3 Boyutlu Özgün Tasarımı ile Çok Renkli LED-Tabanlı Fototerapi Cihazı Üretimi

Manufacturing Multicolor LED-Based Phototherapy Device with a Novel 3D Design

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***Özetçe*— Sarılık vakası kandaki bilirubin seviyesinin artmasından kaynaklı; bebeklerin yaklaşık %60-70'inde gözlemlenmektedir. Yenidoğan üzerinde beyin hasarı, görme kaybı, akciğer ve böbreklerde fonksiyon bozukluğu gibi önemli hasarlar meydana gelebilir, hatta ölüme neden olabilir. Sarılığın tedavisinde kullanılan yöntemlerden biri fototerapidir. Bu çalışmada hedef alanı arttırmak için katlanabilir 3 LED paneli içeren bir tasarım gerçekleştirilmiştir. Ayrıca mavi-yeşil-beyaz dalga boyuna sahip yüksek voltajlı LED'ler kullanılmıştır. Böylelikle yoğun mavi ışıktan kaynaklı mide bulantısı, baş dönmesi riskleri en aza indirilmek istenmiştir. Sıcaklık, ışık yoğunluğu sensörleri kullanılarak otomatik bir sistem elde edilmiştir. Bebeğe zarar verir nitelikte olan sıcaklıklarda ve ışık yoğunluğunda sistem kullanıcıya uyarı verecektir.**

Anahtar Kelimeler—*Fototerapi; sarılık; LED; Arduino; yenidoğan.*

***Abstract*— Jaundice is a condition that results from an increase in bilirubin level in the blood. Its prevalence in newborns is around 60-70%. When this temporary jaundice becomes pathological and left untreated, significant damages may occur such as brain damage, vision loss, lung and kidney dysfunction, and even death. One of the methods used for the treatment of jaundice is phototherapy. In this study, a design has been made with 3 foldable LED panels to increase the target area. In addition, high-voltage LEDs with blue-green-white wavelengths were used. Thus, it was aimed to minimize the risks of nausea and dizziness caused by intense blue light. An automatic system has been achieved by using temperature and light intensity sensors. The system will warn the user at temperatures and light intensity that are harmful to the baby.**

Keywords— Phototherapy; jaundice; LED; Arduino; new-born baby.

I. INTRODUCTION

Jaundice is a complex disease caused by increased bilirubin in the blood. It is also known as hyperbilirubinemia. Bilirubin is a yellow toxic substance. When it increases in the blood, it is stored in the skin, mucosa, and organs. Jaundice is observed when the total serum bilirubin (STB) value exceeds 5 mg/dl [1, 2]. 80% of bilirubin is formed by the breakdown of aged red blood cells. Bilirubin is transported to the liver cells in the form bound to plasma albumin or alpha 1 and alpha 2 globulin. The bilirubin decomposed in the liver is transported to the intestine in the bile duct and excreted from the body [3-4]. Transient hyperbilirubinemia (physiological jaundice) is encountered in at least 2/3 of newborns in the first week. The highest bilirubin value is reached on the seventh day of the newborn. In the case of physiological jaundice, jaundice disappears between the 10^{th} and 14^{th} days. This situation continues in pathological jaundice and can give fatal consequences. The bilirubin accumulated in the circulatory system attacks the tissues. Bilirubin toxicity can cause serious irreversible brain damage. This pathological jaundice, which causes damage to cells with its accumulation in the brain stem, is called kernicterus. It also causes dysfunction in the lungs and kidneys. Toxicity can lead to loss of vision and hearing and with increasing effect, it also causes death [5, 6, 7]. Blood exchange, drug therapy, and phototherapy are available treatment methods for newborns with jaundice. When the amount of bilirubin increases, phototherapy is applied first. Light with a certain wavelength is absorbed by bilirubin and bilirubin is broken down. Although this method is applied routinely, exchange transfusion is applied in cases of an increase in the progress of the disease.

Phototherapy is the most commonly used treatment method for the control of newborn jaundice. Cremer et al. determined that bilirubin absorbs blue light in the visible region and developed a blue light-emitting phototherapy device. Blue fluorescence close to the UV wavelength was used in phototherapy studies in Japan, but it was found that short wavelengths caused damage to cells [8]. Various light sources such as halogen spotlight, metal halide gas discharge tube, fluorescent lamp, and light-emitting diodes (LEDs) are used in phototherapy treatment. Important factors in determining the phototherapy dose are;

● Spectral properties of the light source: For the light to be absorbed by bilirubin, it must be blue light with the wavelengths in between 430-490 nm [9,10]. 460 nm is peak value for light absorbtion by bilirubin [11]. On the other hand, the green region of the visible spectrum (500–520 nm) is more effective on the photoisomers of bilirubin [12].

