Design and Low Cost Construction of Neonatal Bilirubin Phototherapy Equipment

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Abstract

The objective of this project was to design and construct low cost neonatal bilirubin phototherapy equipment. This project has adopted the principle of changing the chemical structure of bilirubin by using the blue light and the principle of light and electronics. The design and construction of the project consisted of 4 main parts: 1) The power supply consisted of switching power supply 12 volts and 5 volts, 2) The light source consisted of 460 nanometer wavelength of blue light emitting diode, 660 nanometer wavelength of red light emitting diode, LED driver circuit and pulse width modulation circuit, 3) The control and display part consisted of microcontroller PIC18F252 and 7-segment display to show the spectral irradiance and therapy time and 4) The light intensity measurement part comprising of a light dependent resistor (LDR). The result of functional testing compared with Phototherapy Radiometer FLUKE DALE 40 found that the average percentage error of light intensity at the mattress and pad was 3.85% which does not have any effect on the neonatal jaundice. The project could set for 0-24 hours. All the materials could be found in the country and cheap.

Keywords: *neonatal jaundice, neonatal bilirubin phototherapy equipment*

1. Introduction

Neonatal jaundice is a common problem in newborn (Ullah, Rahman, & Hedayati 2016). The yellow colors of skin and the sclera (whites of the eyes) of an infant are due to the collection of bilirubin in the skin and mucous membranes (Ayyappan et al., 2015). In the first week after birth, almost all babies have a higher bilirubin level than normal and more than two-thirds of newborns have jaundice that is called physiologic jaundice, which is visible to the eyes. Physiologic jaundice is the most abundant type of newborn hyperbilirubinemia. It is found normal babies without causing harm. But some jaundice babies are abnormal from several causes, are called pathologic jaundice, which can cause permanent brain abnormalities (Ultah et al., 2016). Diagnosing the two conditions is used to separate and select the appropriate treatment.

The blue light is used for reducing the concentration of bilirubin in the body of infants or the treatment of hyperbilirubinemia in the newborn which is called Phototherapy, was first described by Cremer, Perryman and Richards (1958). This treatment generally reduces bilirubin levels in serum by converting bilirubin into dissolved isomers that can be eliminated without passing conjugation in the liver (Ennever, McDonagh, & Speck, 1983). The dose of phototherapy is very important to determine how quickly it works; the dose is determined by the wavelength of the light, the intensity of the light (irradiance), the distance of the light source to the infant and the body surface area exposed to the light respectively. The phototherapy equipment uses the 410 - 490 nm wavelength of blue light and the intensity of light 4 - 34 $\mu W/cm^2/nm$ is suitable (Lamola & Russo, 2014).

In commercially available intensive phototherapy systems, they commonly used daylight fluorescent, special blue bulb, halogen, LED and fiber optics (Sugar, Fishman, Kobernick, & Goodman, 1970). By comparison with five bulbs found that the efficiency of reducing the bilirubin level daylight fluorescent is less than the special blue bulb. The disadvantage of the special blue bulb is the blue light that can cause numbness in the eyes, nausea for the operation. Halogen lamps are as effective as daylight fluorescent but the light shines with narrow space, high heat that causes harm to baby easily and breaks easily. Currently fiber optic blanket is used for reducing the concentration of bilirubin but fiber optics blanket is expensive.

