Innovative Approaches for Non- Intrusive Hemoglobin Detection: A Comparative Analysis

Megha Chakole
Department of Electronics & Telecommunication Engineering
Yeshwantrao Chavan College of Engineering
Nagpur, India
mdorle@gmail.com

Shrutika Janbandhu
Department of Electronics & Telecommunication Engineering
Yeshwantrao Chavan College of Engineering
Nagpur, India
shrutijan358@gmail.com

Rutuja Saharkar
Department of Electronics & Telecommunication Engineering
Yeshwantrao Chavan College of Engineering Nagpur, India
rutujasaharkar21@gmail.com

Tejasvini Lichade
Department of Electronics & Telecommunication Engineering
Yeshwantrao Chavan College of Engineering
Nagpur, India
ranilichade904@gmail.com

Sanjay Dorle
Department of Electronics Engineering
G H Raisoni College of Engineering
Nagpur, India
sanjay.dorle@raisoni.net

Roshan Umate
Department of Research and Development Datta Meghe Institute of Higher Education and research
Wardha, India
roshanumate111@gmail.com

Abstract- **In order to diagnose, assess, and treat a wide range of disorders, blood Hemoglobin level (Hgb) monitoring is essential. There is a global urge for an economical hemoglobin measuring solution, which is especially important in underdeveloped nations. This research paper refers to describe concise and organized information about different techniques of non-intrusive continuous hemoglobin monitoring (such as Image analysis using CNN (Convolutional Neural Network), Cyanmethemoglobin Method, PPG Theory, Embedded Platforms, Smartphone Method) and also a most effective technique which can be preferred all over. There are currently less commercially viable non-intrusive hemoglobin monitors on the market, despite the efforts of several research organizations to create wearable sensors for continuous Hemoglobin monitoring. Non-intrusive methods of hemoglobin monitoring are easy, effective with 90.9% of accuracy with no infection chances as in invasive (intrusive) method of monitoring because non-invasive method uses finger probe or other sensing element which can be attached to our skin and hence concentration level can be measured irrespective of having fair chances of using infectious needles in case of invasive method. Finger Probe can bring into an operation with the help of hardware system, made with a use of an electronic components such as Arduino Uno (with inbuilt Embedded System), OPT101 (Light Sensing Diode-Photodiode), Multi-Emitter Chip, Liquid Crystal Display (LCD). In future for any disorder diagnosis or treatment which requires time to get a report of our blood test in order to identify hemoglobin concetration level in the body, this device will greatly help so that doctors can treat patient fast in order to avoid any discrepancies with a patient's health and hence treatment will be started sooner.**

Keywords- ***Non-Intrusive, Hemoglobin, CNN (Convolutional Neural Network), Cyanmethemoglobin, PPG (Photoplethysmography Signal), Embedded Platform, Finger Probe, Arduino Uno, OPT101, Multi-Emitter Chip, Liquid Crystal Display, Smartphone Method***

I. INTRODUCTION

A human's body comprises of blood which strews over the whole body. Blood is a component of human body that is distributed throughout the body to help sustain life.
It is responsible for supplying nutrients, hormones while maintaining body heat and transporting certain signals all over the body. Either directly or indirectly, blood is necessary for everything in the life cycle.
With blood comes another essential component i.e., Hemoglobin. Hemoglobin is responsible for carrying the fundamental need of the body Oxygen to various parts of the body. Naturally, the deficiency of such crucial element in our body can leave one anaemic. Anaemia is a real challenge to humankind. Every age group, from young children to teenagers, is affected by Anaemia, regardless of whether they live in developed or poor nations. World Health Organization (WHO) has concluded that an estimated 1.6 billion people are anaemic. This collectively counts to approximately 30% of the total population of the world. Surveying the population and measuring the Hemoglobin level in each individual's blood is one of the essential steps in figuring out the prevalence of Anaemia. Over the years, there has been a significant change in the estimation of Hb. Hemoglobin concentration tests now available are mostly invasive or less invasive procedures that need drawing blood from the patient, which might be uncomfortable for the patient. Naturally, there's a risk of cross-infection, a delay in real time detection and a requirement for professionals to work. Repeated blood testing may also result in low compliance. Various techniques for the estimation of Hb have been evolved over the decades of constant research and innovations in distinct parts of the world. The document provides an overview of the different methods and instruments that have been developed and are currently being developed for the measurement of Hemoglobin levels.

