ANN-BASED NON–INVASIVE JAUNDICE MEASUREMENT SYSTEM USING OPTICAL TECHNIQUE

NURASHLIDA BINT ALI

A thesis submitted in

fulfillment of the requirement for the award of the

Degree of Master of Electrical Engineering

Faculty of Electrical and Electronic Engineering

Universiti Tun Hussein Onn Malaysia

FEBRUARY 2023

To my beloved father and mother who have never stopped praying for me,
Ali Darji and Shaidah Rusdan

And my encouraging husband and children

Muhammad Afiq Akmal bin Kassim and children Nur Azzahra Faiha binti Muhammad Afiq Akmal and Nur Azzahra Aisyah binti Muhammad Afiq Akmal

ACKNOWLEDGMENT

Alhamdulillah. I am so grateful to Allah s.w.t for giving me strength and guidance throughout my studies. Again, thank you Allah for easing my path towards Your knowledge.

First of all, I would like to dedicate my deepest and most sincere gratitude to my supervisor PM Dr. Siti Zarina Mohd Muji for her excellent guidance, supervision, and abundant support which helped me to complete this thesis successfully.

My special thanks to Dr Ariffuddin Joret for his guidance and assistance during thesis writing. To all my fellow research members, together we gained the spirit to achieve our Master from the first day I joined Universiti Tun Hussein Onn Malaysia (UTHM). Thanks to all Project Lab technicians who contributed to the completion of this project.

Lots of gratitude for the financial support from Fundamental Research Grant Scheme (FRGS), Kementerian Pengajian Tinggi Malaysia (KPM) for granting me the scholarship.

Last but not least, I would like to give my deepest thanks to my parents, sibling and my soulmate for their support, love, and patience. Without their encouragement and motivation, it would have been impossible for me to complete this work.

ABSTRACT

Jaundice is a common condition in neonates and occurs due to an increase in the concentration of bilirubin in the body. The conventional method of detecting this condition is through an invasive procedure which extracts blood samples from the neonate's vein in order to assess the concentration value of bilirubin. However, this method might be traumatizing for neonates. The research undertaken in this work mainly focused on a non-invasive jaundice detecting system that utilized optic energy to minimize neonates' discomfort relative to the conventional method. In this system, the blue LED with electromagnetic spectrum wavelength, 470nm was used as a transmitter. The transmitter sent a spectrum of optic energy to the bilirubin, resulting in reflected optic energy which was measured using a photodiode. The measured data was then captured using an microcontroller and transferred to the computer for further classification of 'normal' or 'jaundice' status using the Artificial Neural Network. To assess the developed system, the optical energy reflection values detected in voltage units were mapped to the bilirubin concentration values. Based on that, it was decided if the condition of the neonate had been classified correctly, whether normal or jaundiced. The jaundice meter prototype developed in this study was tested among 44 patients, and the validation results showed an accuracy of 90% with JM103. This research concluded that the proposed system can be used as an alternative method of assessing bilirubin concentration among neonates.

ABSTRAK

Jaundis adalah penyakit yang biasa dihadapi oleh bayi baru lahir dan disebabkan oleh peningkatan tahap bilirubin di dalam badan. Kaedah konvensional untuk mengesan penyakit ini adalah melalui prosedur invasif yang memperoleh sampel darah dari urat bayi untuk menilai nilai tahap bilirubin yang di dalam darah bayi. Penyelidikan yang dijalankan dalam karya ini terutamanya tertumpu kepada sistem pengesan jaundis yang tidak invasif dengan menggunakan tenaga optik untuk mengurangkan ketidakselesaan neonate berbanding dengan kaedah konvensional. LED biru dengan gelombang spektrum electromagnetik 470nm digunakan sebagai alat pemancar cahaya. Pemancar ini menghantar spektrum tenaga optik kepada bilirubin dan menghasilkan pantulan tenaga optik yang diukur dengan fotodiod. Data yang diukur diambil menggunakan board pengawal mikro dan dipindahkan ke komputer untuk klasifikasi, sama ada normal atau berstatus jaundis menggunakan rangkaian saraf tiruan. Berdasarkan kepada sistem pengesanan ini, nilai refleksi tenaga optik yang dikesan oleh sistem dalam bentuk voltan telah dipetakan ke nilai tumpuan *bilirubin* dengan 100% telah di klasifikasi untuk menentukan keadaan bayi, sama ada normal atau jaundis. Prototaip meter jaundis yang dibangunkan dalam kajian ini telah diuji oleh 44 pesakit, dan hasil ujian menunjukkan kadar pengesahan dengan JM103 ialah 90%. Kajian ini menyimpulkan bahawa sistem yang dicadangkan boleh digunakan sebagai cara alternatif untuk menilai tahap *bilirubin* bayi.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

