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NON-INVASIVE JAUNDICE DETECTION SYSTEM USING COLOUR CARD TECHNIQUE

by

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TABLE OF CONTENTS (meter reading)

	PAGE
DECLARATION OF THESIS	i
ACKNOWLEDGMENT	ii
TABLE OF CONTENTS	iii
LIST OF TABLES	vi
LIST OF FIGURES	viii
LIST OF ABBREVIATIONS	xii
LIST OF SYMBOLS	xiii
ABSTRAK	xiv
ABSTRACT	xv
CHAPTER 1 : INTRODUCTION	1
1.1 Overview	1
1.2 Background	2
1.3 Problem Statement	4
1.4 Objectives	6
1.5 Scope of Study	6
1.6 Contribution	7
1.7 Thesis Overview	8
CHAPTER 2 : LITERATURE REVIEW	9
2.1 Introduction	9
2.1.1 Causes of Jaundice	10
2.1.2 Types of Jaundice	11
2.1.3 Symptom of Jaundice	12
2.2 Bilirubin	14
2.3 Jaundice Assessment	15
2.3.1 Invasive Method: Blood test	16
2.3.2 Non-invasive: Kramer's Rule (visual inspection)	18
2.3.3 Non-invasive: Jaundice Meter (meter reading)	19
2.3.3.1 Bilimed	20
2.3.3.2 BiliChek	21
2.3.3.3 JM-105	22

2.3.4	Non-invasive: USB4000-XR1-ES Spectrometer (meter reading)	24
2.4	Jaundice Meter Sensor	26
2.5	Spectral Reflectance Method	27
2.5.1	Spectral Reflectance of Paper	28
2.6	Wireless Sensor Network in Healthcare	29
2.7	Statistical Method	31
2.7.1	Data Normality Test	31
2.7.1.1	Anderson-Darling Test	32
2.7.2	Data Matching and Correlation	32
2.7.2.1	Linear Regression Analysis	33
2.7.2.2	Pearson's Correlation Coefficient	34
2.7.3	Data Verification and Validation	35
2.7.3.1	Percentage error	35
2.7.3.2	Percentage Reflectivity of Paper	35
2.8	Related Works	36
2.9	Summary	43
CHAPTER 3 : METHODOLOGY		44
3.1	Introduction	44
3.2	Colour Card Prototype	47
3.2.1	Yellow Shades Card	47
3.2.2	Fitzpatrick Human Skin Colour Card	48
3.2.3	Bilirubin Reference Card	49
3.3	Colour Card Combination	50
3.3.1	S Sample Colour Combination	50
3.3.2	BT Reference Colour Combination	52
3.4	System Design	54
3.5	Sensor Type	55
3.6	ZigBee	56
3.7	Dashboard System	58
3.7	Data Collection Method	60
3.8.1	Using OPT101 Sensor	60
3.8.2	Using USB4000-XR1-ES Spectrometer	63
3.9	Experiment Protocol and Data Analysis	65
3.10	Data Analysis Method	67
3.11	Expected Result	68

3.12	Summary	69
CHAPTER 4 : RESULT & DISCUSSION		71
4.1	Introduction	71
4.2	Experimental Data Sampling	71
4.3	Data Normality Verification	75
4.3.1	Anderson-Darling Normality Test (OPT101 Sensor)	75
4.3.2	Anderson-Darling Normality Test (USB4000-XR1-ES Spectrometer)	77
4.4	Data Matching and Correlation	79
4.4.1	Linear Regression Analysis	79
4.4.1.1	Using OPT101 Sensor	79
4.4.1.2	Using USB4000-XR1-ES Spectrometer	90
4.4.2	Pearson's Correlation Coefficient	100
4.4.2.1	Using OPT101 Sensor	100
4.4.2.2	Using USB4000-XR1-ES Spectrometer	104
4.5	Data Verification and Validation	107
4.5.1	Comparison of OPT101 Sensor and USB4000-XR1-ES Spectrometer	107
4.5.2	Percentage Error	110
4.6	GUI Representation	113
4.7	Summary	114
CHAPTER 5 : CONCLUSION		115
5.1	Conclusion	115
5.2	Contribution	117
5.3	Future Recommendation	118
REFERENCES		119
APPENDIX		127
LIST OF PUBLICATIONS		137
LIST OF AWARDS		138