II. CLASSIFICATION / SUB-FINDINGS

1. Prevailing Hb estimation Method: Cyanmethemoglobin method

Principle: Potassium cyanide (KCN) and potassium ferricyanide (C6N6FeK3) are combined in a solution to dilute blood 1:201. Hemoglobin in the sample is oxidized to methemoglobin by potassium ferricyanide. A stable-colored cyanmethemoglobin (hemiglobincyanide, or HiCN) complex is created when methemoglobin and potassium cyanide react further. The amount of hemoglobin contained in the material is exactly proportional to the intensity of the colored complex, which is assessed at 540 nm. The Beer–

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Lambert law has been in use for determining the Hb levels. However, in 2014, Modified Beer-Lambert Law has been proposed by National Library of Medicine which is now a vital law to estimate Hb levels.
The most tested method for measuring hemoglobin is the cyanmethemoglobin method also known as the hemiglobincyanide method. Stadie first suggested the cyanmethemoglobin method in 1920. This particular colorimetric/ spectrophotometric method provides following three main benefits against substitute techniques: measures every kind of hemoglobin, with the exception of sulfhemoglobin, which is often absent from blood. Cyanmethemoglobin reagent is highly stable and readily standardizable.

2. Non-Invasive Methods

2.1. PPG Theory
The method involves altering the arterial blood's ability to absorb light during pulsatile flow through tissue, which appears to be a moving process. The amount of light that reaches tissues The fixed part of the pulse wave is made up of things like fat, muscle, bone, and venous blood. The primary wave and sub-wave are distinctive characteristics of the dynamic part.
Differential absorption of infrared and noninfrared radiations is the foundation upon which photoplethysmography's principle of blood parameters detection rests. the capacity of a specific blood component to absorb Beer-Lambert Law is used to obtain a specific wavelength. A solution's concentration and absorbance, optical coefficient, and molar absorption coefficient are all linearly related by the Beer Lambert law. In addition, the Beer Lambert law states that the absorbance and solution concentration have a linear relationship. In addition, measuring a solution's absorbance allows for the calculation of its concentration thanks to this relationship.

2.2. Smartphone Method
This method makes use of smartphone camera sensors to capture images and videos for the applications like SmartHeLP, HemaApp, Masimo Pronto and Hb Meter determinations. Each video frame was analyzed pixel-by-pixel by separating the red, green, and blue (RGB) pixel intensities in these studies, which involved recording fingertip videos of varying lengths with various smartphones. Each frame was divided into 10x10 blocks of similar size which separated the RGB pixel intensities and generated time-series information for each block across all frames. The major point of attention was found to be close to the smartphone's flashlight, as determined by the pixel data from the group of blocks. Even though this study looked into RGB pixels, only the information about red pixels was used to make the prediction model.

2.3. Image analysis using Convolutional Neural Network (CNN)
The Convolutional Neural Network (CNN) functions by appropriating an image in some estimated weights for the various components of the image, in addition to separating them from one another. One of CNN's primary capabilities is its use of primitive styles. For training its classifiers, making it capable of learn about the object's characteristics. CNN is predicted based on a similar armature, as established in the neurons that make up the human brain, particularly the Visual Cortex.

2.4. Embedded Platforms
Caje Pinto et al. [4] has made use of Arduino based embedded system for carrying out signal processing and A to D conversion of PPG signals. Since Arduino Uno is used as an embedded platform, this method of estimating total hemoglobin has the advantages of being non-intrusive, real-time, and cost-effective. It also provides good accuracy, with a mean absolute error of 0.3499 g/dL.
Jianming Zhu et al. [2] used Xilinx ZYNQ7020 as the core for control. The schematic diagram below shows the working of this system.

