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Non-Invasive Bilirubin Detector With Phototherapy For Neonatal Jaundice

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ABSTRACT

Neonatal jaundice is one of the most common conditions affecting newborns worldwide. It results from elevated levels of bilirubin in the blood, often leading to visible yellowing of the skin and eyes. Early identification is crucial to avoid complications such as kernicterus or neurological damage. In this study, we propose a simple and cost-effective method for detecting signs of jaundice using a combination of camera-based imaging and basic color analysis. By capturing live skin images and analyzing them in color spaces such as YCbCr, RGB, and HSV, the system can differentiate between normal and jaundiced skin tones without invasive testing. When jaundice is detected, a signal is sent to an Arduino controller to activate an LED indicator, simulating the initiation of phototherapy treatment. The approach aims to offer a non-invasive, real-time screening tool, particularly useful in resource-limited settings where access to laboratory testing is delayed or unavailable. Our system is designed to assist healthcare workers and parents by providing an early warning, ensuring timely medical attention. Through careful calibration and analysis, this method demonstrates potential for improving neonatal care by making jaundice detection more accessible, affordable, and rapid.

KEYWORDS: Neonatal, Bilirubin, Phototherapy, Jaundice, Kernicterus

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INTRODUCTION

Neonatal jaundice represents one of the most common clinical phenomena observed in newborns during the early postnatal period. It results from the physiological accumulation of bilirubin, a degradation product, leading to a characteristic yellow discoloration of the skin and sclerae. While transient jaundice is considered a benign, self-limiting process in the majority of cases, elevated or rapidly rising bilirubin levels may progress to severe hyperbilirubinemia, posing a risk for kernicterus and long-term neurological sequelae. Thus, early detection and continuous monitoring of bilirubin levels are critical to ensure timely intervention and prevent complications.

Traditional diagnostic approaches rely heavily on visual examination and laboratory-based serum bilirubin measurements, both of which have limitations in accessibility, subjectivity, and cost, particularly in resource-constrained settings. In response to these challenges, recent research has increasingly explored non-invasive, technology-driven methods for jaundice screening. Skin color analysis through digital imaging has emerged as a promising avenue, leveraging color space transformations to detect subtle changes associated with bilirubin deposition. Parameters such as hue, saturation, and brightness offer quantitative indicators that correlate with bilirubin level. This study aims to develop and validate a camera-assisted neonatal jaundice detection system, integrating image processing techniques with microcontroller-based hardware to support early identification efforts. The proposed approach seeks to enhance neonatal care by providing an accessible, cost-effective, and reliable screening alternative.

LITERATURE REVIEW

The detection and monitoring of neonatal jaundice have witnessed significant advancements in recent years, with various studies proposing non-invasive and accessible methodologies. Bakari et al. [1] validated the Bili-Ruler™, a hand-held icterometer, demonstrating its feasibility and acceptability in low-resource settings. Similarly, the incorporation of IoT technologies in healthcare has been explored by Malathi et al. [2], highlighting the potential for remote patient monitoring, which can be adapted for neonatal care.

Machine learning approaches have also been extensively studied. Abdulrazzak et al. [3] implemented real-time jaundice detection systems based on predictive models, offering promising results in clinical environments. Complementing this, Karim et al. [4] provided a comprehensive review of non-invasive methods for bilirubin assessment, emphasizing the need for accuracy and affordability.

Calibration improvements for bilirubinometers have been proposed by Faramawy [5], while research on non-invasive cardiac output monitoring in neonates by Li and Dong [6] reinforces the broader trend toward minimizing invasive procedures.

Smartphone-assisted technologies have gained prominence as well, with Aune et al. [7] and Prajapati et al. [8] developing user-friendly applications for jaundice detection using mobile imaging techniques. Anggraeni et al. [9] further supported this trend by demonstrating the potential of smartphone cameras in early screening.

