the principles of photoplethysmography (PPG) and the varying light absorption characteristics of oxygenated and deoxygenated blood. The MAX30100 includes two light-emitting diodes (LEDs), one red (approximately 660 nm) and one infrared (approximately 940 nm), which shine light through a part of the body, usually a fingertip or earlobe. A photodetector placed either adjacent to or opposite the LEDs detects the light that passes through or reflected by the tissue and blood vessels. Since oxygenated and deoxygenated hemoglobin absorb red and infrared light differently, the sensor can analyze these differences to calculate the percentage of oxygen in the blood. Simultaneously, the sensor detects the rhythmic pulsing of arterial blood flow, allowing it to calculate the heart rate. Figure 3 shows prototype model of the proposed non-invasive hemoglobin detector.

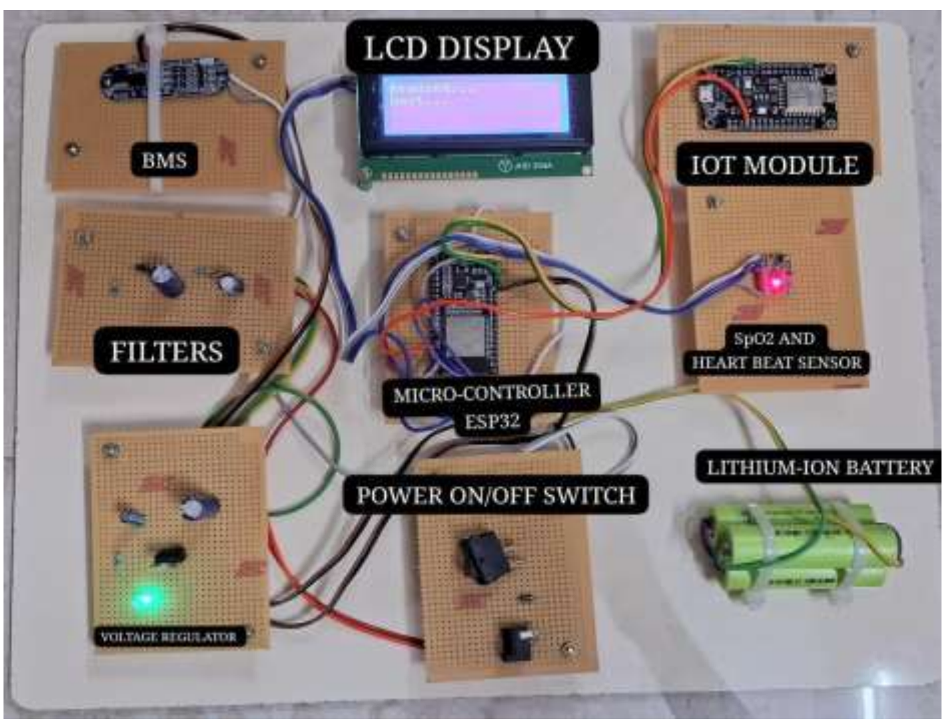

Figure 3. Prototype model of the proposed non-invasive hemoglobin detector.

The collected data are transferred to ThingSpeak through its API, where they are subsequently stored in the appropriate channels. Each channel can hold multiple fields of data, allowing users to track different measurements, such as temperature, humidity, and pressure, simultaneously. Once the data is collected, ThingSpeak offers robust visualization tools, including line charts, bar graphs, and maps, which help users to analyze trends and patterns in real time. Furthermore, ThingSpeak provides the capability to send alerts to clinical personnel or caregivers whenever haemoglobin levels surpass a predetermined threshold.

Results and Discussion

The non-invasive hemoglobin measurement system developed uses photoplethysmography (PPG) and the Beer-Lambert Law to estimate hemoglobin concentration in real time. The system utilizes red (660 nm) and infrared (940 nm) light sources to obtain PPG signals from the fingertip, which are processed to extract AC and DC components corresponding to pulsatile arterial blood and background tissue, respectively.

To estimate hemoglobin (Hb) concentration, the following steps and formulae were applied: the optical sensor setup includes a red LED (660 nm), an infrared LED (940 nm), and a photodiode to detect transmitted light through the fingertip. The microcontroller (Arduino) samples both AC (pulsatile) and DC (non-pulsatile) components of the PPG signal for each wavelength. The measured values are given in Table1.

Table1: The measured values of the signals

Component	**Value**
AC_{RED}	1986
DC_{RED}	50000
AC_{IR}	1200
DC_{IR}	80000

The ratio **R** is calculated using the normalized AC/DC components of red and infrared wavelengths using Equation 1.

$R = (AC_{RED}/DC_{RED}) \div (AC_{IR}/DC_{IR})$ – (Eq.1)

Substituting the values:

$$R = (1986/50000) \div (1200/80000)$$
$$R = 2.648$$

To estimate Hb, a calibration Equation 2 was derived from prior clinical calibration against standard hemoglobin values. The constants used are $a = 3.32$ (slope), $b = 5.3$ (intercept).