LIST OF TABLES

NO.		PAGE
Table 2.1:	Difference between pathological jaundice and physiological jaundice	11
Table 2.2:	TSB level based on zones	18
Table 2.3:	Comparisons of jaundice meter	23
Table 2.4:	Comparison of jaundice assessment method	25
Table 2.5:	Sensor used in jaundice meter	26
Table 2.7:	Summary of related works	42
Table 3.1:	Bilirubin reference card (B1-B4)	49
Table 3.2:	Corresponding BT data group on bilirubin reference card	54
Table 3.3:	OPT101 photodiode sensor selection	55
Table 3.4:	Summary of expected result	69
Table 4.1:	BT data (reference) sampling using OPT101 sensor in voltage unit	72
Table 4.2:	S sample data (input) sampling using OPT101 sensor in voltage unit	72
Table 4.3:	BT data (reference) sampling using OPT101 sensor in reflectance percentage unit	73
Table 4.4:	S sample data (input) sampling using OPT101 sensor in reflectance percentage unit	73
Table 4.5:	BT data (reference) sampling using USB4000-XR1-ES spectrometer in reflectance percentage unit	74
Table 4.6:	S sample data (input) sampling using USB4000-XR1-ES spectrometer in reflectance percentage unit	74
Table 4.7:	Linear regression result for all S sample vs BT data using OPT101 sensor	90

Table 4.8:	Bilirubin value and treatment needed for each data	90
Table 4.9:	Linear regression result for all S sample vs BT data using OPT101 sensor	100
Table 4.10:	Bilirubin value and treatment needed for each data	100
Table 4.11:	Pearson's correlation coefficient result for all S sample vs BT data	103
Table 4.12:	Bilirubin value and treatment needed for each data	104
Table 4.13:	Pearson's correlation coefficient result for all S sample vs BT data	106
Table 4.14:	Bilirubin value and treatment needed for each data	107
Table 4.15:	Linear regression result for OPT101 sensor and USB4000-XR1-ES spectrometer	109
Table 4.16:	Pearson's correlation result for OPT101 sensor and USB4000-XR1-ES spectrometer	110

LIST OF FIGURES

NO.		PAGE
Figure 1.1:	Jaundice assessment method	2
Figure 2.1:	Bhutani nomogram	10
Figure 2.2:	Jaundice in newborn	13
Figure 2.3:	Yellowish of newborn skin	14
Figure 2.4:	Bilirubin bond	14
Figure 2.5:	Bilirubin formation	15
Figure 2.6:	Blood taken from baby's heel	16
Figure 2.7:	Blood test process	17
Figure 2.8:	Kramer's rule zones	18
Figure 2.9:	Bilimed jaundice meter	20
Figure 2.10:	(a) BiliChek and (b) Disposable tip	21
Figure 2.11:	Jaundice meter JM-105	22
Figure 2.12:	Ocean Optics USB4000-XR1-ES spectrometer	24
Figure 2.13:	Diffuse method	28
Figure 2.14:	Directional method	28
Figure 2.15:	WSN application scenario for healthcare	30
Figure 2.16:	Anderson-Darling normal distribution curve	31
Figure 2.17:	Linear and non-linear regression graph	33
Figure 2.18:	Spectral reflectance concept	36

Figure 2.19:	Electronic jaundice meter concept	37
Figure 2.20:	Bilirubin detection system	38
Figure 2.21:	Reflectance point spectroscopy system	39
Figure 2.22:	Image collected using colour detection method	40
Figure 2.23:	Process taken in determining bilirubin value	41
Figure 3.1:	Research methodology flowchart	45
Figure 3.2:	Overview of methodology	46
Figure 3.3:	Yellow shades card	47
Figure 3.4:	Fitzpatrick human skin card	48
Figure 3.5:	Sample (S) from S1 to S6	51
Figure 3.6:	BT reference shade from BT1 to BT6	53
Figure 3.7:	Architecture diagram	54
Figure 3.8:	OPT101 sensor and circuit diagram	55
Figure 3.9:	Xbee S1 module	56
Figure 3.10:	Circuit diagram	57
Figure 3.11:	Block diagram of GUI concept	58
Figure 3.12:	GUI (main page)	59
Figure 3.13:	Device initialization	59
Figure 3.14:	Real-time reading	59
Figure 3.15:	Analog to digital conversion process	61
Figure 3.16:	Distance between sensor and sample	61

