Computer Vision for Jaundice Detection in Neonates Using Graphic User Interface

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Abstract. Physiological jaundice occurs in the first week of life in newborns due to the increase in bilirubin level which in turn leads to yellowish discoloration of skin and sclera. Sever jaundice and toxic level of bilirubin can cause brain damage as bilirubin exists in the central nervous systems. Invasive blood sampling is the optimum method to measure bilirubin level; however, it is painful and stressful for the neonate, and it may cause blood loss and can lead to anaemia, especially when repeated blood tests are required. In addition, blood tests expose the infant to the risk of infections. Moreover, invasive tests are time-consuming as their results are not immediate. Due to all the problems mentioned earlier, this paper proposes a new system for jaundice detection that is based on skin colour analysis. The proposed system uses a digital camera as a colour based screening tool as it is affordable, objective, ubiquitous, and less painful to infants. Based on the analysis obtained from the captured images, jaundice was detected and estimated, opening the door for further case studies in medical applications, especially in diagnosis, monitoring patient’s health, and supplying active treatment.

Keywords— Computer vision, non-contact jaundice detection system; colour image analysis; Graphic User Interface (GUI).

1. Introduction
Jaundice or icterus refers to the yellowish discolouration of the skin or in the whites of the eye. This condition is very common among newborns due to the inefficiency of their immature livers in metabolising bilirubin [1]. Bilirubin results when old red blood cells are broken down. As a matter of fact, the human body continuously produces new red blood cells and breaks down old ones. The red blood cells in an adult last for about 120 days, but in a newborn baby, they last for a much shorter time. Thus, newborns have above normal numbers of red blood cells, which in turn leads to high levels of bilirubin as more red blood cells are being broken down [2]. Normally, the liver metabolises broken blood cells for excretion, which produces bilirubin. Then, bilirubin is excreted in bile and urine [3]. High levels of bilirubin and bile cause the yellowish colour of the skin and may indicate certain diseases such as jaundice. It has been shown by statistics that up to 60% of term infants and 80% of preterm infants were found to develop neonatal jaundice in their first week of life, and 10% of breastfed newborns...
developed jaundice even up to four weeks old [1]. Cumulatively, 24 million newborns get jaundice every year [4]. There are different methods for diagnosing jaundice, but in general, they are categorised as: invasive or non-invasive methods. The optimum method for determining the level of hyperbilirubinemia is Total Serum Bilirubin (TSB) measurement, which is performed by blood sampling [5]. However, the measurement of TSB can be done only by medical caregivers, and it is an invasive and stressful procedure [6]. Also, there are other medical tests for diagnosing jaundice that require the collection of blood samples; but generally speaking, all invasive methods are painful for the newborn, have an increased risk of infections at the site of sampling, and cause anxiety for parents [7]. One example of non-invasive methods is the estimation of serum bilirubin based on appearance. In general, babies whose jaundice is limited to the face and part of the trunk above the umbilicus have a bilirubin level below (205 μmol/L) (less dangerous level). On the other hand, babies with yellowish palms and soles have a bilirubin level over (256.5 μmol/L) (more dangerous level). It has been proved by studies that the assessments of trained clinicians show moderate agreement with TSB [1].

It is known that extremely high level of bilirubin can lead to kernicterus, a rare but serious condition that causes irreversible neurological sequelae characterised by visual abnormalities, athetoid spasticity, and sensorineural hearing loss among its survivors [8]. Hence, treating the increase in bilirubin and severe jaundice is crucial. Luckily, the 20th century witnessed two major advances in the treatment of neonatal jaundice. The use of exchange transfusion was the first, and the discovery of phototherapy was the second. It has been claimed that the essential reason behind the use of phototherapy is to avoid the use of exchange transfusions. However, it can say that the phototherapy is currently the major treatment method as exchange transfusions have become increasingly rare [9]. Contemporary phototherapy was discovered in England when it was noticed that the skin of babies who were exposed to sunlight on a daily basis was less jaundiced than unexposed ones [10]. Ever since, phototherapy has been used extensively in treating jaundice [11].