● Light intensity (irradiance): Intense phototherapy requires a spectral irradiation of 30 W/cm^2/nm [13].

● The distance between the light source and the baby: There should be a distance between the light source and the surface against the risk of heat-induced burns. It is determined as 20 cm in LED therapy devices while it is 40-50 cm on the surface in fluorescent therapy [14].

● The body surface area or "footprint" is exposed to light treatment. The device must be designed with the highest footprint. It should also be considered that the intensity of the irradiation has the highest value in the middle part of the footprint and decreases towards the surroundings [15].

Phototherapy devices such as existing fluorescent tubes, halogen spotlights, and fiber optic blankets have numerous drawbacks. High heat generation, unstable wide wavelength light spread, and DNA damage are the common disadvantages of these systems. Recently, high-density gallium nitride and the semiconductor LEDs have been used in phototherapy. LEDs are basic, economical devices and they have minimal thermal effect on tissue. For this reason, it is commonly used in non-thermal light treatments. While fluorescent tubes produce light of a wider wavelength range, it is more advantageous to use LEDs since they have a narrow wavelength spectrum [16]. This spectrum range is about 50 nm [17]. This situation brings the opportunity to target more bilirubin. Using LEDs with a narrow wavelength range provides the destruction of more bilirubin molecules and the excretion of the urinary lumirubin will be higher [18]. Since LEDs do not have UV wavelengths, they do not cause DNA damage [19]. When the blue light is used alone, the baby's skin color cannot be understood. And it causes dizziness in personnel. Blue light is not used alone, white and green light are used next to it [10-20].

In the guideline of the Turkish Neonatal Society in 2014, the importance of the angle of incidence of light on the baby's body surface for the effectiveness of the treatment was emphasized. When the light comes at an angle of 45° to the body surface, the light intensity decreases by 40% compared to the angle of 90°. In other words, it is of great importance that the light panel of the phototherapy devices used is adjustable according to the baby's surface and that the light is applied perpendicular to the surface. The devices being used transmit light in one direction and do not allow light to be transmitted effectively to the lateral surfaces of the baby.

In this study, we aim to develop a phototherapy device for jaundice treatment with multicolor LED-based light sources with a novel 3D Design that allow a light application with an angle of 90° and allows the maximum light transmission to all parts of a body surface. We also use power LEDs with blue, white, and green wavelengths to reduce the negative side effects of the treatment on the patient. Besides, a foldable panel is designed to increase efficiency with a self-control mechanism via the sensors.

II. MATERIALS AND METHOD

A. Materials

Arduino, blue-green-white high-voltage LEDs, 2x16 LCD, GY-906 MLX90614 non-contact temperature sensor, LED plate, buzzer, Arduino controllable relay, DC-DC regulator, AC-DC converter, LDR, DHT22 sensor.

B. Light source

In the project, a prototype of a phototherapy device was developed with 3 different power LEDs (blue, LED, green LED, and white LED) for the treatment of jaundice. The arrangement of the Power LEDs is shown in Figure 1.

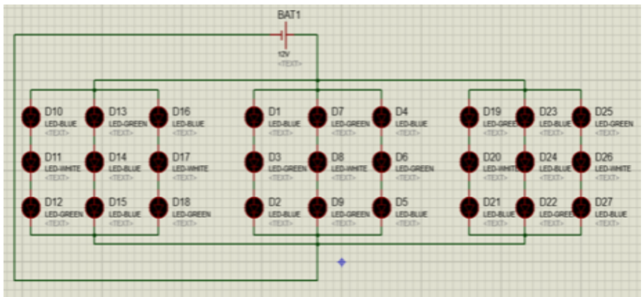

Figure 1. Organization of the LEDs on an LED array

The system had 3 separate panels with the same LED arrays, thus it was heated with a blown soldering iron and cut with a guillotine. 3 plates containing 3X3 high voltage LEDs were obtained (Figure 2). Thermal paste was applied to the back surface of high voltage LEDs for cooling purposes. Soldering was carried out on the plate.