%	-	Percentage
mg/dL	-	Miligram per Decimel Liter
µm	-	Micrometer
nm	-	Nanometer
ANN	-	Artificial Neural Network
LED	-	Light Emitting Diode
RGB	-	Red Green Blue
RMSE	-	Root Mean Square Error

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Project Background

Jaundice is the one of the most common conditions among neonates [1]. It causes yellow discoloration in the skin and eyes of neonates as a result of excess bilirubin in the blood. Under normal conditions, bilirubin is excreted in the liver to become conjugated bilirubin which is a water-soluble composition of the human body. However, neonates' livers cannot excrete bilirubin successfully as their organs are still too new and weak to conform to the external and internal environments. Jaundice commonly appears within the first 24 hours after birth [2]. Jaundice that lasts for more than 14 days is diagnosed as prolonged jaundice [2]. This diagnosis is often accompanied by and confirmed via other clinical tests. Sick neonates with high concentrations of bilirubin-displacing metabolites, and premature neonates that have impaired blood-brain barriers are prone to severe hyperbilirubinemia, which in turn can cause permanent brain damage (kernicterus). Kernicterus could lead to devastating disabilities, such as hearing impairment, athetoid cerebral palsy, and speech impairment. Some neonates with kernicterus do have normal cognitive levels, however, they lack control over their bodily abilities [3].

Generally, the normal level of bilirubin in the blood is less than 1.0 mg/dL (17 μmol/L), while levels above 2-3 mg/dL (3451 μmol/L) result in jaundice [4]. Besides, the pale appearance of the skin, discharge of dark urine, and chalky stools have also been used to help identify neonates who might have jaundice [5]. In Malaysia, 60% to 70% of healthy neonates were found to have experienced jaundice, which normally occurs during the first week after birth [5].

In most hospitals, the conventional method of diagnosing jaundice and measuring bilirubin is invasive in nature [6]. The research undertaken in this work is mainly focused on a non-invasive jaundice monitoring system utilizing an optics-based method to minimize the discomfort of neonates, relative to the conventional method. This is due to the fact that a system that is non-invasive in nature, which offers painless, safe procedures and does not require the drawing of blood samples or urine samples for laboratory tests in the monitoring of a neonate patient's condition, is often desirable.

Thus far, biomedical researchers worldwide have suggested a number of methods to address the trade-offs in traditional clinical practices. A robust and non-invasive technique for jaundice detection has been the subject of extensive research in recent years. Over the years, several non-invasive methods have been developed to assess the extent of jaundice such as icterometer devices made of clear plastic. These devices provide inaccurate results and are often time consuming as extra time is required for comparative reasons [7]. For non-invasive optical imaging approaches, reflectance spectroscopy uses multiple polynomial regression, neural networks, and supports vector regression but it involves too much analysis and requires a bulk-sized system [8]. Moreover, the commonly used product on the market is quite expensive because it involves a wide range of optical spectrum.

Although research on non-invasive jaundice detection systems is relatively established [9], the system proposed in this study is capable of detecting the jaundice condition of the neonate through the use of an electromagnetic spectrum wavelength of 470nm by an optical method. Based on this method and an Arduino Uno based prototype system utilizing the artificial neural network (ANN) classification technique, the prototype system detects the optical energy spectrum reflected by the bilirubin as most of the spectrum of the optical energy transmitted is absorbed by the bilirubin. The prototype system with its photodiode sensor determines this reflection value as voltage value to be mapped to the bilirubin concentration to alert the user if the bilirubin value is above normal levels. This system of detecting the bilirubin would be less painful for the neonate. The prototype can be a suitable alternative for neonate patients in rural areas; as the prototype is portable, it avoids the need for patients to undergo invasive jaundice tests in distant hospitals.

1.2 Problem Statement

To date, most hospitals are still using the conventional method to determine bilirubin concentrations [10]. These conventional clinical methods are either through the drawing of blood samples (phlebotomy technique) or via observation of plasma clotting [10]. They have several drawbacks such as unnecessary blood loss, an increased risk of inflammation of bone (osteomyelitis), and infection at the sampling site [11-13].