Light Emitting Diode (LED) is a light source which passes through by an electric current. When LED is connected in forward bias, LED will emit the visible light. The light from LED is monochromatic which occurs at a single wavelength. The output from a LED can range from blue which has a wavelength of approximately 410-490 nm. The big problem from the source of the LED which contacts directly with skin is the heat conduction of the junction of LED semiconductor, which may cause serious skin burns. The adjusted amplitude modulating and the adjusted time multiplexing of LED can keep the LED within a safe temperature range. LED is also durable, low power consumption for the high brightness. The light of the tube is directed straight, no light distribution, long life and the light used does not cause skin damage. Therefore, LED lamps have a role in medicine due to a smaller size, they can be combined in any shape to produce highly efficiency brightness, greater lifetime, spectral stability and reduced power requirements. A low-voltage power supply is sufficient for LED brightness. The high intensity of light from light-emitting diodes (LEDs) is used as possible light sources for the phototherapy of hyperbilirubinemia neonates. The low power of the light source has the potential to transmit high-intensity waves of narrow wavelengths in the blue of the visible light spectrum, which overlap with the absorption spectrum of bilirubin (Chang et al., 2005). LED light source are as effective as fluorescent tubes for phototherapy of preterm infants with indirect hyperbilirubinemia but LED light source has less frequent side effects, less energy consumption, long life, and lower costs and LED phototherapy seems to be a better option than fluorescent tubes phototherapy (Mohammadizadeh, Eliadarani, & Badiei, 2012).

2. Objectives

The objectives of the study aim to design and construct low cost neonatal bilirubin phototherapy equipment which is low cost but can still be used correctly and accurately. The equipment is cheap and material can be found inside the country. The light source of the equipment comes from LED light which has intensity light adjusting by using the microcontroller to control. There is a time control system and also the structure of the equipment is created to adjust the height in order to use conveniently with other medical devices and moving as well.

3. Materials and methods

The principle of low cost of neonatal bilirubin phototherapy equipment was to use the principle of changing the chemical structure of bilirubin by using blue light and the principle of electronics. There were 4 different components in this equipment. The first part was the electric power. The second part was the light source. The third part was the control and display part. The fourth part was the measuring the intensity of the light by using LDR. The diagram illustrating low cost of neonatal bilirubin phototherapy equipment was shown in Figure 1.

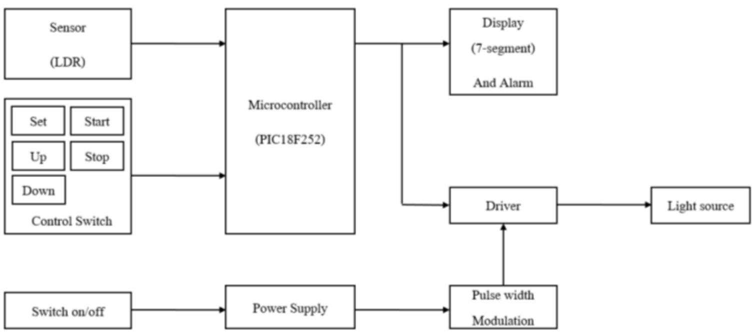

Figure 1 Diagram illustrating low cost of neonatal bilirubin phototherapy equipment

3.1 Design and construction of DC power supply circuit

The design and construction of power supply circuit part used two batteries to generate power to the light source and control circuit. The first battery used 12-volt of switching power supply to generate the voltage to drive Pulse Width Modulation Circuit and LED Driver circuit. The second battery used 5-volt of DC power supply to apply to microcontroller to control circuit.

3.2 Design and construction of the light source part

The design and construction of the light source which consisted of LED panel, LED circuit, intensity light controlled circuit and LED driver circuit.

LED panel would be designed by giving the dimension of 92 inches square of octagon in order to allow the brightness to cover the whole infant body by using the blue LED which had the wavelength of 460 nanometer in order to reduce the concentration of bilirubin, and red LED which had the wavelength of 660 nanometer in order to reduce the dizzy head of the user, to be the light source. The dimension of the light source was the width 28 centimeters, the length 38 centimeters and the thickness was 0.2 centimeters as shown in Figure 2.

