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AN IMPROVED LIGHT-SOURCE FOR A NEONATE HELIOTHERAPY DEVICE

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Abstract: This research focuses on the improvement of a neonate heliotherapy device light source by replacing the conventional fluorescent light with Blue Light Emitting Diodes (BLED). The improved light source achieved low power consumption. Also a microcontroller, ATMEGA 328P was used to regulate the radiation dose in the device making it safe for the treatment of jaundice for newborn babies. The novelty of this work is in the use of a monochromatic light source which offers a wide range of advantages over the fluorescent light-source technology. A Junction Field Effect Transistor was implemented to achieve a high transconductance in this device because of its ability to deliver amplified current with the application of low voltage. The improved heliotherapy device was able to reduce the bilirubin level of a baby with Hyperbilirubinemia from 20 mg per deciliter to 5 mg per deciliter in 48 h.

Keywords: ATMEGA 328P microcontroller, bilirubin, heliotherapy, hyperbilirubinemia, jaundice, LEDs

Introduction

Over the years, some specific light-sources had been used in the heliotherapy equipment. Heliotherapy is the exposure to light in order to remedy medical complications. The use of heliotherapy in this work is to reduce the bilirubin level in neonates. The limitation was due to the available technology as at that period. The light-sources used presently include the fluorescent bulbs, halogen quartz lamps and fiber-optic mattresses.

However, this work seeks to implement Blue Light Emitting Diodes as the light source for the phototherapy equipment. This will achieve the following: reduce heat dissipation, enhance light transmittance, reduce electrical power consumption and provide proper control for the radiation making the device to be very safe for the treatment of neonate jaundice (Oduah, and Yang, 2015).

Neonatal Jaundice (or Hyperbilirubinemia)

Neonatal Jaundice which could also be regarded as Hyperbilirubinemia is a medical condition in newborns in which much bilirubin is present in the body (Dobbs and Cremer, 1975). 65% of newborn babies in Nigeria have jaundice meanwhile only 20% of the infested babies have access to phototherapy equipment. The unavailability of the phototherapy device in the hospitals is due to high cost of the equipment. Consequently, jaundice is a major cause of natal death in Nigeria. Theoretically, when red blood cells are broken-down, a substance called bilirubin is formed. Babies are not likely to get rid of the bilirubin easily and it can build-up in the blood and other tissues and fluids of the baby's body. A yellowing of the baby's skin, eyes and other tissues makes it obvious that the infant is infected with Jaundice. This is because of the pigment or colouring of bilirubin. Depending on the cause of hyperbilirubinemia, it could manifest at birth or anytime afterwards.

Based on these facts, ways were devised to remedy the medical condition. These include the use of heliotherapy. However, based on the level of technology as at that time, direct interference with sunlight was the solution to jaundice if not too severe. Various light sources were used as a source in the heliotherapy equipment. Thereafter, technology improved and the use of sources such as white light from fluorescent tubes was used. The system was so complex and expensive. This makes its availability limited.

The chief rationale of treating newborn jaundice is the prevention of kernicterus, a devastating and often fatal outcome attributed to bilirubin's effects on the basal ganglia. Infants so affected commonly develop a characteristic choreoathetoid form of cerebral palsy accompanied by severe intellectual disability (Kalz *et al.*, 1978).

In the late 1950s, heliotherapy emerged as another potential treatment of jaundice. In 1956 at Rochford General Hospital in Essex, England, Sister J. Ward noted that sunshine decreased neonatal jaundice. Meanwhile, hospital biochemists noted erroneously low bilirubin levels in samples sitting in sunlight before processing (Leung *et al*, 1992). Soon afterward came the first evidence for light as an effective therapy for infantile Hyperbilirubinemia. A decade later the landmark randomized controlled trial showing the efficacy of heliotherapy was published by Pediatrics editor (Lucey, 1973).

Heliotherapy or Phototherapy

Heliotherapy as the name implies is any medical therapy by exposure to light. It is the use of light to treat disorders of the skin and certain mood disorders also. In this work, we are concerned majorly on using heliotherapy for newborns having Jaundice (hyperbilirubinemia) (Stokowski, 2006).

Heliotherapy was developed in the late 1950s and is today considered the mainstay of managing neonatal jaundice. Yet prominent academic leaders continued to promote the older approach of exchange transfusion well into the 1970s, despite the considerable risks involved (Moerschel *et al.*, 2008).