The blood drawing process can be painful to the patients, especially for the neonates. In newborn neonates diagnosed with jaundice, blood samples need to be consistently drawn until their bilirubin levels return to normal. This is likely to cause anxiety to parents who have to go through the ongoing process. It must also be mentioned that there are several types of non-invasive devices available in the market with the ability to determine one's bilirubin concentration. However, none of these non-invasive devices manage to replace the above mentioned conventional methods [14-16]. These devices are not reliable and lack accuracy due to differences in the patients' skin color [17-19].

Therefore, this research takes into account the use of ANN classification technique to classify the data collected by the developed non-invasive jaundice detecting device prototype in order to increase its reliability on different patients' skin color. The basis of the methodology of ANN lies its ability to self-learn as well as find patterns and relationships within large quantities of collected bilirubin data [20]. Therefore, ANN can enable the construction of prototypes that meet the task of predicting and forecasting levels of bilirubin based on wavelength from unknown skin samples. The ANN technique can extract the required medical information from raw bilirubin data as well as assign and predict classes of the bilirubin data to its expected category, whether it normal or jaundiced. Thus, it assists in medical decision-making in combination with medical expertise.

1.3 Aim and Objectives

1.3.1 Aim

The development of a non-invasive jaundice detection system using optical sensor and ANN classification technique and aims to provide a less traumatizing ,time consuming alternative to the invasive method of bilirubin detection system used on newborns currently and improve accuracy.

1.3.2 Objectives

The objectives for this research are:

1. To develop a prototype of a non-invasive jaundice detecting system for a newborn.
2. To implement the ANN classification technique in the developed non-invasive jaundice detecting system to improve the detecting performance.
3. To validate the accuracy of developed ANN-based on the non-invasive jaundice detecting system.

1.4 Scope of Research Study

The scope of this research is as listed:

1. The prototype jaundice detecting system was developed using blue led as light source with a wavelength of 470nm.
2. The prototype was developed using an Arduino Uno board embed with ANN classification technique. Next, the ANN classification system was developed and analyzed using MATLAB ANN toolbox.

3. The clinical data collection was done by pediatric doctor, Dr Hairin Anisa Tajuddin in Johor Bahru and data was collected from the subjects' foreheads.
4. The analysis used data from 80 subjects, where 60 subjects' data were used as training data, 12 subjects' data for validation and 8 subjects' data for testing.
5. In this study, the validation of the prototype system was performed by comparing the results of the system with the results obtained from a Drager Jaundice Meter, JM103.

1.5 Significance of Research

The significance of this research is as stated below:

1. The development of a prototype jaundice detecting system which is based on optical energy and can be considered as a non-invasive jaundice system. The proposed system has been proven to be applicable to newborn babies without any harm.
2. The classification technique deployed in the prototype is based on ANN which is considered as a new approach. The proposed system can classify jaundice and non-jaundice conditions of a newborn baby based on three measurements taken.

1.6 Thesis Outline

This thesis is organized as follows. Chapter 1 discusses the use of non-invasive jaundice monitoring systems based on the optical technique. It also states the problem statement, aims, objectives and main scope of the research study.

Next, the literature review is stated in Chapter 2. Observations and research information on jaundice, bilirubin and the history of non-invasive techniques are provided to determine the flow of previous findings.

Based on the previous findings, the suitable circuit of the jaundice prototype meter was constructed with a processing algorithm. The latter deployed an ANN classification technique to increase its accuracy in detecting the test sample, as elaborated in Chapter 3.

Once the circuit was ready to be used, experiments were conducted among the research subjects and the results obtained were compared with invasive test results. The results are discussed in Chapter 4.

Lastly, in Chapter 5, all the information and data collection are analyzed. These could provide beneficial findings to the medical field. This chapter also includes some recommendations for the future research in this field.

CHAPTER 2

2.1 Overview

This chapter provides an overview of literature review related to this research. Section 2.2 and Section 2.3 discuss the human skin structure with the component underneath the skin. A review of previous works involving the non-invasive detection of bilirubin is elaborated in Section 2.4, followed by the ANN data classification in Section 2.5. In Section 2.6, the previous works on ANN jaundice detection applications are explored thoroughly.

2.2 Human Skin Properties

Human skin is an inhomogeneous structure divided into three main layers, namely, epidermis, dermis, and subcutaneous tissue [21]. Figure 2.1 shows the cross sectional image of human skin layer. The epidermis layer is the outer part and the thinner layer that covers the dermis layer. The epidermis consists of two further layers: living cells and non-living cells. It is also known as the blood free layer; therefore, it receives the nutrients from the dermis layer. The dermis is known as the blood-rich layer and lies sheltered under the epidermis. The connective tissues are present in this layer, where it consists of elastic fibers and collagen fibers. Besides, numerous sensory nerves are also present in this layer. Meanwhile, subcutaneous tissues are the thickest among these three tissues; it contains fats to absorb nutrients and provide energy. These three layers have different thicknesses depending on the individual.