III. RELATED WORK

This section highlights the relevant ways of estimating the Hemoglobin levels. The preceding section discussed some of the most widely used models for obtaining Hb, while this section provides an analysis of these various methods. Caje Pinto et al. [8] suggested the design and development of an in-house algorithm system to estimate total Hb levels using the Arduino based Embedded system. A finger probe with five LEDs on a multi-chip with wavelengths of 670 nm, 770 nm, 810 nm, 850 nm, and 950 nm,[4,8] a single silicon photo detector with an integrated trans-impedance amplifier, and the Photoplethysmography (PPG) principle have been developed. All of the sources are contained in a small, densely packed area of the Multi-chip Emitter. Additionally, when the forward current is 20 mAmpere, all of the LEDs produce approximately 5 mW. When the finger is inserted into the finger probe, there is certain current across the OPT101 due to its smaller size, reduced space, and its prime use. The multi-chip LEDs are placed on the top side of the finger test and OPT101 is assembled on the counter side of the finger test. With Arduino Uno, the finger probe was connected to the Band Pass Filter. A 10-bit analog to digital converter was used to get the PPG signal for each wavelength There was a detail examination of two-component mixture (Oxy-hemoglobin and Deoxy hemoglobin) by taking into consideration of The Modified Beer Lambert Law[8].

Suresh Mestry et al. [3] makes use of specific PPG data features and multiple machine ways to develop a non-invasive strategy for literacy predicting hemoglobin levels. The instrument known as "Hemocue Hb201TM" was used to check both the hemoglobin position and the blood count simultaneously. Module testing and training (with DCNN) classification is a crucial part of systems for determining hemoglobin levels. Due to the use of an image to measure hemoglobin levels, finger classification is the process to be considered first most. Image information based on levels can be recognized. The photos from training set are used to train the classifier. An image with high as well as low levels of Hb was characterized by the classifier.
Taking into account the use of regression, Zhencheng Chen et al. [5] discuss three regression principles, eXtreme Gradient Boosting (XGBoost), logistic regression (LR), and support vector regression (SVR). He proposes that logistic models have been in use to regulate confusion, strengthen explanatory domain and to assess the predictors. Support

Vector Regression (SVR) is a machine learning method which is prompt in solving practical problems and carefully minimizing the actual errors. Finally, the algorithm of XGBoost has helped expanding the speed and precision of the device. Furthermore, XGBoost is the foundation to specialized medical database for the device

A smart-phone camera-based, non-invasive anemia detection system was presented by Anggraeni et al.[11], based on palpebral colour observation. Their system used an Asus Zenphone 2 Laser smartphone to take digital images of the palpebral conjunctiva in natural light without a flash. The images were then colour-corrected using white paper. The captured data were used to extract red, green, and blue (RGB) pixel values, which were then analysed using regression. The red colour intensity had the strongest relationship among the three intensities, with a correlation coefficient of 0.92 and a R2 of 0.8139.

Masimo Pronto [7] is a Pronto Pulse Co-Oximeter. In general, this application for smartphones made use of the fingernail beds (usually lacking pigment) are used to measure Hgb by comparing the colour of the nails.

Md Kamrul Hasan et al. [10] with all the respective creditors has created a smartphone application named as SmartHeLP. This application uses ANN (Artificial Neural Network) to predict the Hb levels by extracting 10 second fingertip videos using a smartphone. In contrast to other machine learning algorithms like the decision tree, ANN can learn from continuous data and update the model. Using the

MATLAB net function, the Hb levels of the testing sets were determined.

IV. PROPOSED SYSTEM DESCRIPTION

This section outlines proposed system for Non-Intrusive Hemoglobin Detector shown in figure 1. The proposed system sure to include several components in architecture that would be beneficial for a broad range of applications. Arduino Uno, Multi-Chip LED Finger Probe, Optical Sensor OPT101, Band Pass Filter and LCD display (ILI9341), LED's. To upload programs and interact with the Arduino boards, an Arduino Software connection is made.