Figure 3.17:	Casing dimension and circuit inside casing	62
Figure 3.18:	Data collection method using OPT101 sensor	62
Figure 3.19:	NIR spectrometer equipment and PTFE diffuse reflectance standard	63
Figure 3.20:	Data collection method using spectrometer	64
Figure 3.21:	Real-time spectrometer reading	64
Figure 3.22:	Summary of data collection method	66
Figure 3.23:	Analysis method	67
Figure 4.1:	Anderson-Darling normality test result for BT data using OPT101	76
Figure 4.2:	Anderson-Darling normality test result for S sample using OPT101	77
Figure 4.3:	Anderson-Darling normality test result for BT data using USB4000-XR1-ES spectrometer	79
Figure 4.4:	Anderson-Darling normality test result for S sample using USB4000-XR1-ES spectrometer	79
Figure 4.5:	Linear regression results of S1-S6 vs BT data using OPT101 sensor	82
Figure 4.6:	Linear regression results of S7-S12 vs BT data using OPT101 sensor	83
Figure 4.7:	Linear regression results of S13-S18 vs BT data using OPT101 sensor	84
Figure 4.8:	Linear regression results of S19-S24 vs BT data using OPT101 sensor	85
Figure 4.9:	Linear regression results of S25-S30 vs BT data using OPT101 sensor	86
Figure 4.10:	Linear regression results of S31-S36 vs BT data using OPT101 sensor	87
Figure 4.11:	Linear regression results of S36-S42 vs BT data using OPT101 sensor	88

Figure 4.12:	Linear regression results of S1-S6 vs BT data using spectrometer	92
Figure 4.13:	Linear regression results of S7-S12 vs BT data using spectrometer	93
Figure 4.14:	Linear regression results of S13-S18 vs BT data using spectrometer	94
Figure 4.15:	Linear regression results of S19-S24 vs BT data using spectrometer	95
Figure 4.16:	Linear regression results of S25-S30 vs BT data using spectrometer	96
Figure 4.17:	Linear regression results of S31-S36 vs BT data using spectrometer	97
Figure 4.18:	Linear regression results of S36-S42 vs BT data using spectrometer	98
Figure 4.19:	Percentage error of BT data	112
Figure 4.20:	Percentage error of S sample	113
Figure 4.21:	GUI representation	114

LIST OF ABBREVIATIONS

ABSS	Artificial bilirubin standard solution
AD	Anderson-darling
ADC	Analog to digital converter
APS	Application support
DOA	Direction of arrival
GUI	Graphical user interface
HSV	Hue, Saturation and Value
K-NN	K-nearest neighbors
MAC	Medium access control
NIR	Near Infrared
PC	Personal computer
RGB	Red, Green, Blue
TcB	Transcutaneous bilirubinometer
TDOA	Time difference of arrival
TSB	Total serum bilirubin
UV	Ultraviolet
WSN	Wireless sensor network
ZBO	ZigBee device object

LIST OF SYMBOLS

% error	Percentage error
% reflectivity	Percentage reflectivity
p	P-value
r	Pearson's correlation coefficient
R ²	Regression coefficient
mg/dl	Milligram per deciliter
μmol/l	Micromole per liter

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SISTEM PENGESANAN DEMAM KUNING BUKAN INVASIF MENGUNAKAN TEKNIK KAD BERWARNA