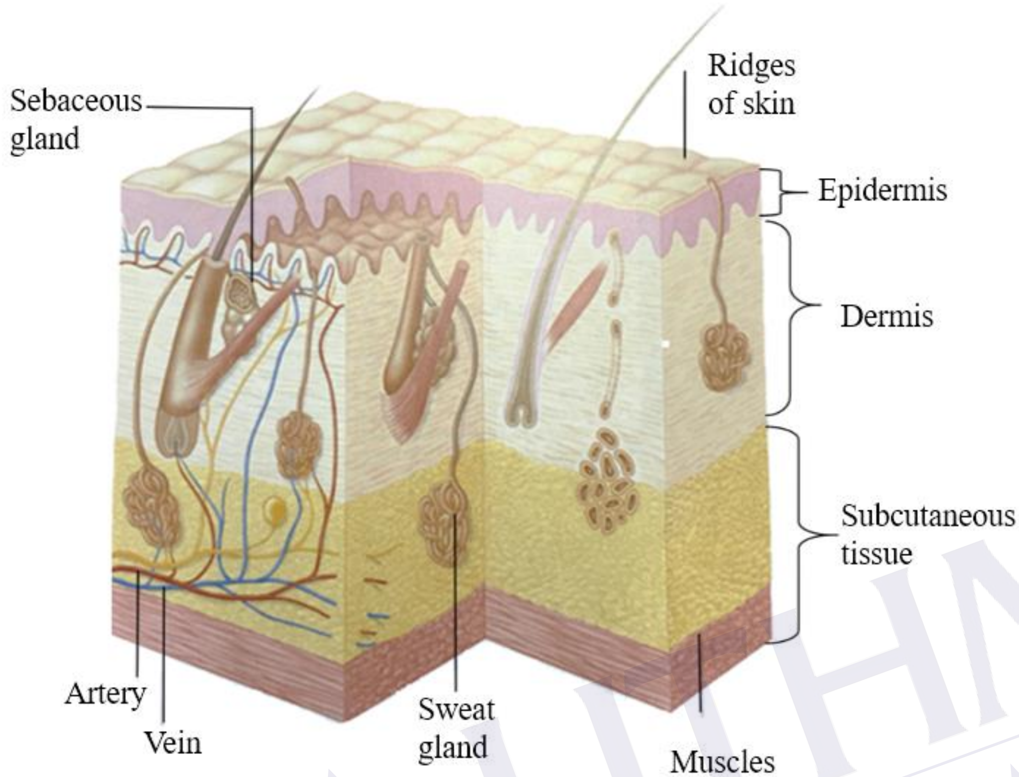

Figure 2.1: The human skin structure [21]

The knowledge of skin structure and properties is important in understanding the operating principle of optical energy reflection. The optical properties in each particular layer are different. Each layer has a different thickness and structure. The skin modeling previously used in Monte Carlo simulation was divided into seven layers as presented by Meglinski and Matcher [22]. In epidermis layer, it was divided into two layers, namely, stratum corneum and living epidermis, whereas the dermis layer was divided into four layers: papillary dermis, upper blood net dermis, reticular dermis and deep blood net dermis. The deepest layer consists of subcutaneous tissues. In studies on light penetration into the skin, these seven layers are considered. The thickness of each skin layer is presented in Table 2.1.

REFERENCES

[1] Shahroni, N. and M.M. Addi. An Automatic and Portable Phototherapy Garment (APPG) with Integrated Non-Invasive Bilirubin Detector. in TENCON 2018 - 2018 IEEE Region 10 Conference. 2018.

[2] Ong, P.E., Reflectance spectroscopy system for real time and non-invasive detection of transcutaneous bilirubin level., Universiti Tun Hussein Onn Malaysia. 2018.

[3] Bhutani, V.K. and L.H. Johnson, Newborn jaundice and kernicterus—health and societal perspectives. The Indian Journal of Pediatrics, 70(5): p. 407-416, 2003.

[4] Pereira, W.D., Jaundice A Review. International Journal of Pharmaceutical Sciences Review and Research, 44(2): p. 80-82, 2017.

[5] Sahib, S.Z., Ibu tak perlu risau. 2012.

[6] Grohmann, K., et al., Bilirubin measurement for neonates: comparison of 9 frequently used methods. Pediatrics, 117(4): p. 1174-1183, 2006.