Innovations in wearable biosensors, as shown by Ning et al. [10], explored diaper-based bilirubin monitoring, presenting an integrated biosensing solution. Wearable phototherapeutic devices using OLEDs were also proposed by Choi et al. [11] as a treatment alternative. Harrison-Smith [12] provided an in-depth exploration of novel optical diagnostic tools, underscoring the significance of real-time non-invasive technologies.

Visual assessment reliability among different populations was critically assessed by Dionis et al. [13], who found notable variations based on skin tone. Okwundu and Saini [14] reviewed a variety of non-invasive bilirubin measurement techniques, reinforcing the need for standardized evaluation frameworks. Transfer learning models for smartphone-based jaundice detection were explored by Althnian et al. [15], while GUI-based computer vision systems were investigated by Hashim et al. [16,17], demonstrating advancements in user interfaces for clinical application.

Wearable devices capable of real-time colorimetric monitoring of jaundice were innovatively designed by Inamori et al. [18], combining vitals monitoring and bilirubin assessment. Shaw and Devgan [19] highlighted the effectiveness of smartphone imaging for skin-based bilirubin estimation, complementing earlier work on how skin anatomy influences transcutaneous bilirubin measurements, as detailed by Erk et al. [20].

Mohniya et al. [21] evaluated the clinical effectiveness of transcutaneous bilirubinometers, promoting their use in neonatal care. On a broader scale, Olusanya et al. [22] emphasized the global health burden associated with neonatal jaundice, advocating for improved diagnostic strategies.

Earlier technological developments included Aydın et al. [23], who proposed a structured jaundice detection system, and Ramy et al. [24], who studied the potential DNA damage from phototherapy, raising concerns about treatment modalities. Leung et al. [25] introduced scleral color analysis through digital photography, highlighting the possibility of objective visual diagnostics.
Collectively, these studies illustrate a significant shift toward non-invasive, accessible, and technology-integrated solutions for neonatal jaundice detection, with an overarching focus on affordability, reliability, and ease of deployment in diverse healthcare settings.

METHODOLOGY

The neonatal jaundice detection system developed in this study integrates webcam-based skin tone detection with a color sensor TCS34725 to estimate bilirubin levels non-invasively. The system begins by capturing an image of the neonate's skin using a standard webcam. The forehead or chest of the neonate is selected as the region of interest, as it provides a consistent area for detecting jaundice symptoms. To ensure accurate skin tone detection, the captured image undergoes pre-processing steps, including resizing to a standard resolution, noise reduction through Gaussian filtering, and conversion to color spaces such as YCbCr and HSV, which are sensitive to skin hues, particularly the yellowish tint associated with elevated bilirubin. Threshold values are applied to the chrominance components of these color spaces to isolate skin regions from the rest of the image, facilitating the detection of potential jaundice symptoms.

Once skin detection is achieved, the system triggers an Arduino-based circuit equipped with a TCS34725 color sensor to estimate bilirubin levels. The sensor is positioned near the neonate's skin and captures the red, green, and blue (RGB) light intensities, which are indicative of the yellowish tint in the skin. These RGB values are then processed to correlate the intensity of the yellow hue with bilirubin concentration and its severity represented in table 1. The system uses an algorithm that links the sensor's RGB readings with empirical bilirubin levels, adjusting for ambient lighting conditions and the neonate's skin pigmentation to improve the accuracy of the bilirubin estimation.