ABSTRAK

Penyakit demam kuning digambarkan melalui perubahan warna kuning di kulit dan tisu-tisu lain pada bayi yang baru lahir dan ianya disebabkan oleh kadar bilirubin yang tinggi iaitu pada 5 mg/dl atau 85 μ mol/l. Di Malaysia, kajian yang dijalankan oleh Kementerian Kesihatan Malaysia membuktikan bahawa kira-kira 75% bayi yang baru lahir mengalami demam kuning pada minggu pertama kelahiran. Kaedah-kaedah terkini pemeriksaan demam kuning mempunyai kelemahannya tersendiri. Kaedah tradisional (Kramer's Rule) dianggap kurang sesuai kerana ianya bergantung kepada ketepatan anggaran visual dan boleh menjurus kepada kesilapan manusia. Oleh itu, ujian darah perlu dilakukan dimana sampel darah diambil dari tumit bayi dan ianya menyebabkan trauma kepada bayi dan juga ibu bapa mereka. Selain itu, alat pengukur demam kuning digital yang terdapat di pasaran adalah mahal dan tidak mampu untuk disediakan di semua klinik kesihatan. Teknik mengesan penyakit demam kuning menggunakan kad berwarna ini dilihat berkesan dan berpotensi memberikan impak yang positif terhadap bidang perubatan dan penjagaan kesihatan. Penyelidikan ini membangunkan suatu sistem pengesanan dan ramalan tahap demam kuning (hyperbilirubinemia) beserta cadangan rawatan berdasarkan teknik kad berwarna. Kajian ini tidak melibatkan subjek ataupun bayi sebagai bahan ujikaji. Data dikumpul dengan mencerap pelbagai warna yang berbeza menggunakan teknik pantulan spektrum optikal terhadap kad berwarna. Kad berwarna tersebut mewakili warna rawak bilirubin dalam badan pesakit, warna kulit manusia dengan mengadaptasikan kad berwarna Fitzpatrick, dan warna kepekatan bilirubin piawaian sebenar. Semua data yang terkumpul hasil dari bacaan sensor dihantar ke komputer melalui rangkaian tanpa wayar untuk diproses. Data yang dicerap diproses dan disahkan menggunakan analisa Anderson-Darling serta regresi linear dan analisa pekali korelasi Pearson untuk melihat persamaan diantara sampel ujian terhadap carta rujukan untuk mendapatkan nilai bilirubin dan cadangan rawatan yang diperlukan. Analisis ralat peratusan digunakan untuk mengesahkan samada peranti yang direka menepati fungsi peranti sebenar atau sebaliknya. Keputusan untuk setiap sampel yang diuji diterjemahkan dalam bentuk grafik pada komputer pengguna dan hanya pengguna yang mempunyai akses sahaja dibenarkan untuk melihat paparan keputusan ujian ini. Daripada keputusan yang diperolehi, regresi linear menunjukkan nilai peratusan (R^2) yang tinggi diantara 86.4% hingga 99.4%, dan korelasi Pearson (r) dengan 0.918 hingga 0.997. Ralat peratusan tertinggi (% error) menunjukkan nilai 9.90% membuktikan alat ini menepati fungsi dan tujuan yang diinginkan. Justeru, dapat disimpulkan bahawa teknik kad berwarna ini menepati piawaian dan boleh sesuai digunakan untuk meramal tahap demam kuning.

NON-INVASIVE JAUNDICE DETECTION SYSTEM USING COLOUR CARD TECHNIQUE

ABSTRACT

Jaundice is described as yellow discoloration of the skin and other tissues of a newborn infant and it is conjunctiva due to the increase of bilirubin up to 5 mg/dl or 85 μ mol/l. In Malaysia, a survey made by Ministry of Health Malaysia proves that about 75% of newborns had jaundiced in the first week of life. Current jaundice assessment method have their own drawbacks. The traditional method (Kramer's Rule) is not convenient since there are limits to the accuracy of visual estimation and may lead to human error. Thus, a blood test taken from baby's heel remains to be necessary but it leads to traumatization for the baby as well as their parents. Moreover, the available jaundice meter in the market is expensive. This jaundice detection using color card demonstrated in this research shows a high potential to give positive impact on the medical and healthcare fields. This research work proposed an automated jaundice (hyperbilirubinemia) detection system and the suggested treatment based on the color card technique. This research does not involve any subject or infant. It acquires data by capturing different type of color shades using spectral reflectance method. It represent random bilirubin color in patient's body, the human skin color represented by Fitzpatrick shades, and bilirubin concentration color card using silicon photodiode sensor. The data gained are transferred wirelessly to a gateway and subsequently to a computer to perform computation and analysis. The input data were validated using Anderson-Darling normality and compared with the reference card using linear regression and Pearson's correlation coefficient analysis to predict the particular bilirubin value and treatment needed for each input sample tested. Percentage error analysis is used to verify and validate the experimental device. The final outputs are shown in a graphical user interface on medical staff's PC and can be viewed only by the authorized personnel. Based on the results of linear relationship and correlation between input sample and reference data, it shows high percentage result (R^2) between 86.4% to 99.4%, and correlation value (r) 0.918 to 0.997. Result of highest percentage error (% error) shows value of 9.90% and verify that this device is reliable. Thus, it can be concluded that the color card technique is reliable and can be used to detect and predict the jaundice level for any type of skin color.