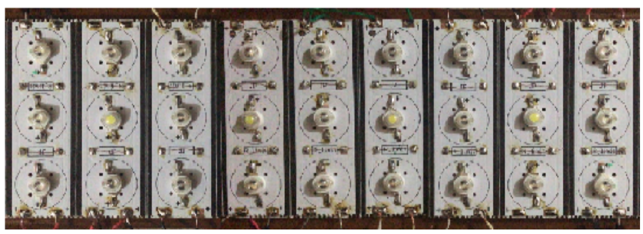

Figure 2. 3 LED panels in the system

C. Electronic Codes for the Sensors

The brightness adjustment of the light sources in the system was intended to be designed in 5 different modes. The resistances determined in the potentiometer modified to the DC-DC regulator were adjusted manually by using a rotary switch. The Arduino-compatible GY-906 MLX90614 non-contact temperature sensor was deemed suitable for instantaneous measurement of the newborn's temperature. Coding with Arduino was completed, the temperature was instantaneously printed on the LCD screen in Celsius. The coding was completed to give visual and audible reports. The temperature and humidity values of the environment were obtained with the DHT22 sensor and recorded on the LCD screen. When it falls outside the specified range, it was coded in a way to give visual and auditory warnings at it is seen Figure 3.

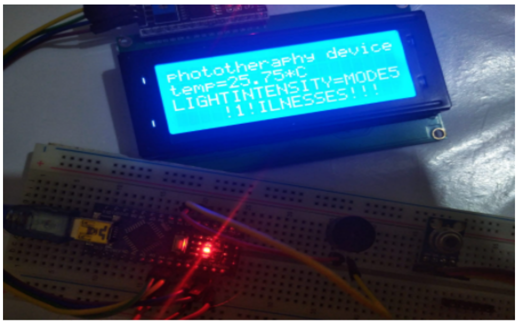

Figure 3. Visual and auditory warnings

Light intensity was measured with the LDR and printed on the screen. Since the DC-DC regulator was not controlled by Arduino, a relay controllable with Arduino was used to stop the system in warning or emergencies. It was designed in such a way that when the system is controlled, Arduino will turn on the relay in case of a warning, and no current will be transferred from the DC-DC regulator to the light sources.

D. Mechanical Design

Drawings for the mechanical design of the system have been performed via SOLIDWORKS (Figure 4). A fixable hinge was used to ensure the mobility of the light panels. It was intended to increase the footprint with a foldable 3-panel system. The mechanical parts were printed with PLA filaments in a 3D printer.

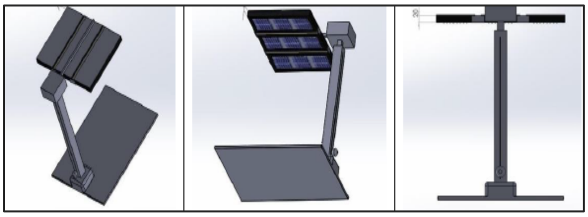

Figure 4. Mechanical design of the system with 3 foldable panels

III. Results and Discussion

In this study, a system with blue-green-white wavelengths with 3 foldable LED panels was designed for the treatment of jaundice. The brightness setting of the system can be changed in 5 different modes. The values in Table 1 have been achieved as a result of measuring the light intensity levels.

Mods	Measured light intensity values
1	28 W/cm^2/nm
2	24 W/cm^2/nm
3	16 W/cm^2/nm
4	14 W/cm^2/nm
5	10 W/cm^2/nm

Table 1: Intensity values obtained with this system

In addition, surface temperatures were measured and an increase of 0.5°C was observed at a distance of 30 cm. Temperature and light intensity sensors were used in this design. When temperatures and light intensities were outside of the specified ranges, the coding has been made to ensure that the system warns the user and automatically turns off the light sources. In Figure 5, basic diagram of the system is given.

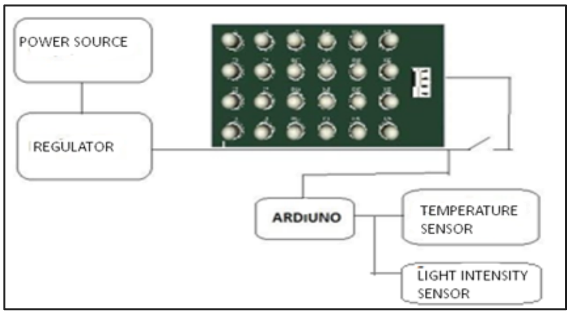

Figure 5. Basic diagram of system

The flowchart in Figure 6 explains the general operation of the system. Briefly, a self-controlled phototherapy device prototype was designed with blue-green-white wavelengths, a user warning system, and the foldable 3 LED panels to increase the footprint on the target.