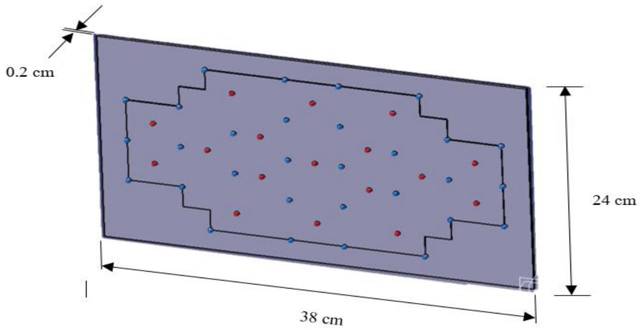

Figure 2 Dimension of LED panel

In LED circuit, the resistor was necessary to limit current to prevent damaging the LEDs in the circuit. The resistance of the LED series circuit could calculate by using equation (1)

$$R = \frac{V_S - V_F}{I_F} \quad (1)$$

where R was resistance, V_S was the voltage of power supply, V_F was the forward voltage in volts which dropped across the LED and I_F was the forward current in amperes of LED.

From the description of the red LED light, it showed that there would be a forward voltage of 1.8 Volts and a forward current of 20 mA but actually used 15 mA which was 75% of maximum current. Then the resistance which was connected in series with 6 bulbs in circuit, was shown in equation (2)

$$R = \frac{12V - 6(1.8V)}{15mA} = 80\ \Omega \quad (2)$$

Consequently, it was suitable to use the resistance 100 **Ω** 1/8 W in LED circuit to connect in series with the red LED light, which was 6 bulbs per series, total of 3 sets and there was 18 bulbs and the blue LED light, which was 4 bulbs per series, total of 10 sets and there was 40 bulbs in total. Then each set was connected by parallel circuit as shown in Figure 3.

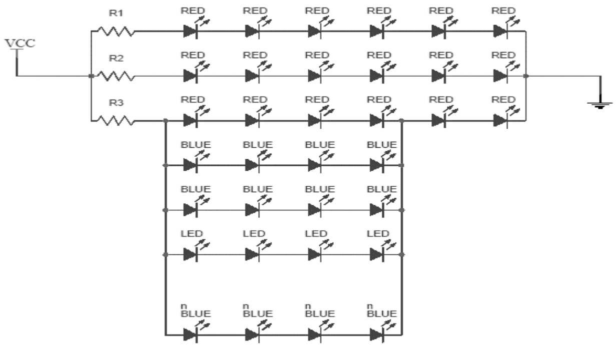

Figure 3 LED circuit

The intensity light control circuit was used for controlling the suitable brightness for treatment. The block diagram of intensity light control circuit was shown as Figure 4.

Figure 4 Block diagram of intensity light control circuit

The intensity of light controller circuit was used LM 324 to generate Pulse Width Modulation (PWM) to control the brightness of light source which was suitable for treatment.

LED driver circuit used to drive the current in 58 LEDs. From the calculation, the total current was used 0.48 A in 58 LED bulbs and the total current in LED driver circuit required 1A in practice. In circuit design, the LEDs used 12 volts and the microcontroller used 5 volts, then the circuit used IC optocoupler to separate current in the LEDs and the microcontroller due to prevent damaging with the microcontroller. The LED driver circuit of the research was designed as shown in Figure 5.

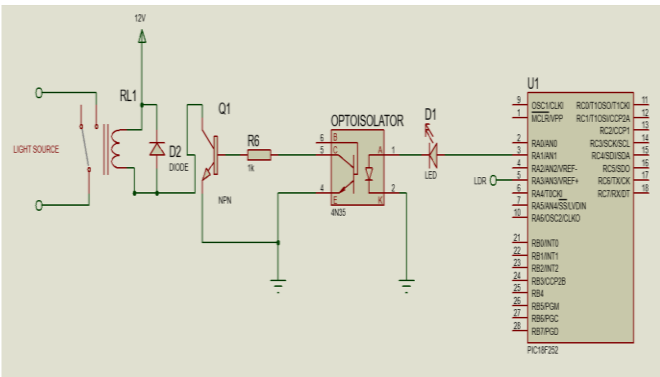

Figure 5 LED Driver Circuit

3.3 Design and construction of light intensity adjustment system and timer system

The design of light intensity adjustment system and the timer system for phototherapy used microcontroller PIC18F252. The details were as followed.

