Pearson's Correlation Coefficient Analysis of non-invasive Jaundice Detection based on Colour Card Technique

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Abstract. Jaundice is describes as yellow discoloration of the skin and other tissues of a newborn infant. It happens when the bilirubin pigment rises up to 5 mg/dL or 85 μmol/L due the organs just started to developed. 75% of newborns in Malaysia had jaundice in the first week of life. Conventional assessment method is not convenient since it unable to detect all type of human skin colours, caused traumatization and costly. This research work proposed jaundice detection system based on the colour card technique that represent all types of human skin colours. This research does not involve any subject due to parent's cooperation and ethics limitation. The input data is represented by the colour card shades. It represents random bilirubin colour in patient's body, all types of human skin colour, and standard reference bilirubin concentration colour. It acquires input data by capturing different type of colour card shades using OPT101 photodiode sensor and USB4000-XR1-ES spectrometer. The input data collected were verified through Anderson-Darling normality test and analysed using Pearson's correlation coefficient to measure the strength of the association between the two variables for each input sample tested. Based on the correlation results, it shows high correlation value (r=0.997). Percentage error analysis is used to validate the experimental device and shows value of 9.90% which prove this technique is reliable. The significant contributions of this work is the improvement of the accuracy in detecting jaundice level for all type of human skin colours through this system.

1. Introduction

Jaundice in newborn or neonatal hyperbilirubinemia, is a yellow discoloration and shows common sign of liver not functioning appropriately caused by the pigment of bilirubin that rises above 85μmol/l or 5mg/dl [1, 2, 3]. A survey conducted by Ministry of Health Malaysia found that about 75% of newborns experience jaundiced in the first week of life, based on data collected from government hospitals and health centers [4]. The statistic shows how crucial this medical condition among Malaysians. Jaundice disorder happens due to the organs and metabolism of a newborn is just starting to develop [5]. It typically results from the deposition of unconjugated bilirubin pigment in the skin and mucous membranes [6]. For infants, their liver is immature and potentially cannot fully remove the bilirubin from body which causes the yellowing of the skin [7]. Babies may develop kernicterus when the excess bilirubin traverse from the bloodstream to the brain tissue, which can cause death, while survivors will suffer cerebral palsy and high frequency hearing loss [9, 10]. Treatments use to cure jaundice are phototherapy (exposing baby to fluorescent light) and blood exchange transfusion [10].

2. Jaundice Assessment Method

Jaundice assessment method is a marker used to identify those infants who may be at risk for developing severe hyperbilirubinemia which can potentially lead to brain damage. Clinical examination usually reveals the degree of hyperbilirubinemia by referring to the TSB (Total Serum Bilirubin) levels [11]. Jaundice assessment is divided into two types that are invasive and non-invasive method.

2.1. Invasive Method: Blood Test

Blood test is considered the best way to detect any disease in human body which bring into accurate results, including jaundice [12]. Most hospitals in Malaysia uses this invasive method, by taking a specific amount of infant's blood and test it in the laboratory. The blood samples are taken from the baby's heels using capillary stick as shown in Figure 1 [13]. Unfortunately, invasive jaundice measurement has some drawbacks which are painful for the infants, caused delay in obtaining results which can lead to serious problem to the infant with high TSB.

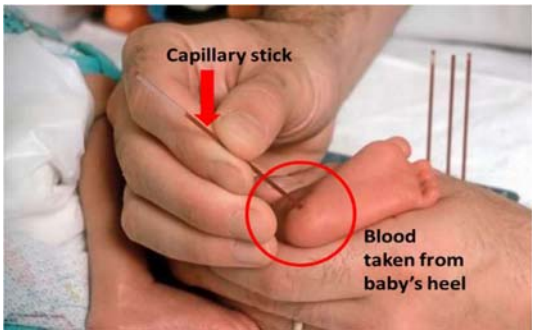

Figure 1. Blood taken from baby's heel [13].