The aim of therapy is to reduce the concentration of circulating bilirubin or stop it from increasing. This can be accomplished by using the energy of light to alter the structure and shape of bilirubin, transforming it to molecules that can be excreted even when normal conjugation is insufficient. Light absorption by dermal and subcutaneous bilirubin stimulates a fraction of the pigment to experience several photochemical reactions that happen at very different rates. Light absorption by bilirubin occurs most strongly in the blue region of the spectrum (near 460 nm), as explained in Figure 1. In this region, the penetration of light through tissue increases significantly with the increase in wavelength. Specifically, the intensity and wavelengths of used light greatly control the formation rate of bilirubin photoproducts only wavelengths that are absorbed by bilirubin and penetrate tissue have a phototherapeutic effect. Taking these factors into consideration, the most effective lamps for treating hyperbilirubinemia are those that have output in the 460 to 490 nm blue region of the spectrum [12].

Hospital phototherapy using blue LED lamps may be more effective at reducing the time spent under phototherapy compared with conventional phototherapy in term and preterm infants [13]. As maximum skin exposure is necessary, the infant should be naked and placed in an incubator to avoid cold stress. Body temperature should be monitored regularly because of the direct effect of radiant energy on skin temperature and also because heat may be transmitted from the phototherapy unit to the incubator [14].

This study is organised as follows: Section 2 describes the related work is such a field. Section 3 presents the methods and materials of the proposed jaundice detection system, including data collection, system framework and the practical circuit. Section 4 presents the experimental results based on data analysis and Matlab GUI and depicts some study limitations. Finally, section 5 concludes the study and suggests a direction for future work.
2. Related Work

In this section, a summary for some of the research that focuses on the diagnose of jaundice in neonates has been presented. In a study by Puppalwar et al. [15], the authors relied on measuring bilirubin level to build a comparison between some of the available detection techniques. The techniques considered in [15] were both invasive and non-invasive. Penhaker et al. [16] proposed a design for a cost-effective electronic instrument that measures bilirubin level. The proposed design uses light transmission through the skin of infants, and it was connected to an analogue to digital unit to produce computer visualisation and record the readings of bilirubin level and their times in a database. The authors in [17] developed a visual technique named as “Optical Technique”, which was a non-invasive technique for jaundice detection. The main motive in [17] was to improve the accuracy of early detection of bilirubin levels in newborns with the use of automated detection or sensors.

A low-cost system for jaundice detection that deploys a smartphone camera attached to an 8-megapixels camera was introduced in [18]. The system uses a calibration card that is placed on the newborn’s abdomen; sternum and forehead before a set of images is captured. However, this technique may be subjected to error or underestimation of the bilirubin level in newborns with dark skin colour. In [19], a new technique for screening neonatal jaundice based on the scleral images was proposed. The technique uses a Nikon D3200 camera with the specifications of 24.6 megapixel CMOS sensor with a prime macro lens of 60 mm focal length. The captured images were analysed using MATLAB and a customised colour chart was also used as a reference. The technique uses the hue of the sclera to estimate the bilirubin level, and it was tested on 110 newborns. It was proven that the proposed technique is a promising screening tool, especially in cases in which TSB level was above 205 μmol/L. The correlation analysis between the scleral hues and the measured quantification of TSB level was reasonably high with a linear correlation of 0.75, assessed in 110 newborns.