In the project, the microcontroller PIC18F252 with 32 kB of program memory and 256-byte data memory runs at 4-10 megahertz, which was suitable for use in the project. It was divided into 2 parts: Hardware and Software as follows.

Hardware part consisted of microcontroller PIC18F252 in signal processing. The microcontroller RC2 RB2-RB4 and PC0-PC1 port was connected to the switch in order to receive data. The RA2 port was connected to the Buzzer. The RA3 port was connected to LDR in order to measure the light intensity and used the RA2 port to connect to the LED driver LED in order to drive the LEDs in the panel. The processed data was passed into RC port which was connected to the 7-segment display in order to show data on a screen. By adopting the PIC microcontroller converted an analog signal to 10-bit digital (ADC). If the voltage input to ADC of PIC microcontroller was 5 V and a conversion resolution of 255 due to the 10-bit ADC selected, then the resolution from converting could be calculated from equation (3).

$$\text{Resolution} = \frac{5V}{2550} = 1.96 \text{ mV} \tag{3}$$

Therefore, the step of resolution at each step that ADC was used to convert to 5 V was 1.96 mV.

To design the program to calculate the light intensity by receiving the data from the light intensity circuit, which had an output in analog signal, the conversion of analog to digital must be made. The A/D will convert analog to digital information then the digital information will be used to find the relationship equation between digital output and light intensity.

In order to create an equation, the circuit test must be done. In this research, the adjustment of light intensity came from the light source. The measurement was done by Phototherapy Radiometer and recorded the output in digital data by obtaining it from A/D conversion in the microcontroller. The test would be done 31 times refer to Table 1.

Table 1 The result of the light intensity circuit test

Trail	Multimeter (V)	Phototherapy Radiometer (μW/cm^2/nm)	Digital Output
1	0.33	6	3
2	0.52	10	5
3	0.70	18	7
4	0.91	26	9
5	1.03	31	10
6	1.12	33	11
7	1.21	39	12
8	1.30	42	13
9	1.41	52	14
10	1.51	56	15
11	1.60	64	16
12	1.73	69	17
13	1.81	78	18
14	1.92	83	19
15	2.00	96	20
16	2.12	105	21
17	2.22	114	22
18	2.32	129	23
19	2.41	135	24
20	2.50	150	25
21	2.63	156	26
22	2.70	177	27
23	2.83	190	28

Trail	Multimeter (V)	Phototherapy Radiometer (µW/cm^2/nm)	Digital Output
24	2.90	206	29
25	3.03	228	30
26	3.09	248	31
27	3.16	272	32
28	3.31	292	33
29	3.43	314	34
30	3.51	323	35
31	3.61	361	36

In Figure 6, the graph is created by output voltage (X) and light intensity (Y)

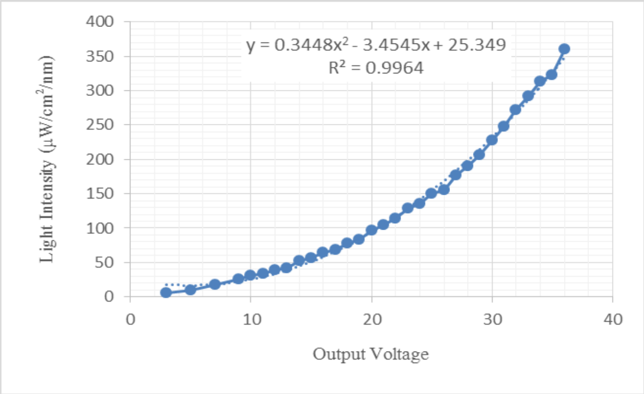

Figure 6 Relation between output voltage and light intensity

From Figure 6, the equation can be written as follows:

$$y = 0.3448x^2 - 3.4545x + 25.349 \quad (4)$$

Apply the equation that was used in the program for calculation the light intensity in the project. The processed data was displayed on the screen. This process could be written as a diagram as shown in Figure 7.