Table 1: Bilirubin Concentration and it's severity

Bilirubin Concentration (mg/dL)	Severity
5	Low Risk
10	Mild Risk
15	
20	High Risk
25	
30	
35	
40	
45	
50	

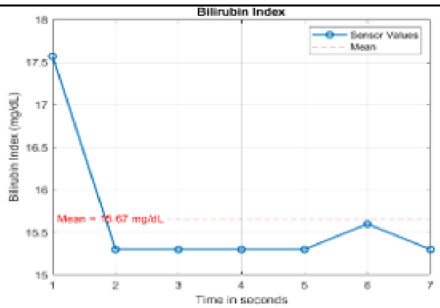
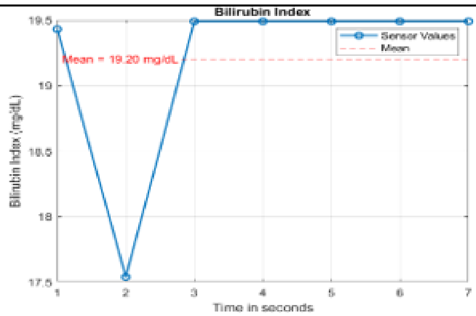
The integration of the webcam and the TCS34725 sensor is controlled by an Arduino microcontroller, which coordinates the system's operations. Upon detecting the skin, the microcontroller activates the sensor to capture RGB data. The Arduino then processes the color readings and applies the bilirubin estimation algorithm to determine the level of jaundice. The results are displayed on an OLED screen or transmitted to a serial monitor for further analysis. Additionally, visual indicators such as an LED light are used to signal the jaundice status (e.g., green for normal bilirubin levels and red for elevated bilirubin levels).

To ensure the system's accuracy, extensive testing and calibration are carried out. The system is tested under controlled lighting conditions using a set of neonatal images with varying jaundice levels. The RGB readings from the TCS34725 sensor are compared against known bilirubin levels to calibrate the algorithm. A calibration curve is developed to establish a reliable relationship between the sensor readings and the corresponding bilirubin concentrations. This ensures that the system provides accurate and consistent results. Furthermore, ethical considerations are taken into account, including ensuring privacy by handling the neonate’s skin images securely and obtaining informed consent from parents or guardians in clinical settings before using the system.

RESULTS AND DISCUSSIONS

The results from the conducted experiments demonstrate the potential of the developed system for non-invasive jaundice detection in neonates. Upon detection of the neonate's skin using a webcam, the system successfully triggered the bilirubin estimation circuit, utilizing the TCS34725 color sensor to obtain real-time data. To visualize and analyze the data, several graphs were plotted, which were instrumental in understanding the relationship between the skin color parameters and bilirubin levels. These graphs, summarized in Table 2, include Estimated Bilirubin Value vs. Time, HSV vs. Time, and RGB vs. Time. Each of these plots reveals distinct trends that underscore the correlation between the changes in skin color, as represented by the RGB and HSV values, and the estimated bilirubin concentration over time.

Table 2: Estimated Bilirubin Level, RGB Values vs Time and HSV Parameters vs Time for Data 1 and Data 2