$H_b = (a \times R) + b$ – (Eq. 2)

$H_b = (3.32 \times 2.648) + 5.3$
$H_b = 14.09\text{g/dL}$

The final values displayed on the LCD are:
HR (Heart Rate): 148 bpm
SpO_2 (Oxygen Saturation): 95%
Hb (Hemoglobin Level): 14.09 g/dL

These values were read in real-time and updated on the display after computation.

To determine the relationship between the PPG-derived R ratio and actual hemoglobin levels (Hb), sample data was collected from multiple subjects. For each subject the R value was calculated from AC/DC components of RED and IR signals. Linear regression was used to derive calibration constants a (slope) and b (intercept) (Table 2).

Table 2. Sample calibration data

Subject	**AC_{RED}**	**DC_{RED}**	**AC_{IR}**	**DC_{IR}**	**R value**	**Lab Hb (g/dL)**
1	1200	50000	1000	80000	1.92	11.7
2	1500	50000	1000	80000	2.4	13.2
3	1986	50000	1200	80000	2.65	14.09
4	2200	50000	1400	80000	2.51	13.65
5	1700	50000	1300	80000	2.09	12.2
6	2400	50000	1400	80000	2.74	14.4
7	1000	50000	900	80000	1.78	11.1

Using the above data, the following linear regression was performed to calibrate the curve for Hb vs. R. The best fit Equation found is shown as Equation 3. This equation was derived by plotting R values (X-axis) vs. Lab-measured Hb values (Y-axis) and applying linear regression using software Python (NumPy/Matplotlib) and is shown in Figure 4. The calibration plot shows a linear relationship between the R value (ratio of normalized AC/DC from IR and Red PPG signals) and hemoglobin levels measured from a clinical lab.

$H_b = (3.32 \times R) + 5.3$ – (Eq. 3)

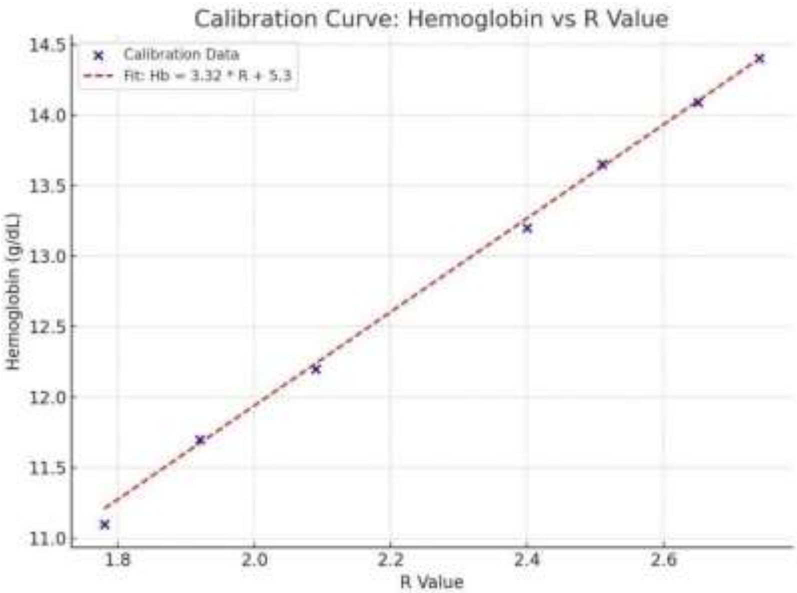

Figure 4. Calibration for the curve

The red dashed line signifies the regression line created on the equation, as shown in Equation 4. This equation was derived from the least squares fit of the above data points and is used in the project for real-time hemoglobin estimation.

$H_b = (3.32 \times R) + 5.3$ – (Eq. 4)

The regression constants a and b were derived through calibration by comparing measured PPG ratios with known hemoglobin levels obtained from laboratory analysis. This calibration ensures the system's reliability for practical use. The accurate estimation confirms that the device can serve as a cost-effective, non-invasive screening tool for hemoglobin monitoring, particularly beneficial in rural or resource-limited settings. The modular design ensures it can be easily integrated into larger diagnostic platforms.

Conclusion

The development of the Non-Invasive Hemoglobin Level Detector successfully demonstrates that accurate, fast, and user-friendly hemoglobin monitoring is achievable without the need for painful blood draws. With an accuracy of approximately 85–90% compared to standard lab results, and a simple, portable, and cost-effective design, the device meets the essential criteria for real-world healthcare applications, especially in remote and rural areas. Its complete non-invasiveness, suitability across all age groups, and optional IoT connectivity make it an excellent tool for both personal and clinical use. Furthermore, the system's high scalability potential opens the door for future advancements through AI and wearable technology integration. This research highlights a significant step toward making advanced healthcare more accessible, affordable, and patient-friendly, particularly benefiting under-served populations worldwide.

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