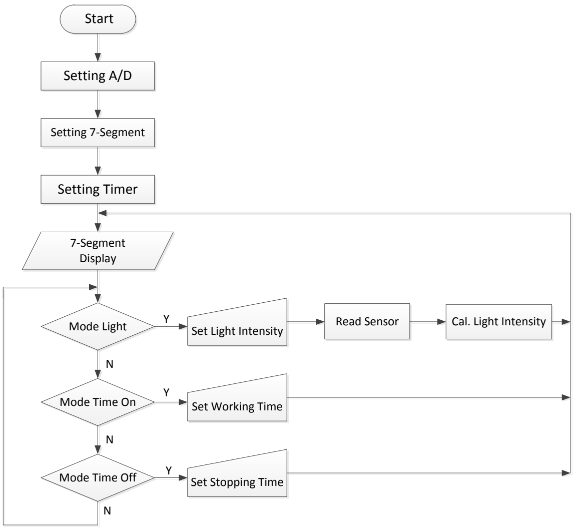

Figure 7 Flowchart of the processed data was displayed on screen

For the design of timer for phototherapy, a time can be counted in hours, minutes, and seconds. A 10 MHz-crystal in crystal circuit was used to generate time signal to determine the frequency of the clock in the operation of the LED and each of time treatment. Timer counted in each second from 1 second to 60 seconds and in minutes from 1 minute to 60 minutes, so it would advance to count in an hour. When the device was in mode “Time on”, the light source was bright until the end of time setting after that the device was in mode “Time Off” the light source was darkness.

For input system and display, the research had adopted micro-switch to use as the input of the device. Input system used five micro-switches total to connect with a microcontroller and used resistance 10 kΩ to connect in the circuit. The project used 7- segment digit LED display 4 alphabets size 0.56 inches type common cathode in order to show data enough and clearly see data from a distance. The LED display connected with IC Max7219 as shown in Figure 8 in order to receive the command from the microcontroller to control the display output.

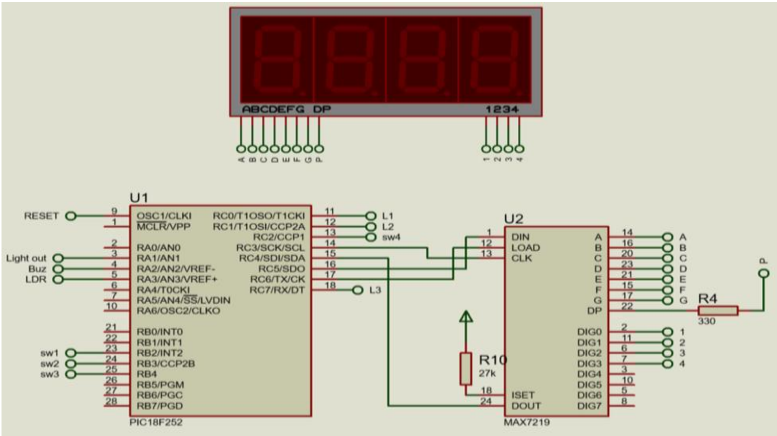

Figure 8 LED display connected with IC Max7219

3.4 Design and construction of light meter

The light meter design focused on measuring the intensity of light in the range of 4 - 34 μW / cm^2 / nm at the wavelength in range 425 to 475 nm by using LDR as a sensor. The research has adopted 10 millimeters of LDR which has the resistance of 10 kΩ and used the voltage divider to connect with a 10-bit A / D within the microcontroller.

Out of the various parts of phototherapy for the treatment of neonatal jaundice, when it assembled parts together, can be written as a diagram of operation as Figure 9.