There are two major ways to remedy Jaundice which are Exchange transfusion and Heliotherapy. Exchange transfusion is the replacement of the baby's deficient blood with a donors' blood to increase the red blood cell count. This method is used when a baby's bilirubin level is higher than 20 mg/dL at extreme conditions termed Kernicterus. This means, Exchange transfusion is only employed upon critical cases. In a situation where there is unbound bilirubin from the albumin which increases the chances of it penetrating the brain blood barrier to gain entrance into the brain, then exchange transfusion is applied. Phototherapy could take different forms such as Phototherapy lamp and Fibreoptic blanket(Ennever, 1986). Fibreoptic blanket is placed underneath the newborn. It could be used alone or alongside the Phototherapy lamp. Phototherapy Lamp would have an improved performance as well as being cost effective when its source of energy is Light Emitting Diodes (LEDs). There are other light sources used in the past which include incandescent bulbs, fluorescent tube, mercury light etc. (Ennever, 1990).

Conventional phototherapy provides light in the 425-475 nm wavelength band corresponding to the peak absorption of light by bilirubin. The usual light intensity is 6-12 $\mu W/cm^2$ per nm. There have been many modifications of the traditional phototherapy over the last 3 decades - the number and configurations of phototherapy bulbs, the source of light (fluorescent vs. halogen bulb) and the colour of bulbs (white, blue, or green). All, however, have involved the delivery of light from a source at a distance from the baby, usually 35-50 cm above the baby. The number of the bulbs used range from six to eight, comprised of blue (F20T12/B), special blue light (F20T12/BB) or Daylight fluorescent tubes (Ohmeda, 2001). Special blue light has the disadvantage of making the infant look blue, although in healthy newborns this is generally not a concern. To mitigate this effect, four special blue light tubes may be used in the central portion of a standard phototherapy unit and two daylight fluorescent tubes may be used on either side of the unit. Other units use tungsten-halogen lamps in different configurations (Speck and Rosenkranz, 1979).

Fibre Optic Phototherapy (FOPT) uses a fibreoptic cable, containing about 2000 – 2400 individual acrylic fibres was first used in 1989, to deliver light from a tungsten halogen lamp to a light pad where the fibres are woven together. The pad, which remains cool, is inserted into a disposable paper jacket to avoid soiling of the pad and allowing it to be held securely to the infant's back. The baby can be dressed and wrapped normally thus enhancing his postural and autonomic stability, and can be nursed by the mother without interruption of phototherapy during breast-feeding. It is unnecessary to cover the eyes of babies nursed with the FOPT. The light delivered is in the 400-500 nm broad wavelength band and is of high intensity (35 $\mu W/cm^2$ per nm ± 20% on the higher setting), compared to up to 16 (usually 6-12) $\mu W/cm^2$ per nm in the 380-480 nm range for conventional phototherapy, but the area of exposure is smaller. Much of the spectral emission of the FOPT device is in the green region that is less effective than blue light. Because the fibre optic material used in the FOPT system is relatively small, the area of exposure is smaller as compared to the conventional setup (Polin, 1990). With increasing body weight, the fraction of body surface exposed to fibre optic light will become less. The first generation FOPT unit was the 'Wallaby' system, but studies on its effectiveness were disappointing. The Bili-blanket Ohmeda, Columbia, M D, USA, is a more sophisticated system containing a greater number of fibres with more points of light and a greater intensity of 35 $\mu W/cm^2/nm$.

Intensified Phototherapy (IP) is a system that provides an increased irradiance of 26 - 40 $\mu W/cm^2/nm$, as compared to the irradiance of 7-16 $\mu W/cm^2/nm$ in conventional phototherapy. There are three (3) methods available for providing IP namely (i).Using seven daylight fluorescent tubes placed close under the floor of the crib with the sides and top of the crib covered with a reflecting film. (ii). Using high intensity blue lights with seven overhead lamps and four lamps placed below the infant. (iii) High intensity double surface phototherapy on a fluid bed - this gave an irradiance of 26 to 30 µW/cm2/nm using a standard phototherapy unit close to the floor of the bassinet and conventional phototherapy given from above. The fluid bed acts as a thermal reservoir smoothing out temperature fluctuations (Cabana, 1998).