CHAPTER 1 : INTRODUCTION

1.1 Overview

This research focuses on the development of real-time patient health (Jaundice) monitoring using colour card technique and wireless sensor network (WSN) for data collection. It detects jaundice by scanning the skin colour using spectral reflectance method. The color card technique is used as a reference to represent the skin colour with concentration of bilirubin value in human body.

For mimicking human skin tone, Fitzpatrick colour card is considered as the basis. This method is then converge with the WSN for the data to be transferred wirelessly to the computer in real-time for continuous monitoring. Furthermore, the system function as a decision support by recommending the type of intervention or treatment required by the patients based on the bilirubin level detection.



Figure 1.1: Jaundice assessment method

1.2 Background

Jaundice in newborn or neonatal hyperbilirubinemia, is a yellow discoloration and shows common sign of liver not functioning appropriately and blood disorders (Ellairaja, Shenbagavalli, Ponmariappan, & Vasantha, 2017; Fevery, 2008; Houlihan, Armstrong, & Newsome, 2011; Ramappa & Aithal, 2011). It is caused by the pigment of bilirubin that rises above $85\mu\text{mol/l}$ or 5mg/dl (Lewandowski, 2015; Mishra, Agarwal, Deorari, & Paul, 2008; Mohamed Abd El-Halim Abd El-Aal, 2012; Zakaria et al., 2015). This medical condition happens due to the organs and metabolism of a newborn is just starting to develop (Osman, Zulfadhli, Afandi Ahmad, 2014).

Jaundice assessment is divided into two types that are invasive and non-invasive as shown in Figure 1.1.