2.2. Non-invasive Method: Kramer's Rule (visual inspection)

Kramer's Rule is a method that fully relies on human manual visual assessment. Kramer divide the body into five zones; starts from head and neck, upper trunk, lower trunk and thigh, arms and lower legs and lastly the palms and soles as shown in Figure 2 [14]. Unfortunately, Kramer's Rule is not beneficial if the baby has dark skin. Also, this manual visual assessment may lead to human error and unreliability issues [15].

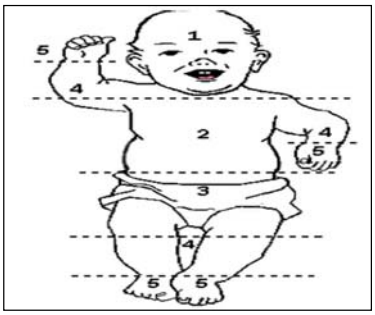

Figure 2. Kramer's rule zones[14]

2.3. Non-invasive Method: Jaundice Meter

Jaundice meter or mostly known as transcutaneous bilirubinometer is a non-invasive technique that is painless, eliminates traumatization and offer fast result by using the concept of optical reflection and absorption [14]. It works by directing light into the skin of the neonate and measuring the intensity of a specific wavelength that is returned to the photocell [16]. Indeed, jaundice meter available in the market offers painless effect and fast results, but not all jaundice meter concern on the human skin factor based on the human skin colour variations [17].

3. Data Collection Method

This system consists of a sensing module, microcontroller for data processing and GUI for display and monitoring. Figure 3 shows the block diagram of the system with OPT101 silicon photodiode sensor is used as the sensing module, white LED (Light Emitting Diode) functioned as light source, and spectral reflectance method is applied as a standard optical method. The sensor senses the change of intensity of the colour, then the input data is processed by a microcontroller that translates the colour intensity to an arbitrary displayed voltage value. The data are then transmitted wirelessly using XBee transmitter to the receiver, processed and displayed through GUI (Graphical User Interface) on the computer in real-time manner. All data are collected using experimental device (OPT101 silicon photodiode sensor) and actual device (Near Infrared (NIR) spectrometer USB4000-XR1-ES). Each sample measurement is taken for 10 seconds per reading and repeated for five times for each sample. The reason of this process is to make sure the device sensor is fully stabilize, and ready to read the data. Figure 4 shows the data collection method for both experimental and actual device.