At present, Phototherapy device uses majorly white fluorescent as light source because of the low cost. The special blue fluorescent light is found to cause nausea and dizziness among the nursery staff. In the United States of America, Light Emitting Diode lights are used (Kumar *et al*, 2011). This work is to look into making available a prototype of what existed but at a reasonable cost using Blue LEDs and a controllable intensity in order to achieve an appropriate irradiance dose (Vreman *et al.*, 2004).

Materials and Methods

The entire process for the development of the improved neonate heliotherapy lamp is presented on the block diagram in Fig. 1.

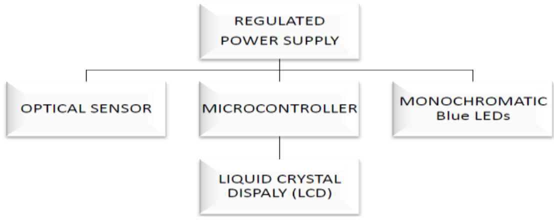

Fig.1: Block diagram of an improved neonate phototherapy device

Based on the block diagram in Fig. 1, the device is interfaced with the AC mains and stepped-down with the aid of a transformer which outputs 15 volts and rectifies it accordingly. The rectified voltage serves as an input to the optical sensor which senses the light and communicates with the microcontroller. The microcontroller converts the analog voltage signal from the optical sensor to digital signal. This feedback signal regulates the intensity of the light of the LEDs and sends the message to the display unit. The Liquid Crystal Display (LCD) displays the welcome note as well as the intensity of the LEDs.

Power supply: The power source comprises of the components and the electrical power flow in this device. It uses AC source which is interfaced with a 220 V/15 V step-down transformer. An adjustable DC voltage regulator (LM317T) is used for the rectification of the voltage. The voltage going into the optical sensor is adjusted and controlled by the above component. The voltage regulator IC responsible for regulating the voltage going into the Microcontroller is a fixed linear voltage regulator also known as 7805. It is a positive voltage regulator that is designed to produce a positive voltage relative to a common ground. It produces 5 V to power the Microcontroller.

Optical sensor: This is the unit where the sensing of the light occurs. The use of Light Dependent Resistor (LDR) or Photoresistor or photocell was employed. It is a light controlled variable resistor. Its resistance changes with the light intensity that falls on it.

Microcontroller and display: The microcontroller is the brain of the entire system. It controls all the functions of the entire circuit using the program stored in its memory. The Microcontroller used in this research is the ATMEGA328P 8-bit AVR microcontroller. The Microcontroller receives the analog data from the LDR and outputs it on the display in digital form. The value displayed is the intensity of the incident light on the LDR. This Microcontroller uses a voltage of 5 volts for its powering. The Microcontroller helps to control the brightness of the LEDs connected to the circuit with the help of three buttons. The buttons consist of the increase brightness control, the decrease brightness control, and the reset brightness control respectively. When the buttons are activated, the Microcontroller interprets the action and initiates the program immediately.

Lighting (Illuminating) process: The Blue LED's are coupled to the Microcontroller in the circuit. The wavelength of blue light ranges from 450 nm to 550 nm which is effective for the configuration of unconjugated bilirubin in the body serum. Also, it requires less power and voltage for its operation. The IRF3205 Field Effect Transistor was used to control the supply of current to the LEDs. The FET has the ability to use low voltage to drive high current to the Blue LEDs. The voltage supplied to the FET is controlled by the Pulse Width Modulation (PWM) achieved through the Microcontroller.

The components used for the development of this heliotherapy device are:

- ATMEGA 328P Microcontroller (8-bit)
- NIST calibrated Light Dependent Resistor
- Liquid Crystal Display (LCD)
- IRF3025 Field-Effect Transistor (FET)
- 7805 Voltage Regulator
- LM317T Adjustable DC Voltage Regulator
- Step-down Transformer
- Blue Monochromatic LEDs
- Capacitors
- Resistors
- Connecting wires and jumper wires

These components and their package are given in Table 1.