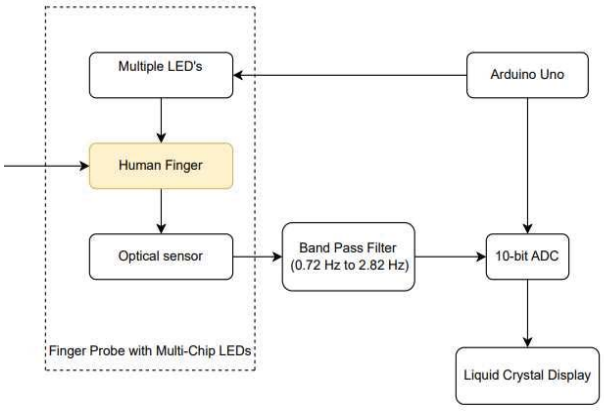

Fig .1. Block diagram Non-Intrusive Hemoglobin Detector

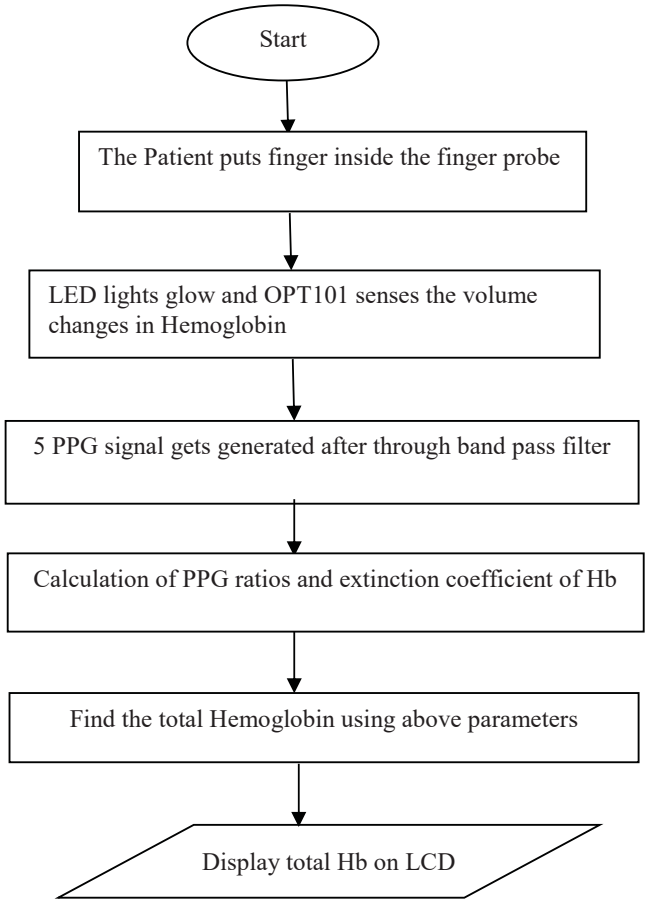

Fig 2. Methodology to Operate a Hardware System

Methodology to operate hardware system is illustrated in figure 2.

A. Multi-Chip LED Finger Probe

This component is made up of five LEDs, each of which emits light at a distinct wavelength: 770, 850, 950, 810, and 670 nm. The LEDs' purpose is to illuminate the finger. Various wavelengths aid in estimating blood qualities such as hemoglobin levels by measuring the amount of light absorbed by the blood at different depths.

B. Optical Sensor OPT101

A photodetector with an inbuilt trans-impedance amplifier is called the OPT101. Its function is to measure the quantity of light passing through the finger and translate it into a voltage signal called a photo-plethysmography (PPG) signal. Weak signals are assisted in becoming a voltage level that can be used by the integrated amplifier.

C. Band Pass Filter (Signal Conditioner)

A bandpass filter is a device that lets frequencies inside a specific range pass through while blocking frequencies outside of that range. Its goal is to remove noise from the PPG data by concentrating on the heart rate's frequency band (0.72 Hz to 2.82 Hz). This facilitates the meaningful extraction of heart rate data from the signal.

D. LCD: Liquid Crystal Display

An LCD is a type of flat-panel display that generates visual images using liquid crystals. It shows the user the processed data, heart rate and projected hemoglobin levels. It offers a graphical user interface for feedback.

E. Embedded System (Arduino Uno)

An integrated development environment for programming is included with the Arduino Uno microcontroller board.

Its functions include operating the LEDs, obtaining data from obtaining data from the OPT101 through its analog-to-digital converter ADC), processing the data with an algorithm, and computing hemoglobin levels. In order to present results, it also controls the LCD's interactivity. An operational amplifier circuit that transforms current into voltage is known as a trans-impedance amplifier. The proposed hardware of system is showed in figure 3.