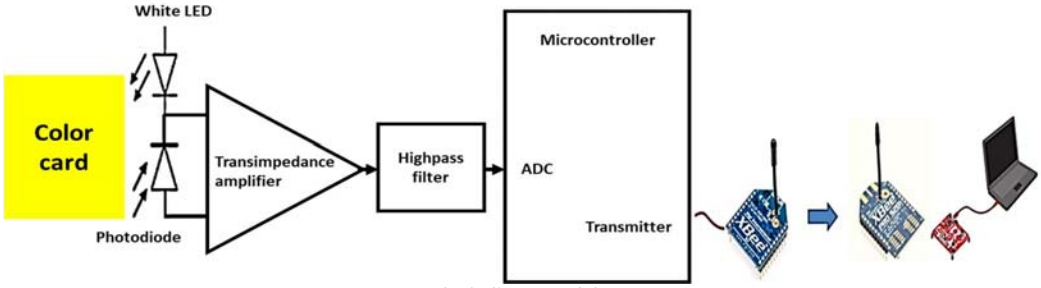

Figure 3. Block diagram of the system

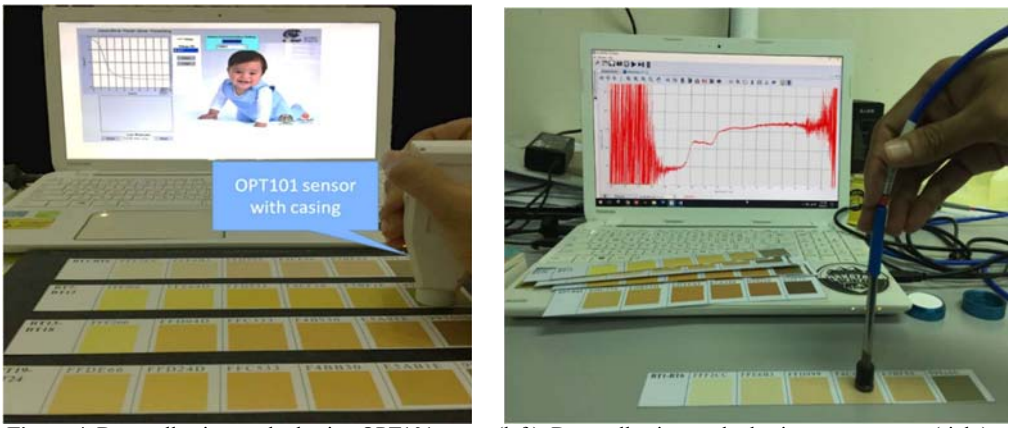

Figure 4. Data collection method using OPT101sensor (left), Data collection method using spectrometer (right)

3.1. Colour Card Prototype

Three types of colour card are used as the input and standard reference data for this research. Yellow colour card shades shows the arrangement of seven yellow colour represents random bilirubin colour tissue of jaundice patient because bilirubin appears to be in yellow colour [18]. Fitzpatrick human skin colour card is used to represents a classification scheme for human skin colour standardization [19]. This is to highlight the concern usage of human skin colour element in detecting jaundice as it is one of the main disadvantage in the current jaundice detection system. The third colour card is the bilirubin reference card which represents the standard reference colour of bilirubin and concentration for each colour as well as the treatment required [20]. This bilirubin colour card is used as reference chart in this research.

3.1.1. Colour Card Combination.

This section describes the combination and mixture of yellow shade, Fitzpatrick human skin colour shade, and bilirubin reference card. Each type of yellow shade (Y1 to Y7) and Fitzpatrick shade (T1 to T6) are combined together using colour mixer generator from http://kotoritone.com/color/en/ website, resulting a sample name S1 to S42 [21]. Also, the colour combination involves the mixture of yellow shade and bilirubin reference card (B1 to B4), resulting new reference standard name BT1 to BT24 [21]. Some example of this input data are shown in Figure 5 and Figure 6.