Table 1: List of electronic materials used and their package

Category	Quantity	References	Value	Stock Code
Capacitors	2	C1-C2	22pF	
Capacitors	1	C3	100nF	
Capacitors	1	C4	10nF	
Capacitors	1	C5	10uF	
Capacitors	1	C6	1000u	MaplinDT69A
Capacitors	1	C7	10n	Maplin YR75S
Resistors	3	R1,R10,R15	10k	M10K
Resistors	1	R2	330R	M330R
Resistors	1	R7	1k	M330R
Resistors	1	R8	100R	M100R
Resistors	1	R9	270R	M270R
Integrated Circuits	1	U1	ATMEGA328P	
Integrated Circuits	1	U2	7805	
Integrated Circuits	1	U3	LM317T	
Transistors	1	Q2	IRF3205	
Diodes	2	D1,D10	LED	
Diodes	5	D2,D4-D6,D8	1N4007	
Miscellaneous	4	6V BAT,LED,RESET,VIN	TBLOCK-I2	
Miscellaneous	6	AC,BUT,C+,C--S1,SWITCH	CONN-SIL2	
Miscellaneous	1	LCD	CONN-SIL12	
Miscellaneous	2	RV1-RV2	POT	
Miscellaneous	1	RV3	1k	
Miscellaneous	1	UART	CONN-SIL5	
Miscellaneous	1	X1	CRYSTAL	

The circuit was designed using a Computer Aided Design (CAD) tool known as Proteus. The software was used to generate the schematics, the Printed Circuit Board (PCB) view and the three-dimension view. The mirrored PCB view was printed on a glossy paper using a laser-jet printer. This was transferred to a single-faced copper sheet through heat transfer. After the transfer, the drill machine was used to bore the holes and the components are mounted on the copper sheet. Soldering was finally done to fasten the components to the board.

Figs. 2 and 3 show the schematics of the circuit design as well as the three-dimensional view. After the mounting of the components, the microcontroller was then programmed to control the light intensity using the Arduino programming.

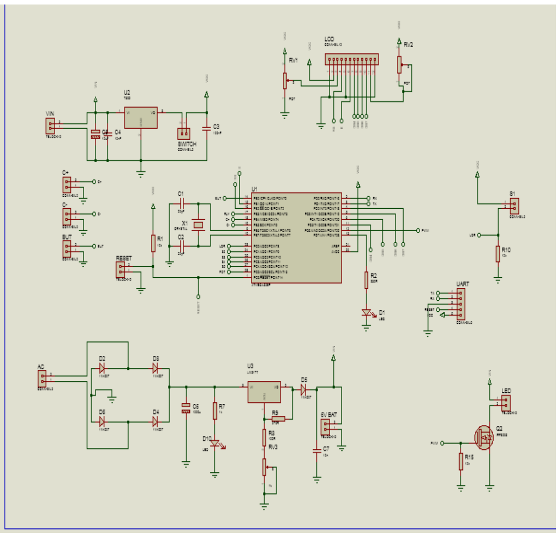

Fig. 2: Schematics of the circuit design

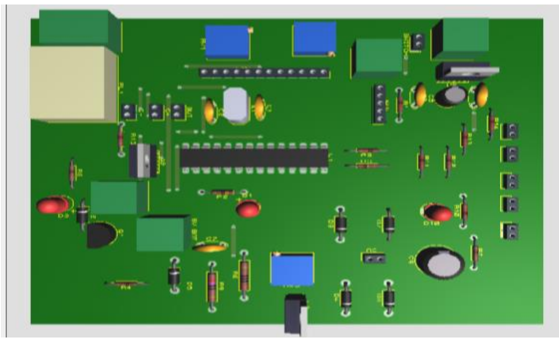

Fig. 3: The 3-D design showing after soldering

The packaged prototype neonate heliotherapy device is shown in Fig. 4.

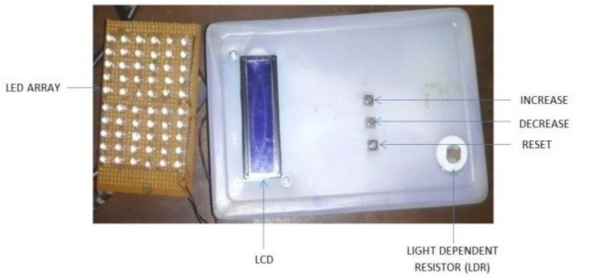

Fig. 4: The final package with the designation of each part and button

Results and Discussion

The developed heliotherapy device was taken to Lagos University Teaching Hospital Idiaraba, Lagos, in the Neonatal Unit so as to compare the intensity with that of the standard NeoBlue Heliotherapy device. The results obtained taking the measurements at five different points and at different distances below the lamp and the average was recorded which are illustrated in Table 2.