[7] Varvarigou, A., et al., Transcutaneous bilirubin nomogram for prediction of significant neonatal hyperbilirubinemia. Pediatrics, 124(4): p. 1052-9, 2009.

[8] Fouzas, S., et al., Transcutaneous bilirubin levels for the first 120 postnatal hours in healthy neonates. Pediatrics, 125(1): p. e52-7, 2010.

[9] Sammir, M.R., et al. Design and Implementation of a Non-invasive Jaundice Detection and Total Serum Bilirubin Measurement System. in 2018 10th International Conference on Electrical and Computer Engineering (ICECE). 2018.

[10] Polley, N., et al., Development and optimization of a noncontact optical device for online monitoring of jaundice in human subjects. Journal of biomedical optics, 20(6): p. 067001, 2015.

[11] Bosschaart, N., et al., Limitations and opportunities of transcutaneous bilirubin measurements. Pediatrics, 129(4): p. 689-694, 2012.

[12] Dai, J., D.M. Parry, and J. Krahn, Transcutaneous bilirubinometry: its role in the assessment of neonatal jaundice. Clinical biochemistry, 30(1): p. 1-9, 1997.

[13] Lilien, L.D., et al., Neonatal osteomyelitis of the calcaneus: complication of heel puncture. The Journal of pediatrics, 88(3): p. 478-480, 1976.

[14] Bassari, R. and J.B. Koea, Jaundice associated pruritis: a review of pathophysiology and treatment. World Journal of Gastroenterology: WJG, 21(5): p. 1404, 2015.

[15] Chang, Y.-H., et al., The effectiveness of a noninvasive transcutaneous bilirubin meter in reducing the need for blood sampling in Taiwanese neonates. Clinical Neonatology, 13(2): p. 60-63, 2006.

[16] Kumar, D., Comparison of Non-Invasive Bilirubin Detection Techniques for Jaundice Prediction, 4, 2016.

[17] De Greef, L., et al. Bilicam: using mobile phones to monitor newborn jaundice. in Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing. 2014.

[18] Swarna, S., et al., The smart phone study: assessing the reliability and accuracy of neonatal jaundice measurement using smart phone application. International Journal of Contemporary Pediatrics, 5(2): p. 285-289, 2018.

[19] Addi, M.M., N.A.Z. Abidin, and S.A. Daud. Development of a portable phototherapy garment (PPG) for jaundice treatment. in 2016 IEEE EMBS Conference on Biomedical Engineering and Sciences (IECBES). 2016.

[20] Ferreira, D., A. Oliveira, and A. Freitas, Applying data mining techniques to improve diagnosis in neonatal jaundice. BMC medical informatics and decision making, 12(1): p. 1-6, 2012.

[21] Abrahams, P.H., How the body works. Amber Books. 2009.

[22] Meglinski, I.V. and S.J. Matcher, Quantitative assessment of skin layers absorption and skin reflectance spectra simulation in the visible and near-infrared spectral regions. Physiological measurement, 23(4): p. 741, 2002.

[23] Zhang, R., et al., Determination of human skin optical properties from spectrophotometric measurements based on optimization by genetic algorithms. Journal of biomedical optics, 10(2): p. 024030-02403011, 2005.

[24] Maeda, T., et al., Monte Carlo simulation of spectral reflectance using a multilayered skin tissue model. Optical review, 17(3): p. 223-229, 2010.

[25] Anderson, R.R. and J.A. Parrish, The optics of human skin. Journal of investigative dermatology, 77(1): p. 13-19, 1981.

[26] Hplc.chem.shu.edu. Beer-Lambert Law. 2014.

[27] Life.nthu.edu.tw. Beer-Lambert Law. 2014.

[28] Chandra, F., A. Wahyudianto, and M. Yasin, Design of vein finder with multi tuning wavelength using RGB LED. Journal of Physics: Conference Series,. 853: p. 012019, 2017.

[29] Bashkatov, A., et al., Optical properties of human skin, subcutaneous and mucous tissues in the wavelength range from 400 to 2000 nm. Journal of Physics D: Applied Physics, 38(15): p. 2543, 2005.

[30] Prahl, S., Optical absorption of hemoglobin. Oregon Medical Laser Center, http://omlc. ogi. edu/spectra/hemoglobin/index. html, 15, 1999.

[31] Stahl, W. and H. Sies, Antioxidant activity of carotenoids. Molecular Aspects of Medicine, 24(6): p. 345-351, 2003.