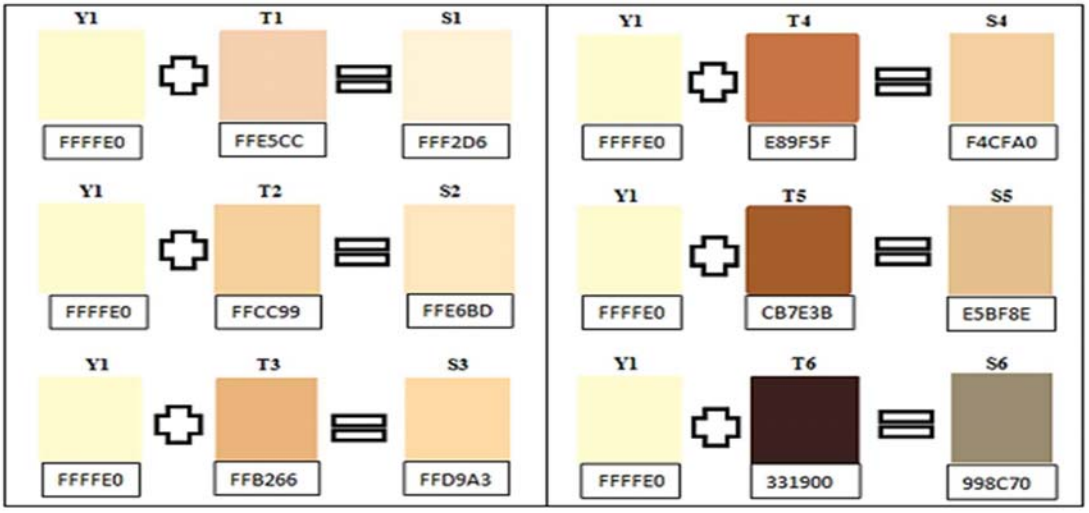

Figure 5. Sample from S1-S6

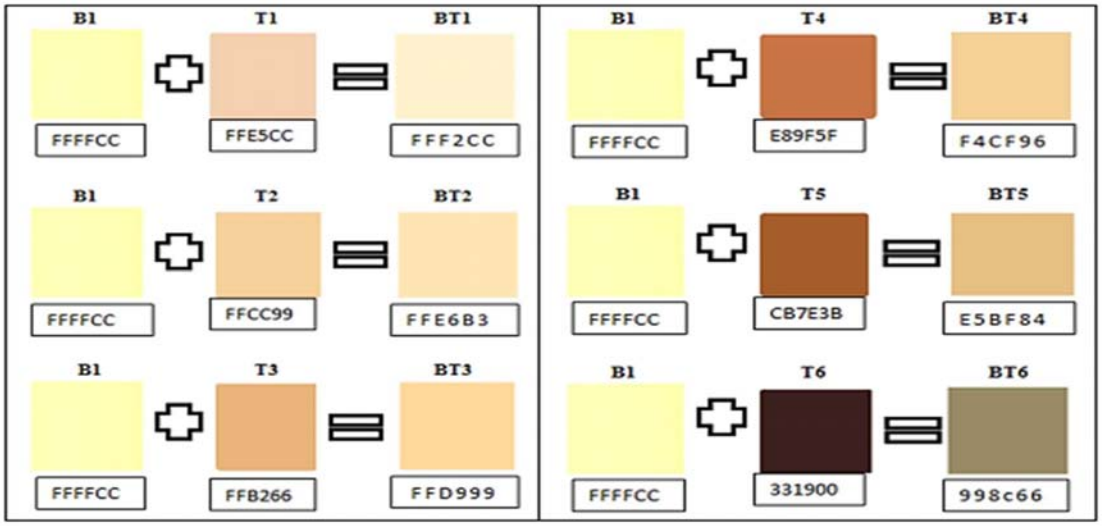

Figure 6. BT reference standard shade from BT1-BT6 (right).

4. Results and Discussion

A total of 42 S samples (S1 to S42) of input data representing random patient bilirubin colour combined with human skin colour, and 24 shades (BT1 to BT24) reference chart are collected and verified through Anderson-Darling Normality Test to measures how well the data follow and fits a specified distribution.

4.1. Pearson's Correlation Coefficient

The verified data then being analyzed using Pearson's correlation coefficient. It is a measure of the strength of the association between the two variables. Table 1 shows the correlation result for data collected using experimental device (OPT101). There are significant positive correlation between S1-S6 and BT1-BT6 with (r =0.988, p =0.000). From the correlation result of sample S7-S12, S13-S18, and S19-S24, it is apparent that the sample have high correlation with BT7-BT12 at (r =0.991, p =0.000); (r =0.997, p =0.000); (r =0.997, p =0.000). There is a clear statement saying that sample S25-S30 have high correlation with BT13-BT18 at (r =0.995, p =0.000). The sample S31-S36 and S37-S42 have strong correlation of (r =0.997, p =0.000); (r =0.995, p =0.000) with BT19-BT24.

Table 1. Correlation results for experimental device (OPT101 sensor)

	Pearson's correlation coefficient result (r)							
BT reference data	Correlation	S1-S6	S7-S12	S13-S18	S19-S24	S25-S30	S31-S36	S37-S42
BT1-BT6 (0-4 mg/dL)	Pearson Correlation	0.988	0.98	0.948	0.942	0.947	0.901	0.908
	p value	0.000	0.004	0.004	0.005	0.004	0.014	0.012
BT7-BT12 (5-14 mg/dL)	Pearson Correlation	0.895	0.991	0.997	0.997	0.994	0.955	0.961
	p value	0.016	0.000	0.000	0.000	0.000	0.003	0.002
BT13-BT18 (15-19 mg/dL)	Pearson Correlation	0.862	0.967	0.978	0.992	0.995	0.991	0.993
	p value	0.027	0.002	0.001	0.000	0.000	0.000	0.000
BT19-BT24 (> 20mg/dL)	Pearson Correlation	0.827	0.904	0.924	0.952	0.963	0.997	0.995
	p value	0.043	0.013	0.008	0.003	0.002	0.000	0.000

Similar method of analysis was carried out for USB4000-XR1-ES spectrometer. This is to support the result obtained from the OPT101 sensor and to prove whether the device sensor is reliable or otherwise. The Pearson's correlation coefficient results for S sample vs BT data using USB4000-XR1-ES spectrometer are presented in Table 2 with highlighted area shows the highest correlation between S samples tested vs BT reference data.