<table>
<tr><th>Parameters</th><th>Data 1</th><th>Data 2</th></tr>
<tr><td>Estimated Bilirubin Level</td><td>
</td><td>
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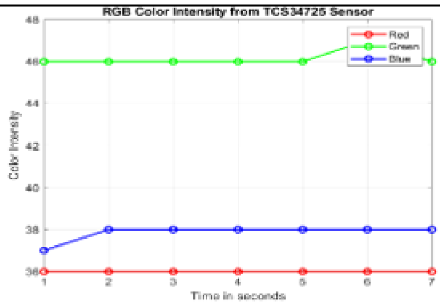
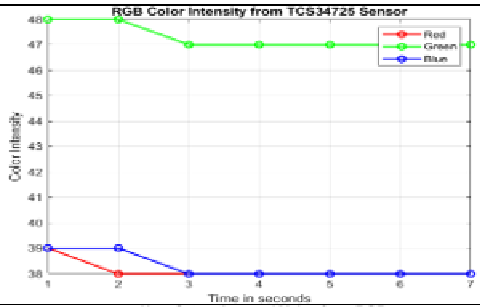
<tr><td>RGB Values vs Time</td><td>
</td><td>
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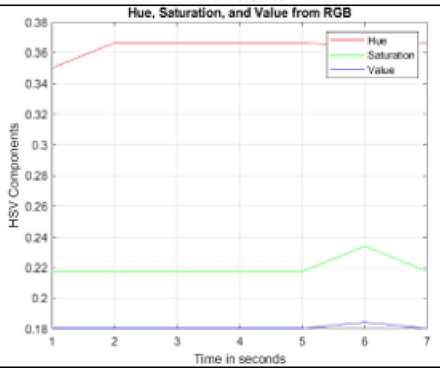
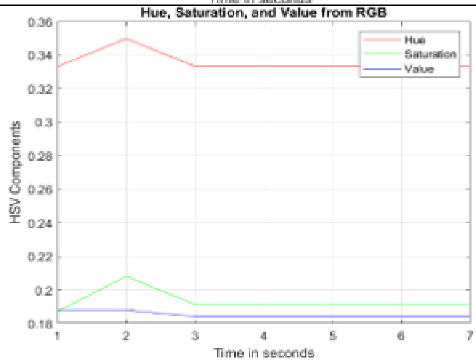
<tr><td>HSV Parameters vs Time</td><td>
</td><td>
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The table 2 is a comprehensive comparison between two datasets (Data 1 and Data 2), evaluating the estimated bilirubin levels, RGB intensity values, and their corresponding HSV (Hue, Saturation, Value) components over a short period. In the first row, the Estimated Bilirubin Level plots illustrate the bilirubin index derived from sensor readings. Data 1 reveals a relatively stable trend with slight variation and a moderate mean value, indicating a lower bilirubin concentration. In contrast, Data 2 begins with a noticeable drop at the second, followed by consistent high readings, resulting in a higher average value. These differences in trends provide insights into fluctuating bilirubin concentrations, potentially reflecting different stages or severity of jaundice.

In the second row, the RGB Values vs Time graphs reflect the light intensity captured by the TCS34725 sensor in the red, green, and blue channels. Across both datasets, green remains the dominant component, aligning with typical reflectance from neonatal skin. For Data 1, RGB readings are relatively stable, suggesting uniform exposure and consistent lighting. In Data 2, a slight drop in red and green intensities is observed initially, followed by stabilization—this could be due to momentary sensor shadowing or skin movement.

The third row illustrates the HSV Parameters vs Time, offering a transformed perspective from RGB to the HSV color model, which is more perceptually relevant for human vision. Data 1 shows steady hue and brightness values with a slight increase in saturation mid-session. On the other hand, Data 2 demonstrates slightly higher hue values, reflecting a different skin tone or lighting condition, while maintaining low saturation and brightness across the timeline. These HSV metrics can be particularly useful in estimating skin pigmentation changes related to bilirubin accumulation.

Collectively, these graphs not only validate sensor responsiveness but also highlight the potential of using colorimetric data for non-invasive bilirubin level estimation. By analyzing the trends and variations in both color space domains (RGB and HSV), a better understanding of skin reflectance properties linked to jaundice diagnosis can be achieved.

Additionally, Table 3 presents the average values of hue, saturation, and brightness (HSB) for the detected skin, providing further insight into the skin's color characteristics associated with bilirubin levels. These average HSB values offer a more granular view of the variations in skin color and can be instrumental in improving the system’s accuracy in detecting jaundice.

Table 3: Average Hue, Saturation and Brightness

Parameter	Data 1	Data 2	Data 3	Data 4	Data 5
Hue	0.364	0.336	0.345	0.372	0.354
Saturation	0.220	0.193	0.206	0.235	0.215
Brightness	0.181	0.185	0.189	0.192	0.183