[32] Lister, T., P.A. Wright, and P.H. Chappell, Optical properties of human skin. Journal of biomedical optics, 17(9): p. 0909011-09090115, 2012.

[33] Zulkarnay, Z., et al. An overview on jaundice measurement and application in biomedical: The potential of non-invasive method. in Biomedical Engineering (ICoBE), 2015 2nd International Conference on. 2015.

[34] Alla, S.K., J.F. Clark, and F.R. Beyette Jr. Signal processing system to extract serum bilirubin concentration from diffuse reflectance spectrum of human skin. in Engineering in Medicine and Biology Society, 2009. EMBC 2009. Annual International Conference of the IEEE. 2009.

[35] Kudavelly, S., P. Keswarpu, and S. Balakrishnan. A simple and accurate method for estimating bilirubin from blood. in Instrumentation and Measurement Technology Conference (I2MTC), 2011 IEEE. 2011.

[36] Fog, J. and A. Bakken, Conjugated and unconjugated bilirubin determined in icteric sera by direct spectrophotometry. Scandinavian journal of clinical and laboratory investigation, 20(1): p. 88-92, 1967.

[37] Zucker, S.D., P.S. Horn, and K.E. Sherman, Serum bilirubin levels in the US population: gender effect and inverse correlation with colorectal cancer. Hepatology, 40(4): p. 827-835, 2004.
[38] Barko, H., G. Jackson, and W. Engle, Evaluation of a point-of-care direct spectrophotometric method for measurement of total serum bilirubin in term and near-term neonates. Journal of perinatology, 26(2): p. 100, 2006.
[39] Ponhong, K., et al., Successive determination of urinary bilirubin and creatinine employing simultaneous injection effective mixing flow analysis. Talanta, 133: p. 71-76, 2015.
[40] Bhutani, V.K. and L.H. Johnson, Jaundice technologies: prediction of hyperbilirubinemia in term and near-term newborns. Journal of Perinatology, 21(S1): p. S76, 2001.
[41] Bosschaart, N., et al., Limitations and opportunities of transcutaneous bilirubin measurements. Pediatrics, 129(4): p. 689-694, 2012.
[42] Danaei, N., et al., Evaluating the diagnostic value of skin bilirubin in comparison with plasma bilirubin to identify hyperbilirubinemia in healthy babies. Middle East Journal of Rehabilitation and Health, 3(1), 2016.
[43] Slusher, T.M., et al., Transcutaneous bilirubin measurements and serum total bilirubin levels in indigenous African infants. Pediatrics, 113(6): p. 1636-1641, 2004.
[44] Cremer, R., P. Perryman, and D. Richards, Influence of light on the hyperbilirubinaemia of infants. The Lancet, 271(7030): p. 1094-1097, 1958.
[45] Lucey, J., M. Ferreiro, and J. Hewitt, Prevention of hyperbilirubinemia of prematurity by phototherapy. Pediatrics, 41(6): p. 1047-1054, 1968.
[46] McDonagh, A.F. Controversies in bilirubin biochemistry and their clinical relevance. in Seminars in Fetal and Neonatal Medicine. 2010.
[47] Maisels, M.J. and A.F. McDonagh, Phototherapy for neonatal jaundice. New England Journal of Medicine, 358(9): p. 920-928, 2008.
[48] Ives, N.K., Management of neonatal jaundice. Paediatrics and Child Health, 21(6): p. 270-276, 2011.
[49] Baharuddin, H., et al., Bile pigments detection via IR sensor. 2010.
[50] Rowntree, L.G. and G.E. Brown, A tintometer for the analysis of the color of the skin. The American Journal of the Medical Sciences, 170(3): p. 341-347, 1925.
[51] Madlon-Kay, D.J., Home health nurse clinical assessment of neonatal jaundice: Comparison of 3 methods. Archives of Pediatrics & Adolescent Medicine, 155(5): p. 583-586,2001.
[52] Alla, S.K., et al. Signal processing system to quantify bilirubin in the jaundice clinical model spectra. in Engineering in Medicine and Biology Society (EMBC), 2010 Annual International Conference of the IEEE. 2010.
[53] Malaysia, H.T.A.S.M.D.D.M.o.H., Non -Invasive Handheld Bilirubinometer. 2009.
[54] Dolan, J.M., D.M. Testa, and R.A. Malkin. Design of a Bilirubin Light Intensity Tester for Developing World Hospitals. in Bioengineering Conference, 2006. Proceedings of the IEEE 32nd Annual Northeast. 2006.
[55] Kajabová, M., Determination newborn bilirubin POCT techniques. 2011.
[56] Watchko, J. and M. Maisels, Jaundice in low birthweight infants: pathobiology and outcome. Archives of Disease in Childhood-Fetal and Neonatal Edition, 88(6): p. F455-F458, 2003.