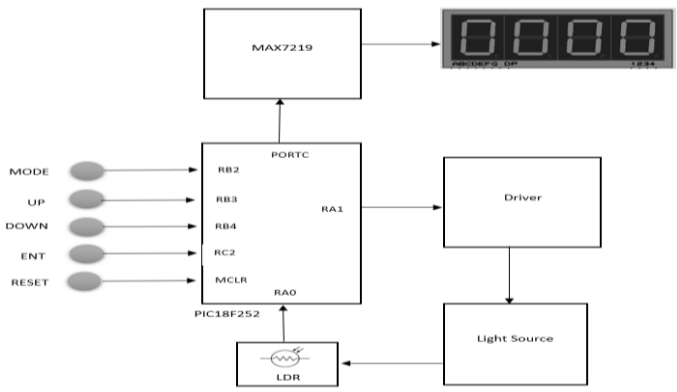

Figure 9 Diagram of the total function of low cost of neonatal bilirubin phototherapy equipment

The combined parts of low cost of neonatal bilirubin phototherapy equipment was shown in Figure 10. In design, all five switches are used as inputs to set up the usage time into the microcontroller. This project used the driver to drive the LED panel. When the LEDs were bright, there was LDR which measured the intensity of light from the LED panel and send data to process in the microcontroller to determine the total intensity of light that the LED panel could be provided. The data was displayed on the screen according to the program designed.

Figure 10 Low cost of neonatal bilirubin phototherapy equipment

4. Results and Discussion

Low cost neonatal bilirubin phototherapy equipment from the design consisted of the light source which consisted of 58 LED light bulbs, the blue LED color with the wavelength of 460 nanometer for 40 bulbs are for curing neonatal jaundice and the red LED color with 660 nanometer wavelength for 18 bulbs was used to reduce dizziness of users. The arrangement was a 92 square inch LED panel on a 24 cm wide base, 38 cm long, 0.2 cm thick, which mounted at the top of a pole. The end of pole mounted to three rods as the base of this equipment which consisted of three wheels which stuck with the end of each rod. The equipment could rotate the lamp 360 degree, so that the lamp could be placed above the baby's body. There was a control box attached to the pole and had a screw to adjust the high level of the lamp to keep away from the baby as much as required and the time treatment could display on the screen. The height of the equipment could be adjusted from 140 to 160 centimeters and the base of the equipment could be moved under the incubator which was placed at the side of the baby. It did not interfere with a nurse working.

The neonatal bilirubin phototherapy has a total of 3 tests. The first test was to test the usage of the parts in the equipment. The second test was to test the efficiency of the equipment and the last test was the safety test.

1. The first test was to test the intensity of LED light. For the setup, the neonatal bilirubin phototherapy will be set 45 CM from the baby cushion with the light intensity of 50%. In order to cover all ranges of light intensity, the test will be in 3 levels, which are 30%, 70%, and 100%, respectively. The light intensity measuring, FLUKE from DALE 40, which had the unit of $\mu W/cm^2/nm$ give us the result as follows.

Table 2 Result of LED light with intensity of 30%

Position	Point1	Point2	Point3	Point4	Point5	Point6	Point7
Point 1	49	71	72	76	73	69	50
Point 2	63	86	89	93	106	97	76
Point 3	67	81	95	110	106	109	95
Point 4	66	79	90	104	101	97	81

Table 3 Result of LED light with intensity of 70%

Position	Point1	Point2	Point3	Point4	Point5	Point6	Point7
Point 1	118	168	166	178	164	149	109
Point 2	147	205	212	218	237	217	231
Point 3	158	192	229	257	244	241	217
Point 4	165	191	212	243	230	222	194

Table 4 Result of LED light with intensity of 100%

Position	Point1	Point2	Point3	Point4	Point5	Point6	Point7
Point 1	172	254	259	265	246	234	172
Point 2	218	327	337	333	382	388	262
Point 3	249	311	365	397	382	392	358
Point 4	247	303	330	392	380	357	322