Table 2: Measurements of light intensity varying the vertical and horizontal distances

Distance (cm)	Light Intensity (lux)					
	OA	OB	OC	OD	Centre	Average
70.0	1 424.6	1 399.4	1 351.3	1 485.7	1 626.3	1457.5
65.0	1 623.3	1 604.8	1 591.0	1 635.3	1 859.6	1662.8
60.0	1 754.1	1 732.7	1 700.6	1 784.2	1 974.9	1789.3
55.0	1 901.0	1 898.1	1 838.8	1 966.5	2 005.4	1921.9
50.0	1 998.8	1 979.5	1 915.2	2 000.9	2 163.6	2011.6
45.0	2 099.3	2 005.6	1 997.3	2 110.8	2 332.1	2109.0
40.0	2 275.1	2 189.9	2 103.7	2 360.7	2 552.3	2296.3
35.0	2 682.6	2 644.0	2 575.0	2 713.4	2 784.2	2679.8
30.0	2 810.3	2 764.3	2 697.6	2 899.1	2 954.3	2825.1
25.0	2 900.4	2 855.2	2 829.1	2 978.6	3 030.1	2918.7

The graph of the intensity against the distance was plotted. The results are presented in Figs. 5, and 6. The graph shows an enhancement on the intensity of the radiation against distance covered. This explains the effectiveness of the radiation in the conjugation of bilirubin.

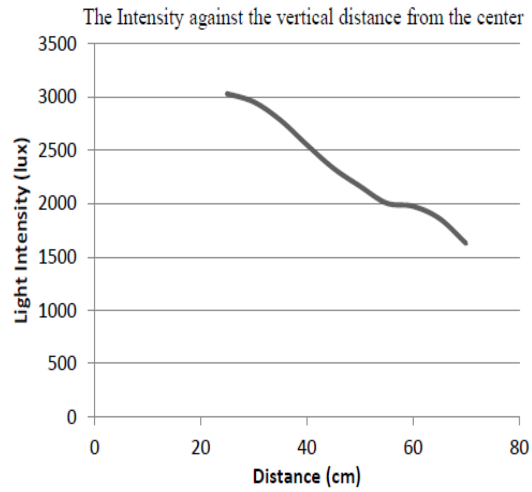

Fig. 5: Graph of Light Intensity (lux) against Vertical distance (cm) from the center

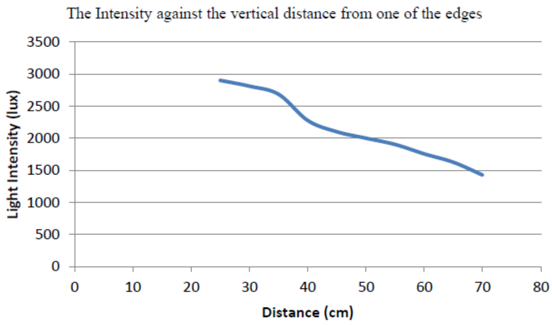

Fig. 6: Graph of light intensity (lux) against vertical distance (cm) from edge OA

The testing of the prototype neonate heliotherapy device is demonstrated in Fig. 7.

The effectiveness of a Heliotherapy device is dependent on

the amount of irradiance i.e. intensity and wavelength of the light incident on the baby being treated. Generally, the farther the lamp, the greater the surface area that would be covered but the lesser the irradiance.

It was observed that the graph of the improved device is similar to the standard Neo-heliotherapy device used to benchmark the developed device. This shows a correlation between the devices. The major difference is that the light-source was improved as well as the irradiance control. The developed heliotherapy device was used for the treatment of a baby with a confirmed case of hyperbilirubinemia. The improved heliotherapy device was able to reduce the bilirubin level of the baby with Hyperbilirubinemia from 20 mg per deciliter to 5 mg per deciliter in 48 hours.

Conclusion

The improved light-source of the neonate Heliotherapy device was effective in the treatment of neonate jaundice. The application of Blue LED's also reduced the cost of the device and extended the lifespan of the light source. Also, the ability to control the irradiance of the device gave the device a better advantage over the conventional device.

Acknowledgement

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Conflict of Interest

Researchers hereby declare that there is no conflict of interest whatsoever in this research.

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