[57] Mansor, M., et al., Jaundice in newborn monitoring using color detection method. Procedia Engineering, 29: p. 1631-1635, 2012.

[58] DeWitt, D.P., R.E. Hannemann, and J.F. Wiechel, Method for determining bilirubin concentration from skin reflectance. , Google Patents, 1977.

[59] McEwen, M. and K.J. Reynolds, Noninvasive detection of bilirubin using pulsatile absorption. 2006.

[60] Kudavelly, S., P. Keswarpu, and S. Balakrishnan. A Simple and accurate method for estimating bilirubin from blood. in Instrumentation and Measurement Technology Conference (I2MTC), IEEE. 2011.

[61] Penhaker, M., V. Kasik, and B. Hrvolova, Advanced Bilirubin Measurement by a Photometric Method. Electronics and Electrical Engineering, 19(3), 2013.

[62] Polley, N., et al., Development and optimization of a noncontact optical device for online monitoring of jaundice in human subjects. Journal of biomedical optics, 20(6): p. 067001-067001, 2015.

[63] Hafizon Baharuddin. Bile Pigments Detection via IR Sensor. in 3rd Engineering Conference on Advancement in Mechanical and Manufacturing for Sustainable Environment. 2010. Kuching, Sarawak, Malaysia: Proceedings of EnCon, 2010.

[64] Mansor, M.N., et al. Jaundice in Newborn Monitoring using Color Detection Method. in Procedia Engineering. 2012.

[65] Youssef, P.N., N. Sheibani, and D.M. Albert, Retinal light toxicity. Eye (London, England), 25(1): p. 1-14, 2011.

[66] Hannemann, R.E., D.P. Dewitt, and J.F. Wiechel, Neonatal Serum Bilirubin from Skin Reflectance. Pediatric Research, 12(3): p. 207-210, 1978.

[67] Mahmoud, B.H., et al., Effects of Visible Light on the Skin†. Photochemistry and Photobiology, 84(2): p. 450-462, 2008.

[68] Veenstra, C., et al., Spatially confined quantification of bilirubin concentrations by spectroscopic visible-light optical coherence tomography. Biomedical Optics Express, 9(8): p. 3581-3589, 2018.

[69] Muji, S.Z.M., et al., Optical Tomography: Transmitter And Receiver Circuit Preparation. Jurnal Teknologi, 54(1): p. 13–22, 2012.

[70] Kulkarni, U.G., Arduino: A Begineer's Guide. 2017: Udayakumar.G.Kulkarni.

[71] Badamasi, Y.A. The working principle of an Arduino. in 2014 11th International Conference on Electronics, Computer and Computation (ICECCO). 2014.

[72] Sumardi, H. and D. Irawan, Coalbed Methane Production Parameter Prediction and Uncertainty Analysis of Coalbed Methane Reservoir with Artificial Neural Networks. 2016.

[73] Thanasarn, T. and C. Warisarn, Comparative Analysis between BP and LVQ Neural Networks for the Classification of Fly Height Failure Patterns in HDD Manufacturing Process. 2013.

[74] Méndez, A., et al., Integrating Matlab Neural Networks Toolbox functionality in a fully reusable software component library. Neural Computing and Applications, 16(4-5): p. 471-479, 2007.

[75] Thamaraiselvi, V.G. and V.K. Kaliappan. Infants Disease Prediction Architecture Using Artificial Neural Networks and Digital Image Processing. in 2014 World Congress on Computing and Communication Technologies. 2014.

[76] Filimon, D. and A. Albu. Skin diseases diagnosis using artificial neural networks. in 2014 IEEE 9th IEEE International Symposium on Applied Computational Intelligence and Informatics (SACI). 2014.
[77] Kim, T., et al., The Use of Large-Scale Climate Indices in Monthly Reservoir Inflow Forecasting and Its Application on Time Series and Artificial Intelligence Models. Water, 11: p. 374, 2019.
[78] Abiodun, O., et al., Comprehensive Review of Artificial Neural Network Applications to Pattern Recognition. IEEE Access, PP: p. 1-1, 2019.
[79] Life, D.T.f., Understanding Newborn Jaundice. 2015.
[80] El-Beshbishi, S.N., et al., Hyperbilirubinemia and transcutaneous bilirubinometry. Clinical chemistry, 55(7): p. 1280-1287, 2009.
[81] Avci, P., et al., Low-Level Laser (Light) Therapy (LLLT) in skin: stimulating, healing, restoring. Seminars in cutaneous medicine and surgery, 32: p. 41-52, 2013.
[82] Moreira, M., R. Prado, and A. Campos, Application of High Brightness LEDs in the Human Tissue and Its Therapeutic Response. 2011.
[83] Jeon, J., et al., The forehead is a better site than the sternum to check transcutaneous bilirubin during phototherapy in sick infants. BMC Pediatrics, 20(1): p. 548, 2020.
[84] Suresh, A. What is a confusion matrix? 2020 [cited 2022 22/02/2022].
[85] Malaysia, M.o.H., Integrated plan for detection & management of neonatal jaundice, F.H. Development, Editor. 2017.