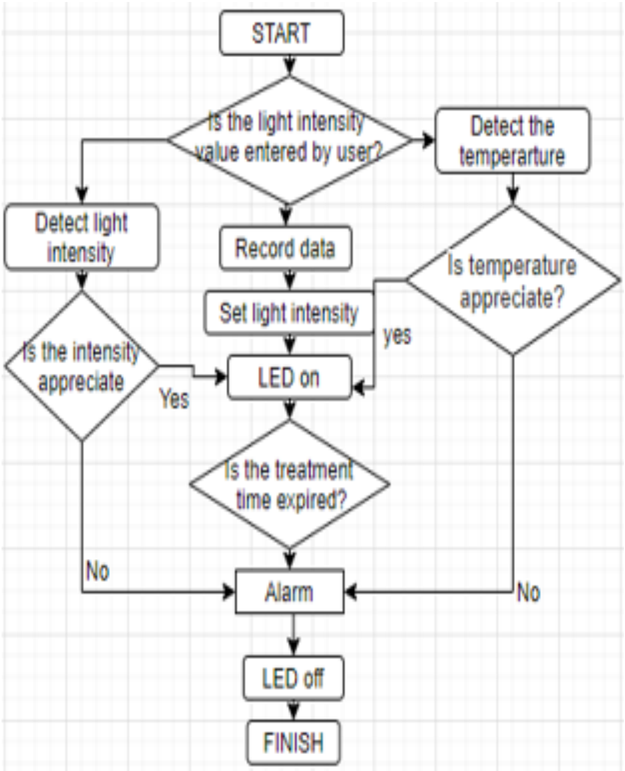

Figure 6. Flowchart for the Algorithm of Phototherapy Device Prototype

In this study, light with 3 different wavelengths of green-white-blue LEDs was used. In addition, a system suitable for the 3-dimensional structure of the baby, in which the light is fully transmitted to all surfaces, has been produced with a foldable panel system. With these features, the system's originality is ensured and it is more advantagous over other existing systems. In the study of Cabacungan and the collegues, a cost-effective system was designed. However, a single wavelength was used and light was transmitted only from one direction in their study [21]. Nabizath and the collegues used green light in addition to blue light in the system they developed. Thus, the efficacy of the phototherapy was increased with their design [22]. In this study, the problems such as dizziness and nausea caused by blue light were tried to be prevented by adding one more wavelength of white light to the system. In addition, LED light sources have been used to decrease the side effects of conventional phototherapy devices such as heat generation on the surfaces, burns, DNA damage. LEDs are used frequently in recent years due to their low cost, stability, and low-bandwidth wave spectrum. In addition, an automatic system with temperature and light intensity sensors was created in the designed study.

Author Contributions

This study is based on B.Y.'s MSc thesis. N.T. is the advisor and Y.I. is the co-advisor. B.Y. and N.T. designed the study. N.T. provided the financial support. All authors developed the system and contributed to writing the manuscript together.

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References

[1] L.C. Ku, N.S.M. Lazim, "Direct Photometry Non Invasive Bilirubin Device", *International Research Journal of Engineering and Technology (IRJET)*, 4, 401-404, 2017.

[2] S.P. Roche, and R. Kobos, "Jaundice in the Adult Patient", *American Family Physician,* 69, 299–304, 2004.

[3] M. Abbas, T. Shamshad, M. Ashraf, R. Javaid, "Jaundice: A Basic Review", *International Journal of Research in Medical Sciences*, 4,1313–1319, 2016.

[4] D.K. Stevenson, H.J. Vreman, R.J. Wong, "Bilirubin Production and the Risk of Bilirubin Neurotoxicity", *Seminars in Perinatology*, 35, 121–26, 2011.

[5] A. Çoban, M. Türkmen, and T. Gürsoy. "Yenidoğan sarılıklarında yaklaşım, izlem ve tedavi rehberi", *Türk Neonatoloji Derneği*, 1-39, 2014.

[6] F.R.S. Faulhaber, R.S. Procianoy, R.C. Silveira, "Side Effects of Phototherapy on Neonates", *American Journal of Perinatology*, 36, 252-257, 2019.