Another study by Ali et al. [20] introduced an algorithm to diagnose the inherited condition of constitutional jaundice. The algorithm consists of two parts, the use of Wavelet Transform to analyse images is the first part, and the calculation of the percentage of grey scales for each image via histogram is the second. Moreover, the following three methods for image enhancement are implemented:
logarithmic transformation, image adjustment, and histogram equalisation. In addition, Grow Cut Method is used in the segmentation of images, while Fuzzy Modelling System Structure is employed for the classification to determine one of three conditions of inherited constitutional jaundice. Castro-Ramos et al. [21] proposed a method to detect newborn jaundice by obtaining the digital skin images of the palm, soles and forehead of the newborns. Analysis in terms of the diffuse reflectance spectra and RGB attributes are performed on the captured images. Afterwards, the computed analysis is further tested by the Support Vector Machine (SVM) to determine the presence of jaundice. The method conferred a sensitivity of 71.8% and the specificity of 78.8% with 20 spectra. Hence, this promising method may be an excellent technique to evaluate the different levels of bilirubin in the newborn. The authors of [22] designed a scleral bilirubin assessment system that is based on the use of a smartphone camera which captures an image of the eye. With deploying machine learning, the system estimates the level of bilirubin depending on the colour of the sclera to regression of bilirubin level. The main advantages of this system are the ability of early diagnosis of jaundice, and the sensitivity and accuracy of this system compared to other existing systems. In [23], the authors developed a system that quantifies bilirubin from skin reflectance spectra by utilising diffuse reflectance spectroscopy. Although the developed system was efficient in calculating hemoglobin and hematocrit level, it didn’t achieve good enough results in predicting bilirubin level. A correlation between bilirubin level in the serum and light absorption with the wavelength of 455 nm was found in [24]; however, the model suggested relied on using an invasive technique. In order to estimate bilirubin level, the authors of [25] used reflectance spectroscopy. Light from a fibre optic was direct to a spot on the hand of subject, and then the obtained reflected light was passed through a diffraction system which is then analysed by a computer. Afterwards, attenuation dependent light is used to estimate the level of bilirubin. An image processing technique to detect neonatal jaundice was proposed in [26]. In this study, the 8-colour calibration card was used to analyse the captured images. The calibration card had to be disposed after each use and replaced with a new one prior to each use to avoid the risk of infection in the newborn, which imposes extra cost.

In this paper, a new detection system for neonatal jaundice is proposed. The proposed system relies on monitoring the changes in babies’ skin colour. This involves the use of a digital camera which takes photos for newborn babies’ skin without any direct contact with them. The taken digital images are then analysed by a computer program, and the colour components are extracted. Based on the levels of the extracted components, we determine the level of bilirubin. Our proposed system is affordable, easy to implement and provides accurate outcomes as shown in the results section below.

3. Methods and Materials

3.1. Data Collection

The data set used in this experiment was collected during two days in the central teaching hospital of paediatric in Baghdad, Iraq. Two infants were included in this study (two males, one with jaundice and another without jaundice) with less than 30 weeks gestational age. A digital camera (Nikon D5300) was placed at a distance of approximately 1–2 m away from the infants, and many images were captured at different times in a day. The image data was captured in ambient lighting using an 18-50 mm lens with a resolution of 6000×4000 and saved in JPEG file format on a computer. Also, many online infant photos were used to test the proposed jaundice detection system. All data collection followed the ethical tenets of the Declaration of Helsinki (Finland 1964) and a written consent from the parents of the infants was obtained after providing a complete explanation of the study procedures before imaging. The data collection of the two infants is shown in Figure 2.

3.2. System Framework

The schematic diagram of the proposed jaundice detection system is presented in Figure 3. The system framework that relies on analysing skin colour based on the Matlab graphic user interface (GUI), has two main parts: skin colour analysis, including region of interest (ROI) selection and colour range selection and the practical circuit.
3.2.1. Skin Colour Analysis