From Table 2-4, the information shows 3 levels of maximum light intensity of 30%, 70%, and 100% respectively. The unit is $\mu W/cm^2/nm$, which had been measured in every 2 inches referral to the size of the sensor in the light intensity measurement device, DALE 40 FLUKE. The diameter is 2 inches with the lamp set up 45 cm above the baby cushion. The result showed that if the baby is placed correctly under the LED light, the intensity of light is used to treat it adequately that refers with standard of the phototherapy ECRI (Emergency Care Research Institute) which the level of light intensity is 4 to 12 $\mu W / cm^2 / nm$ should be appropriate for treatment. The light intensity in this project covers 4 to 12 $\mu W / cm^2 / nm$ then this project is acceptable for treatment of hyperbilirubinemia in the newborn.

2. The second test was to test Phototherapy Radiometer that had been created in this project. The lamp was set 45 cm from the baby cushion. There were 3 levels of light intensity, which had been designed in program, that were 30%, 70%, and 100% respectively. The unit was $\mu W/cm^2/nm$, which had been measured in every 2 inches referral to the size of the sensor in the light intensity measurement device, DALE 40 FLUKE. When the created one compared with the standard device, there were percentage of error. The error results were 3.85% for 30% light intensity, 10.66% for 70% light intensity, and 9.53% in 100% light intensity. The phototherapy radiometer was designed and had an average error less than 10%, which does not have any effect on the therapy.

3. The temperature test of the equipment had been implemented. The lamp was set 45 cm from the baby cushion. There were 3 levels of light intensity, which had been designed in program, that were 30%, 70%, and 100% respectively. The result would be recorded by Incubator Incubadora PC – 305, Medix. The unit of the temperature is in Celsius. The results of the test for 3 levels of light intensity were the same, which were 25.20 Celsius. In summary, the neonatal bilirubin phototherapy had no effect to the temperature inside infant incubator.

4. The test of electrical safety for neonatal bilirubin phototherapy was test by using Fluke ESA612 Electrical Safety Analyzer. The standard machine was used to measure in 3 states.

Table 5 Result of the test of electrical safety for neonatal bilirubin phototherapy

State	Ground Resistance	Leakage Current
Equipment On	0.28 Ω	7.40 µA
Equipment Off	0.28 Ω	6.20 µA
Equipment in rest	0.28 Ω	5.60 µA

From the result, the standard from ECRI (Emergency Care Research Institute) was that the Ground Resistance less than 0.5 Ω and the leakage current less than 300 µA. From the result, this neonatal bilirubin phototherapy could be accepted.

5. Conclusion

Low cost of neonatal bilirubin phototherapy equipment to treat the neonatal jaundice was very low cost prototype. The effectiveness of this device would as well be easily moved from place to place and could be used with other equipment. The design chose the materials in details by the following:

1. The choosing of the blue LED color with the wavelength of 460 nanometer for 40 bulbs was used for curing neonatal jaundice. The red LED color with 660 nanometer wavelength for 18 bulbs used for reducing the headache of the doctors, nurses and other relating person. The chosen LED bulbs would have high endurance, less electrical usage, high brightness, low heating rate and did not do any harms to the baby's skin.
2. The LED panel was designed with the cross-sectional area of 92 inches square in order for the light to shine cover the baby's body.
3. The users could use the timer of the equipment and use the LDR to be the sensor to measure the intensity of the light. The microcontroller in PIC family with C Programming would do the data processing of the result.

Low cost neonatal bilirubin phototherapy equipment consisted of the LED light source, the timer, which could set for 0-24 hours. The screen 7-segment would display the time usage and light intensity. The microcontroller PIC family could adjust the brightness of bulbs. The light intensity measurement will be measured by LDR. The devices will have three wheels in order for easy movement purpose and the equipment could adjust the high level from 140-160 centimeters. All the materials could be found in the country and low price. There was a time control system and also the structure of the equipment was created to adjust the height level in order to use conveniently with other medical devices and moving as well.

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