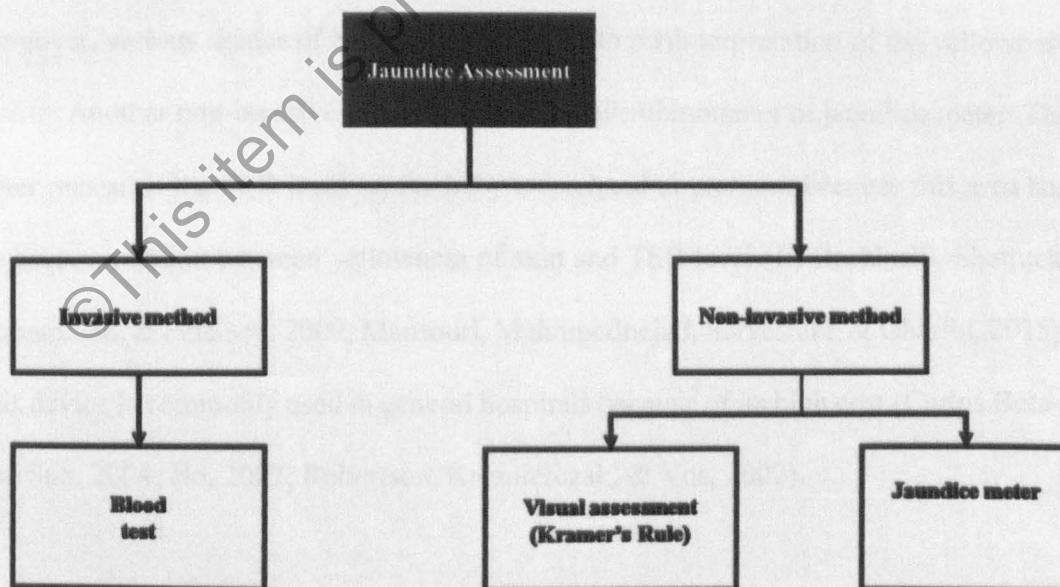


Figure 1.1: Jaundice assessment method

The most accurate method for assessing jaundice is through the invasive (blood test) where the blood sample is taken from the baby's heel to check the Total Serum Bilirubin (TSB) level (Afanetti, Eleni, Yousef, Jrad, & Mokhtari, 2014; Kudavelly, Keswarpu, & Balakrishnan, 2011). Unfortunately, this method can traumatize babies as well as their parents and the trauma may take effect throughout their lifetime. In addition, infections might occur if the instruments used are not properly sterilized (Tomtsis, Kodogiannis, 2001; Kumar, Bhadri, Beyette, Clark, & Wurster, 2005; Slusher, Zipursky, & Bhutani, 2011; Zulkarnay, Jurimah, Ibrahim, Shazwani, & Cheng, 2015). Infection at a severe stage may lead to brain damage or even death.

The non-invasive method involves visual estimation of the yellowness of skin known as Kramer's Rule (Leung et al., 2015; Lewandowski, 2015). Because it only depends on visual assessment, this method of inspection may result in human error as only trained expert medical staff can predict either the baby has jaundice or otherwise. Moreover, various shades of human skin can lead to misinterpretation of the yellowness of skin. Another non-invasive method is by using bilirubinometer or jaundice meter. The meter measures the TSB level on the baby's forehead or sternum because this area has the best correlation between yellowness of skin and TSB level (El-Beshbishi, Shattuck, Mohammad, & Petersen, 2009; Mansouri, Mahmoodnejad, Sarvestani, & Gharibi, 2015). This device is commonly used in general hospitals because of its high cost (Carlos Botas, Yao Sun, 2004; Ho, 2002; Robertson, Kazmierczak, & Vos, 2002).

As the demands for automated and real-time health monitoring in healthcare field increases, it is essential to identify new idea to provide an easy and cost-effective jaundice monitoring with high reliability. WSN have been recently used in many medical applications because of their properties such as low-power consumption, low-cost and support large network deployment (Dayu, 2010; Minaie, Afsaneh, 2013; Tsou & Berber, 2011). Engaging in a large scale hospital requires a higher labour cost to work the section by way of the traditional approach of healthcare management. In modern healthcare, human intervention only occurs when it is required, hence improving labour productivity and resource utilization. This research comprises of light reflectance scanner with the utilization of colour card technique in decision support and provides real-time jaundice information (bilirubin value) wirelessly to a medical system.

1.3 Problem Statement

Based on extensive literature review made from previous research, it is clearly states that jaundice assessment method is the main talking point that need to be improved. The limitations and disadvantages of the jaundice assessment are address as follows:

- i) Kramer's Rule is one of the techniques used to evaluate babies that experienced jaundice and it is completely relying on human visual assessment (Kuan Geok Lan, Wong Swee Lan, 2003; Wan et al., 2014). Unfortunately, Kramer's Rule is not beneficial if the baby has dark skin, and this may lead to human error and misinterpretation in jaundice detection.

- ii) Invasive technique (blood test) is commonly used to detect jaundice among babies (Phil Beeby, 2004) . Unfortunately, the blood test technique is causing trauma and discomfort for both the babies and parents. In addition, the babies are exposed to risk of infection due to small cuts on their skins (Zulkarnay et al., 2015) and the overall process to obtain the final results may take some time to complete as it requires the samples to be process in the lab (Zakaria et al., 2015).
- iii) Jaundice meter or known as transcutaneous bilirubinometer (TcB) available in the market is an example of non-invasive technique that offers painless effect and fast results. But not all jaundice meter concern on the human skin factor based on the human skin colour variations (Slusher et al., 2011; Onyearugha, Onyire, & Ugboma, 2011).

Based on these jaundice assessment method listed, it is clearly shows that each assessment method have its own drawbacks. This research has come out with the solution which implementing the non-invasive technique by using spectral reflectance method. This method mimicking the concept of jaundice meter where it uses spectral reflectance to capture the input sampling data. Kramer's rule concept also been added in this research where it use concept of visual by introducing the colour card that representing random bilirubin colour in human body, Fitzpatrick human skin colour scheme and standard bilirubin colour. By using these implementation, it can helps making the jaundice assessment method become easier and reliable.