Skin colour is a highly informative aspect of various human-related image processing applications [27-31]. Skin colour detection deals with the recognition of skin-coloured pixels and regions in a given image based on three main colour models: RGB (Red, Green and Blue), HSV (Hue, Saturation and Value) and YCbCr (Luminance, Chrominance). The RGB representation of the brightness values changes can be found as follows [32, 33]

\[
R = \int E_\lambda R_\lambda d(\lambda),
\]

\[
G = \int E_\lambda G_\lambda d(\lambda),
\]

\[
B = \int E_\lambda B_\lambda d(\lambda),
\]

where \( E_\lambda \) is the light spectrum, \( R_\lambda, G_\lambda \) and \( B_\lambda \) are the sensitivity functions for the R, G and B components obtained from the colour image, respectively, and \( \lambda \) is the wavelength of the incident spectrum. The colour representation of the YCbCr colour model can be derived from the RGB colour model as follows [34]:

![Figure 2. Data collection under ambient lighting for (a) a healthy infant without jaundice, and (b) an infant with jaundice.](image)

![Figure 3. The schematic diagram of the proposed jaundice detection system.](image)
\[
\begin{bmatrix}
Y \\
C_b \\
C_r
\end{bmatrix} =
\begin{bmatrix}
16 \\
128 \\
128
\end{bmatrix} +
\begin{bmatrix}
0.279 & 0.504 & 0.098 \\
-0.148 & -0.291 & 0.439 \\
0.439 & -0.368 & -0.098 \\
\end{bmatrix}
\begin{bmatrix}
R \\
G \\
B
\end{bmatrix}
\] (4)

Because the blue component is the most prominent channel for yellowness detection compared to other channels, the B and Cb channels were used in this study as main components to detect jaundice. After that, the ROI was manually selected using the MATLAB built-in instruction ‘ginput’ with five inputs to provide several interesting skin data that automatic region detection cannot provide. The ROI was outlined by drawing a square form around ROI. The average value of the brightness pixel for each component within the selected ROI can be extracted using the following equations [35, 36]:

\[
i_B(t) = \frac{\sum_{x,y \in ROI} B(x,y)}{|ROI|}
\] (5)

\[
i_{Cb}(t) = \frac{\sum_{x,y \in ROI} C_b(x,y)}{|ROI|}
\] (6)

where \(B(x,y)\) and \(C_b(x,y)\) are the brightness pixel value at image location \((x,y)\) of the B and C_b components, and \(|ROI|\) is the pixel region of the selected ROI. Eq. (5) is worth between 0 and 255, while Eq. (6) is worth between 16 and 240. The colour range selection for the jaundice was determined based on the average brightness values for the B and C_b obtained from two test subjects as well as more than 50 image samples for infants inside care unit searched from the internet. For infants with jaundice, the selected brightness values from the selected components fall within a range of 30-104, while they fall with a range between 105-190 for normal infants. The MATLAB built-in commands ‘if and elseif’ with the selected range were used to make a decision as to whether to light the skin or not. To verify jaundice and to increase system accuracy, both blue channels must be within the selected range.

3.2.2. The Practical Circuit

The Arduino Nano [37] is a complete and breadboard-friendly device based on ATmega328P microcontroller that is used in many medical applications due to its availability, small size, low cost, efficient interrupt structure and ease to programming with an open-source software using an integrated development environment (IDE) [38, 39]. The Arduino Nano microcontroller has 8 analogue input pins (with a resolution of 10 bits), 14 digital I/O pins and 6 pulse width modulation (PWM) pins with the clock frequency of 16MHz. This microcontroller can be easily linked with the Matlab program via Mini-B USB serial cable. Two Matlab built-in commands ‘arduino’ and ‘writeDigitalPin’ were used to identify the microcontroller and to drive the LED circuit. The practical circuit of the proposed jaundice detection system is shown in Figure 4.