Fig 3. System Hardware

The OPT101's function is to increase the photodetector's tiny current output into a bigger, easier-to-measure voltage signal. The 10-bit Analog-to-Digital Converter (ADC) is a device that transforms analog signals into digital representations

V. DISCUSSION

Table I Comparative analysis of research for Hb estimation

Research Paper	Methodology	Wavelength Used	Algorithm	No. of. Patients Examined	Regression Coefficients	Root Mean Square Error(g/dL)
Caje Pinto et al.[8,4]	PPG	670nm,770nm, 810nm,850nm ,950nm	Linear Regression	8	0.964	0.3499
K.Okazaki et al.[12]	NIRS	660nm	SPSS	120	_	0.34
Zhencheng Chen et al.[5]	PPG	660nm,730nm, 850nm,940nm	XGBoost	58	0.99	0.762
Jianming Zhu et al.[2]	PPG	660nm,700nm, 730nm,800nm, 850nm,880nm, 940nm,960nm	AdaBoost BPNN Regression Models	56	0.91	0.1676
M D Anggraeni et al.[11]	RGB Spectrum	–	Linear Regression	20	0.568	–

Table I shows showcases the efforts of multiple scholars (researchers) in diverse areas of developing technology. The comparative analysis of these studies and their methodologies along with different wavelengths used to analyze Hb concentration using LEDs having different wavelengths associated, their algorithm, number of patients examined by that respective method, its regression coefficients and root mean square error which shows that every field is yet to be discovered fully. As we go on exploring a particular field, we gain higher accuracies.

In the realm of non-invasive hemoglobin estimation, embedded systems, such as those based on Arduino and Xilinx ZYNQ7020, have emerged as highly effective solutions. They combine real-time processing capabilities with cost-effectiveness and ease of use, offering a significant advantage over traditional methods. By leveraging techniques like photoplethysmography (PPG) and advanced signal processing, these systems achieve accurate measurements, evidenced by a mean absolute error of only 0.3499 g/dL.

The integration of embedded platforms facilitates seamless, non-intrusive monitoring, making them ideal for continuous health assessments in various settings. As technology advances, embedded systems are poised to become the preferred choice for non-invasive hemoglobin estimation, enhancing accessibility and patient comfort.

VI. CONCLUSION

For the purpose of estimating Hb levels, each method described in this paper is extremely useful. Using methodology based on several approaches, this paper offers a brief overview of a range of invasive, non-invasive, and pathological laboratory procedures used to quantify the amount of hemoglobin in the blood. A test's utility as a diagnostic tool is greatly influenced by its accuracy and dependability. Accuracy can be ascertained by contrasting the procedure's results with those of a traditional approach.

For non-invasive techniques, more accurate mathematical calibration is required to prevent inaccurate readings from the sensor data. However, given the demand at the moment, a non-invasive monitoring system is required so that patient's readings may be continuously examined, improving therapy. While the accuracy of traditional Invasive method reaching upto 94.5%, some of the non-invasive methods also reaches upto 91%. Non-invasive techniques appear to be less expensive, require no ongoing maintenance or controls, and can be performed by inexperienced personnel.

VII. FUTURE SCOPE

The potential applications of embedded systems in non-invasive monitoring devices for the early diagnosis and treatment of anemia appear very promising. Embedded systems will make it possible to continuously and more precisely monitor hemoglobin levels and other blood parameters non-invasively thanks to developments in sensor technology. The need for intrusive blood testing will decrease as a result of this real-time data collecting, which will enable early anemia diagnosis and prompt treatment.

Additionally, the development of wearable and portable devices will result from the shrinking of embedded systems, which will make it simpler for patients to routinely monitor their condition even in situations with limited resources or distance. These gadgets might be made to notify medical professionals and patients of noteworthy variations in blood parameters, enabling prompt modifications to treatment regimens.

Moreover, iron levels and other relevant indicators linked to anemia will be monitored by embedded devices, offering a more complete picture of the patient's state. This may result in more personalized plans, which would benefit patients' results. With the development of these technologies, regular healthcare procedures will incorporate them more and more, providing a non-invasive, practical, and effective means of managing anemia. Better prevention, monitoring, and treatment options will be made possible by the continued development of these systems, which will ultimately help to lower the worldwide burden of anemia.

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