1.4 Objectives

The objectives of this research are addressed as follows:

- i) To investigate the jaundice assessment disadvantages based on types of bilirubin and Fitzpatrick human skin colour characteristics.
- ii) To develop a non-invasive method for jaundice detection using bilirubin colour card technique and provide a prediction profile and intervention required based on the jaundice level detected by the device.
- iii) To design a spectral reflectance device as a method for data acquisition which can be used repeatedly without requiring any additional tip.

1.5 Scope of Study

This research is aimed to develop a system that can detect and predict jaundice condition based on the selected parameters skin colour and random bilirubin colour. This study does not involve any subject or infant because this research is focusing on non-invasive spectral reflectance method using colour card technique. It detects jaundice non-invasively using spectral reflectance method and all data are collected by capturing different type of colour card shades that represent random bilirubin colour in patient's body, human skin colour, and standard bilirubin concentration colour card using silicon photodiode sensor.

1.7 The data gained are transferred wirelessly to a gateway and subsequently to a computer to perform computation and analysis showcasing the convergence of WSN in healthcare field. It then compares the data obtained from the random bilirubin colour with bilirubin reference colour and classified it accordingly. From that, the treatment for each bilirubin level can be determined. This research address the concern of human skin factor as it is the major disadvantages in most of the non-invasive jaundice assessment. Thus, human skin colours represented by Fitzpatrick shades are considered. This research also aims at creating a reliable jaundice detection system that can be used in hospitals and baby centres. This system consists of sensing module, system controller, data processing and an output display.

1.6 Contribution

To support the development in healthcare field, some new features are introduced in this research. The novelty of this research is the implementation of colour card technique using Fitzpatrick human skin colour card which improve on the concern of human skin colour factor affecting the accuracy of the jaundice assessment. The non-invasive implementation method eliminate traumatization to newborn babies as well as their parents. This research also implements the convergence of engineering technology in jaundice detection with the showcase of real-time data monitoring.

1.7 Thesis Overview

This thesis is separated into five chapters. Chapter 1 of this thesis describes the introduction to this project. The aim of this chapter is to give an overview of the entire project. It consists of problem statement, objectives, and the scope of this research.

Chapter 2 provides a literature review of previous works similar to this research. It contains a comprehensive findings and analysis of the available literature about jaundice and its assessment which leads to the direction for the development of the system.

Chapter 3 explains the methodology undertaken in this project. This chapter provides information about the method used in order to achieve the objectives of this project.

Chapter 4 presents the results obtained and discussion of the findings, mainly focusing on the verifying the sample data obtained with the reference chart. This chapter also presents the linear regression and Pearson correlation analysis used to find the most suits BT reference data that S sample can fit into. From this, the decision on the treatment for each bilirubin concentration level is discussed.

Finally, Chapter 5 provides the conclusion of the project and suggestions for future work.

CHAPTER 2 : LITERATURE REVIEW

2.1 Introduction

Jaundice or neonatal hyperbilirubinemia is a commonly encountered disease in newborn infants. Factors causing jaundice includes the weak liver condition and also enzyme deficiency (Asmah & Daud, 2012; Ellairaja et al., 2017; Fevery, 2008; Houlihan et al., 2011; Ramappa & Aithal, 2011). A newborn infant is diagnosed to have jaundice when the pigment of bilirubin that rises above $85 \mu\text{mol/L}$ or 5 mg/dl (Kumar, 2011; Mishra et al., 2008; Mohamed Abd El-Halim Abd El-Aal, 2012; Wan et al., 2014). Approximately 60% of term infants and 80% of preterm infants develop jaundice in the first week of life (Onyearugha et al., 2011; Slusher et al., 2004). A survey in government hospitals and health centres under the Ministry of Health Malaysia found that about 75% of newborns experience jaundiced in the first week of life (Ives, 2015; Wan et al., 2014). Bhutani nomogram in Figure 2.1 is used as guidance based on the percentage of bilirubin levels and ages. Serum bilirubin readings below 40% is considered as low risk zone, between 40% and 75% describes as low intermediate zone, 75% to 95% is high intermediate zone and 95% above is stated as high-risk zone (Bhutani, VK, Johnson, Sivieri, 1999). The readings of transcutaneous bilirubin or serum bilirubin is oftenly made by the attending expert physician, and Bhutani's nomogram was used to decide whether to start phototherapy or obtain additional blood samples (Woodgate & Jardine, 2011).