Table 2. Correlation result for actual device (USB4000-XR1-ES spectrometer)

	Pearson's correlation coefficient result (r)							
BT reference data	Correlation	S1-S6	S7-S12	S13-S18	S19-S24	S25-S30	S31-S36	S37-S42
BT1-BT6 (0-4 mg/dL)	Pearson Correlation	0.976	0.858	0.905	0.854	0.955	0.961	0.977
	p value	0.001	0.029	0.013	0.030	0.003	0.002	0.001
BT7-BT12 (5-14 mg/dL)	Pearson Correlation	0.918	0.931	0.966	0.918	0.949	0.863	0.885
	p value	0.010	0.007	0.002	0.010	0.004	0.027	0.019
BT13-BT18 (15-19 mg/dL)	Pearson Correlation	0.935	0.905	0.920	0.886	0.991	0.898	0.930
	p value	0.006	0.013	0.009	0.019	0.000	0.015	0.007
BT19-BT24 (> 20mg/dL)	Pearson Correlation	0.890	0.669	0.809	0.808	0.858	0.980	0.986
	p value	0.017	0.047	0.051	0.052	0.029	0.001	0.000

Both correlation results between experimental and actual device are compared and it shows that the experimental device OPT101 follows the same output from USB4000-XR1-ES spectrometer. Each S sample found its own matched BT reference data based on the highest r value which indicate strong correlation between both variables. It can be summarizes that the experimental device OPT101 sensor have the similar outcome results as actual device USB4000-XR1-ES spectrometer. The highlighted area in Table 3 shows the correlation between both devices.

Table 3. Pearson's correlation result for OPT101 sensor and USB4000-XR1-ES spectrometer

		Pearson's correlation coefficient result (r)						
BT reference data	Device	S1-S6	S7-S12	S13-S18	S19-S24	S25-S30	S31-S36	S37-S42
BT1-BT6	OPT101	0.988	0.98	0.948	0.942	0.947	0.901	0.908
(0-4 mg/dL)	USB4000	0.976	0.858	0.905	0.854	0.955	0.961	0.977
BT7-BT12	OPT101	0.895	0.991	0.997	0.997	0.994	0.955	0.961
(5-14 mg/dL)	USB4000	0.918	0.931	0.966	0.918	0.949	0.863	0.885
BT13-BT18	OPT101	0.862	0.967	0.978	0.992	0.995	0.991	0.993
(15-19 mg/dL)	USB4000	0.935	0.905	0.920	0.886	0.991	0.898	0.930
BT19-BT24	OPT101	0.827	0.904	0.924	0.952	0.963	0.997	0.995
(> 20mg/dL)	USB4000	0.890	0.669	0.809	0.808	0.858	0.980	0.986

4.2. Percentage Error

Percentage error analysis is used to validate the experimental device compared to actual device. The percentage error results for BT reference data shows the highest value of % error obtained is 9.62%, whereas S sample show the highest % error of 9.90%. Based on statement by Najmuddin [22], the output obtained from experimental reading must not exceeds 10% of the actual reading output to prove the reliability of the experimental device. Both results for BT reference and S sample shows % error below than 10%, thus, proves that the experimental device is valid and reliable to be used.

5. Results and Discussion

The significant contributions of this work has been to improve the accuracy of non-invasive jaundice assessment for various type of human skin colour by the implementation of colour card technique. Additional to the previous work, this research introduces colour card technique addressing the concern of human skin factor as it is the major disadvantages in most of the jaundice assessment method. Thus, human skin colours represented by Fitzpatrick shades are considered. Since lack of research been made for detecting jaundice in dark skin colour that leads to the disadvantages to previous device, this research combines the variations on human skin colour ranging from type one to six with the random bilirubin colour in human body. In conclusion, it has been shown that the jaundice assessment using colour card technique is a promising enabling technique for non-invasive and non-traumatize. This technique demonstrate reliability, precision in its results and enhance the safety for user.

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