[7] S. Ullah, K. Rahman, M. Hedayati, "Hyperbilirubinemia in Neonates: Types, Causes, Clinical Examinations, Preventive Measures and Treatments: A Narrative Review Article", *Iranian Journal of Public* Health, 45, 558–568, 2016.

[8] Y. Uchida, Y. Morimoto, T. Uchiike, T. Kamamoto, T. Hayashi, I. Arai, T. Nishikubo, Y. Takahashi, "Phototherapy with Blue and Green Mixed-Light Is as Effective against Unconjugated Jaundice as Blue Light and Reduces Oxidative Stress in the Gunn Rat Model", *Early Human Development*, 91, 381–385, 2015.

[9] N. Canbulat, M. Demirgöz, "Yenidoğanın Işık Tedavisi: FOTOTERAPİ", *Zeynep Kamil Tıp Bülteni,* 40, 37-41, 2009.

[10] M. J. Maisels, A. F. McDonagh, "Phototherapy for neonatal jaundice", *New England Journal of Medicine*, 358, 920-928, 2008.

[11] T. Kuboi, T. Kusaka, H. Okada, M. Arioka, K. Nii, M. Takahashi, S. Yamato, T. Sadamura, W. Jinnai, A. Nakano, S. Itoh, "Green light-emitting diode phototherapy for neonatal hyperbilirubinemia: Randomized controlled trial", *Pediatrics International*, 61, 465–470, 2019.

[12] M. Yurdakök, "Phototherapy in the newborn: what's new?" *Journal of Pediatric and Neonatal Individualized Medicine (JPNIM)*, 4(2), e040255, 2015.

[13] L. A. Stokowski, "Fundamentals of Phototherapy for Neonatal Jaundice", *Advances in Neonatal Care*, 6, 303–12, 2006.

[14] F. Ebbesen, P. Vandborg, P. Madsen, "Effect of phototherapy with turquoise vs. blue LED light of equal irradiance in jaundiced neonates", *Pediatric Research,* 79, 308–312, 2016.

[15] M. M. Tatli, C. Minnet, A. Kocyigit, A. Karadag, "Phototherapy increases DNA damage in lymphocytes of hyperbilirubinemic neonates", *Mutation Research - Genetic Toxicology and Environmental Mutagenesis*, 654(1), 93–95, 2008.

[16] A. R. Borden, K. M. Satrom, P. Wratkowski, T. N George, C. A. Adkisson, H. J. Vreman, A. Johnson, K. J. Nichols, T. M. Slusher, "Variation in the Phototherapy Practices and Irradiance of Devices in a Major Metropolitan Area", *Neonatology* 113(3), 269–74, 2018.

[17] P. F. Sebbe, A. B. Villaverde, L. M. Moreira, A. M. Barbosa, N. Veissid, "Characterization of a novel LEDs device prototype for neonatal jaundice and its comparison with fluorescent lamps sources: Photpublisher-idapy treatment of hyperbilirubinemia in Wistar rats", *Journal of Spectroscopy*, 23, 1-13, 2009.

[18] S. Gutta, J. Shenoy, S. P. Kamath, P. Mithra, B. S. Baliga, M. Sarpangala, M. Srinivasan, "Light Emitting Diode (LED) Phototherapy versus Conventional Phototherapy in Neonatal Hyperbilirubinemia: A Single Blinded Randomized Control Trial from Coastal India", *BioMed Research International*, 1-6, 2019.

[19] T. Xiong, Y. Qu, S. Cambier, D. Mu, "The side effects of phototherapy for neonatal jaundice: what do we know? What should we do?", *European Journal of Pediatrics*, 170, 1247-1255, 2011.

[20] J. Wang, G. Guo, A. Li, W. Q. Cai, X. Wang, "Challenges of phototherapy for neonatal hyperbilirubinemia*", Experimental And Therapeutic Medicine, 21*, 231, 2021.

[21] P. Cabacungan, C. Oppus, J. E. Guzman, G. Tangonan, I. Culaba, N. G. Cabacungan, "Intelligent Sensors and Monitoring System for Low-cost Phototherapy Light for Jaundice Treatment", *2019 International Symposium on Multimedia and Communication Technology (ISMAC)*, 1-6, 2019.

[22] M. A. Nabizath, S. Soumya, V. Boomitha, C. Meena, P. Sridharan, "New design for phototherapy device and skin colour analysis", *2017 IEEE International Conference on Smart Technologies and Management for Computing, Communication, Controls, Energy and Materials (ICSTM)*, 253-257, 2017.