APPENDIX G

LIST OF PUBLICATIOAN AND AWARD

1. Nurashlida Ali, Siti Zarina Mohd Muji and Zurina Zainal Abidin, “ A Review of Non-Invasive Jaundice Detection Using Optical Technique in Neonates” , *International Journal of Advancements in Electronics and Electrical Engineering (IJAEEE)*, 2014 , 3(4) , pp 26-28 .

2. N.Ali, S.Z.M.Muji, A Joret, R. Amirulah, N.Podari and N.F.Dol Risep , “Optical Technique for Jaundice Detection”, *ARPN Journal of Engineering and Applied Sciences*, 2015 , 10(20) , pp 9929-9933.

3. Siti Zarina Mohd Muji, Mohd Fauzi Zakaria and Nurashlida Ali, Book Chapter for Arduino and Proteous, *Electrical & Electronic Engineering : Theory and Application Series 1: Embedded System, Mechatronic and Image Processing*, 2015, Penerbit UTHM

4. Nurashlida Ali and Siti Zarina Mohd Muji, Non-Invasive Jaundice Monitoring System Using Optical Technique ,*National Innovation and Invention Competition Through Exihibition (iCompex ’15*) , Jitra , Politeknik Sultan Abdul Halim Mu’adzam Shah(POLIMAS),(Gold).

5. Siti Zarina Mohd Muji, Nurashlida Ali, Nurul Afiqah Izahar, Noran Azizan Cholan, Mohd Helmy Abdul Wahab, Azmi Sidek and Suhaila Sari, Non-Invasive Jaundice Meter, *Innovative Research, Invention & Application EXPO 2017 (I-RIA 2017)* , Sintok, Universiti Utara Malaysia (UUM), (Bronze).

6. P.M Dr Siti Zarina Mohd Muji, Prof. Dr Ruzairi Abdul Rahim, Dr Marlia Morsin, Dr Hairin Anisa Tajuddin, Dr Farhanani Mahmud, Dr Nor Shahida Mohd Shah, Azmi Sidek,Mohd Helmy Abdul Wahab,Nurashlida Ali, NN Jaundice Meter, *The International Conference and Exhibition on Inventions by Insitutions of Higher Learning 2017(PECIPTA '17)*, Kuala Terengganu, Stadium Tertutup Kompleks Sukan Negeri Gong Badak Kuala Nerus,(Gold).

7. P.M Dr Siti Zarina Mohd Muji, Nurashlida Ali, Hairin Anisa Tajuddin, Mohd Helmy Abdul Wahab, Ariffuddin Joret, Marlia Morsin, Azmi Sidek, Nor Shahida Mohd Shah, Nur Anida Jumadi, Ruzairi Abdul Rahim, Abdul Rahman Bahasa, Jaundice Optical Device, *International Conferences and Exposition on Inventions by Institutions of Higher Learning 2019 (PECIPTA '19)*, Batu Pahat, Universiti Tun Hussein Onn Malaysia (UTHM),(Silver).

APPENDIX H

VITA

The author was born in April 23, 1989, in Batu Pahat, Johor, Malaysia. She went to Sekolah Menengah Kebangsaan Canossion Convent, Kluang, Johor, Malaysia for her secondary school. She pursued her degree at the Universiti Kuala Lumpur British Malaysian Institute (BMI), and graduated with the B.Eng. Technology (Hons) in Medical Electronrics in 2013. Upon graduation, she worked in the procurement department at Kluang, Johor. She continued her studies in Masters of Electric and Electronic at Universiti Tun Hussein Onn Malaysia (UTHM). This is her thesis as supported by PM Dr Siti Zarina Mohd Muji and Dr Ariffuddin Joret as lecturers who have never given up on her. Thank you for all doa' for her to finish her thesis.