Data 1 shows a higher average hue 0.364 compared to Data 2, 0.336, indicating a shift toward a more yellowish tone typically associated with jaundiced skin. The saturation in Data 1, 0.220 is also greater than in Data 2 (0.193), suggesting a more intense skin color, likely due to elevated bilirubin levels. Brightness values are fairly consistent between the two sets 0.181 and 0.185, implying that lighting conditions were similar during data collection. Overall, these differences in hue and saturation help differentiate between normal and jaundiced skin tones, supporting the effectiveness of the system in detecting neonatal jaundice. Data 3 shows moderate values for hue 0.345, saturation 0.206, and brightness 0.189, indicating a balanced and neutral color tone with soft vibrancy and lightness. In Data 4, the values are the highest among the three hue at 0.372, saturation at 0.235, and brightness at 0.192 suggesting a vivid and bright appearance, likely representing a more prominent or intense color region. Data 5 has values close to the overall average, with hue at 0.354, saturation at 0.215, and brightness at 0.183, indicating a stable and mildly vibrant tone. Overall, Data 3 appears softer, Data 4 is the most vivid and bright, and Data 5 is well-balanced, making it a reliable mid-point reference in the dataset.

CONCLUSION

Neonatal jaundice, caused by elevated bilirubin levels, is common in newborns and requires timely intervention to prevent complications such as kernicterus. Conventional diagnostic methods—visual inspection and blood sampling—are either subjective or invasive, making them less ideal for continuous or home-based monitoring. This study proposes a non-invasive, integrated solution that combines optical sensing, image analysis, and controlled phototherapy to detect and manage jaundice efficiently.

The system employs a TCS34725 RGB color sensor and a camera module to capture skin chromaticity data, which is analyzed in both RGB and HSV color spaces. By correlating skin tone changes with bilirubin levels, it enables accurate, real-time estimation of jaundice severity. Machine learning algorithms are utilized for image classification, enhancing diagnostic objectivity and minimizing human error across varying skin tones and lighting conditions. A key feature of the system is its closed-loop design. When jaundice is detected, an automated phototherapy unit is activated, emitting blue light in the 460–490 nm range—clinically validated for breaking down bilirubin. This integration of diagnosis and treatment ensures prompt, responsive care without the need for constant medical supervision.

The system also supports real-time monitoring, data logging, and user-friendly interface displays, offering continuous insight into the infant’s condition. This not only improves clinical oversight but also enables remote or home-based care. By eliminating the need for invasive blood draws, the approach enhances patient comfort and accessibility, particularly in low-resource settings.

FUTURE SCOPE

The findings of this research establish a foundation for further exploration into non-invasive neonatal jaundice detection and management systems. Future studies could focus on optimizing the accuracy and sensitivity of bilirubin estimation by integrating advanced optical sensing technologies, such as multispectral or hyperspectral imaging, which may allow for more precise differentiation of skin tones and bilirubin-induced discoloration across ethnically diverse neonatal populations. The incorporation of additional physiological parameters such as pulse oximetry, temperature, and heart rate could facilitate the development of a comprehensive neonatal health assessment framework. Furthermore, implementation of wireless communication modules, including Wi-Fi and Bluetooth, would enable seamless data transfer to centralized hospital information systems or cloud-based platforms, supporting remote diagnostics and telemedicine applications, particularly in rural or resource-constrained environments.

To enhance the predictive performance and adaptability of the system, the underlying machine learning algorithms could be trained on a larger and more heterogeneous dataset encompassing various clinical scenarios. The application of deep learning architectures, such as convolutional neural networks (CNNs), may also be explored to improve feature extraction and classification capabilities for subtle skin tone changes indicative of early-stage jaundice. Moreover, hardware miniaturization and system integration into a wearable or handheld device would support real-time, continuous monitoring with minimal disruption to neonatal comfort. Future iterations may also include closed-loop feedback mechanisms to dynamically regulate the intensity and duration of phototherapy in response to real-time bilirubin estimations, thereby improving therapeutic outcomes while minimizing phototherapy-associated risks. Collectively, these advancements hold promise for translating this system into a clinically viable, cost-effective solution for early jaundice detection and intervention in neonates, ultimately contributing to improved neonatal outcomes and reduced dependency on invasive testing methods.

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