**Figure 4.** The practical circuit of the proposed jaundice detection system.
4. Experimental Results

This section explains how the proposed jaundice detection system could be used to determine whether the infant requires UV therapy or not based on skin colour analysis. The selected ranges for jaundice and non-jaundice skin were used by the MATLAB 2020a environment (MathWorks, NSW, Australia) and determined the skin state and sending a digital output (1 or 0) to the microcontroller circuit that controls the blue LED circuit. The proposed MATLAB GUI panel was carried under the Microsoft Windows 10 operating system with Intel® Core™ i7- 6700HQ CPU 2.6 GHz, 16 GB RAM. It allows the user (doctor or nurse) to load infant image samples, manually select ROI and execute the algorithm to determine the skin state and whether it requires UV therapy or not. The proposed GUI provides an easy tool to see the RGB histogram and their brightness values, skin state (jaundice or non-jaundice skin) and blue LED control. The GUI main panel of the proposed jaundice detection system for normal infant without jaundice in the intensive care unit is shown in Figure 5.

It is clear from Figure 5 that the infant does not need UV therapy as his skin was normal without any yellowness (within a selected blue normal range >105), and the UV LED was OFF in this case. The GUI main panel of the proposed jaundice detection system for an infant with jaundice in the intensive care unit is shown in Figure 6.

![Figure 5](image1.png)
Figure 5. The GUI main panel of the proposed jaundice detection system (non-jaundice skin).

![Figure 6](image2.png)
Figure 6. The GUI main panel of the proposed jaundice detection system (jaundice skin).
It is clear from Figure 6 that the experimental GUI panel could determine the need for the UV therapy as the infant skin was with jaundice (within a selected blue range <104), and the UV LED was ON in this case. The experimental GUI panel was also tested on many infant’s photos from the internet with a very high detection rate for the skin state. Table 1 shows the performance of the proposed jaundice detection system on 10 photos for infants with and without jaundice.

**Table 1.** The performance of the proposed jaundice detection system on 10 infants with and without jaundice.

| Infant | B Channel | C<sub>B</sub> Channel | Infant condition | UV LED state | Detection rate |
|--------|-----------|-----------------------|------------------|--------------|----------------|
|        | 91.9269   | 90.5235               | JAUNDICE.        | ON           | 100%           |
|        | 113.596   | 109.049               | NORMAL           | OFF          | 100%           |
|        | 81.2578   | 70.9996               | JAUNDICE.        | ON           | 100%           |
|        | 74.2974   | 86.8331               | JAUNDICE.        | ON           | 100%           |
|        | 96.5359   | 94.734                | JAUNDICE.        | ON           | 100%           |
|        | 135.001   | 111.526               | NORMAL           | OFF          | 100%           |
|        | 78.3901   | 93.8925               | JAUNDICE.        | ON           | 100%           |
|        | 72.2732   | 87.3965               | JAUNDICE.        | ON           | 100%           |
|        | 62.144    | 70.9126               | JAUNDICE.        | ON           | 100%           |
|        | 149.787   | 106.868               | NORMAL           | OFF          | 100%           |

Despite the proposed jaundice detection system was accurate, efficient, cost-effective, easy to use and easy to program, it has some disadvantages that require to be considered in the future. The first disadvantage is that the lighting conditions as the proposed system is limited to work only in a well-lit environment setup. The second disadvantage is that the ROI is manually selected. Although the manual selection of ROI enables the user to select many regions for the same infant, it limits such practical applications that need ROI to be selected automatically. The last limitation rises when the background is similar to skin tone.

**5. Conclusion**

The computerised image processing techniques have many efficient medical applications nowadays, especially in diagnosis, monitoring the patient's health, and supplying active treatment. In this study, a developed non-contact system for detecting neonatal jaundice was proposed based on the changes in infants’ skin colour. The hardware design of the proposed system was carried out by using the Arduino Uno Microcontroller linked with Matlab GUI panel to drive the blue LED when jaundice exists. The preliminary experiments performed on several images obtained from two infants in intensive care units as well as many infant images were involved in the experiment. The preliminary experimental results were promising in the neonatal jaundice detection. However, future improvement can be expanded to work with further subjects under different lighting conditions and skin tones to achieve better outcomes.
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