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The Design, Manufacturing and Applications of a Novel LED-Based Phototherapy Device

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The Design, Manufacturing and Applications of a Novel LED-Based Phototherapy Device

Abstract

Jaundice is a very common disease in infants. It is caused by an increase in the level of bilirubin in the blood. Its incidence in newborns is around 60-70%. When jaundice becomes pathological, it can cause much damage to the body: brain damage, vision loss, lung and kidney dysfunction, and even death. With the increase of bilirubin and its accumulation in the organs, irreversible damage occurs. There are different methods such as exchange transfusion, medication, and phototherapy to remove bilirubin from the environment. Blue light with a wavelength of 430-490 nm is required for light to be absorbed by bilirubin. In this study, a 3D (dimensional) design with different wavelengths beyond standard phototherapy devices was aimed to make the treatment of jaundice more effective. In addition, it is desired to create a system in which the user is warned in case of light intensity and temperature increase. To degradation of bilirubin molecules, the causative agent of jaundice, 1 Watt LED light source with a green-white color band was used next to the blue color band. Since it supports the production of lumirubin, which is rapidly eliminated from the body and has low toxicity, 1Watt LEDs with green light bands have been added to the system. The reason for using white light is to minimize the effects of blue light such as dizziness and nausea. It is also to better detect the change in skin color. Generally used devices have a single mechanical panel. The light is sent to the baby vertically from the top; however, considering the 3D feature of the baby, the light cannot be sent to the sides of the baby in sufficient quantity. The device has 3 separate panels. These panels, where the light sources are located, are fixed to each other with hinges.

In this way, the angle between the panels is changed. Thus, it was desired to increase the amount of light coming to the baby and the light was ensured to be perpendicular to the side surface. A phototherapy device containing sensors that control temperature and light intensity during application has been developed. Blue, green and white 1 Watt LED light sources are used to ensure the degradation of bilirubin that causes jaundice. In addition, a 3D structure is targeted to increase the footprint and support bilirubin breakdown. With this study, a new technological development has been provided to solve a serious problem frequently encountered in clinics. To examine whether the device is effective; output power measurement, bilirubin degradation test, and temperature tests were performed at different distances (20 cm, 30 cm) and angles (90°, 135°, 180°). Output power was measured at different distances and angles and the highest value of 0.3370 mWatt (20 cm, 180°) was reached. It was desired to test the effect of the device on bilirubin and the prepared bilirubin solution was placed on the plates. The light was applied to the bilirubin solution at different distances and angles for 30 minutes. 7.6 % success was achieved in bilirubin tests. Another thing to consider is temperature variation. The light was applied at different angles and distances for 30 minutes and the temperature increase was determined. Data were taken from the thermal camera and the temperature sensor. The temperature at the surface reached its highest value at a distance of 20 cm. A maximum temperature rise of 0.1°C was measured. This value is a reliable amount of increase.

A phototherapy device is developed containing sensors that control the temperature and light intensity during application. Blue, green and white LED light sources are used to ensure the degradation of bilirubin molecules that causes jaundice. Also, 3D structure is aimed for raise footprint and supporting bilirubin degradation. When unwanted data is obtained with light intensity and temperature sensors, the user is warned. In future studies, it is desired to increase the light output power obtained from the device. With this study, new technological development will be provided to solve a serious problem frequently encountered in clinics.

Keywords: Jaundice, bilirubin, LED, lumirubin, phototherapy

Yeni Bir LED Tabanlı Fototerapi Cihazının Tasarımı, Üretimi ve Uygulamaları

Öz

Sarılık bebeklerde çok sık görülen bir hastalıktır. Kandaki bilirubin seviyesindeki bir artıştan kaynaklanır. Yenidoğanlarda görülme sıklığı %60-70 civarındadır. Sarılık patolojik hale geldiğinde vücutta birçok hasara neden olabilir: beyin hasarı, görme kaybı, akciğer ve böbrek fonksiyon bozukluğu ve hatta ölüm. Bilirubinin artması ve organlarda birikmesi ile geri dönüşü olmayan hasarlar meydana gelir. Bilirubini ortamdan uzaklaştırmak için kan değişimi, ilaç ve fototerapi gibi farklı yöntemler vardır. Işığın bilirubin tarafından absorbe edilebilmesi için 430-490 nm dalga boyunda mavi ışık gereklidir. Bu çalışmada sarılık tedavisini daha etkin bir hale getirmek için standart fototerapi cihazlarının ötesinde farklı dalga boylarına sahip 3 boyutlu bir tasarım amaçlanmıştır. Ayrıca ışık şiddeti ve sıcaklık artışı durumunda kullanıcı uyarıldığı bir system oluşturulmak istenmiştir. Sarılığın etken maddesi bilirubini yıkmak için mavi renk bandının yanında yeşil-beyaz renk bandına sahip 1 Watt LED ışık kaynağı kullanılmıştır. Vücuttan atılımı hızlı olan ve düşük toksisiteye sahip lumirubin üretimini desteklediği için yeşil ışık bandına sahip 1 Watt LED'ler sisteme eklenmiştir. Beyaz ışık kullanılmasının nedeni mavi ışığın kişide oluşabilecek baş dönmesi ve mide bulantısı gibi etkilerini en aza indirmektir. Ayrıca cilt rengindeki değişikliği daha iyi tespit etmektir. Genelde kullanılmakta olan cihazlar tek parçadan oluşan panele sahiptir. Işık üstten dik bir şekilde bebeğe gönderilmekte; fakat bebeğin 3 boyutlu özelliği göz önüne alınırsa bebeğin yan kısımlarına ışık yeterli miktarda gönderilememektedir. Cihaz mekanik tasarım olarak 3 ayrı panele sahiptir. Işık kaynaklarının bulunduğu bu paneller birbirine menteşe ile sabitlenmiştir.

Bu sayede paneller arasındaki açı değiştirilmektedir. Böylece bebeğe gelen ışık miktarını arttırılmak istenmiş ve ışığın yan yüzeye dik gelmesi sağlanmıştır. Uygulama sırasında sıcaklık ve ışık şiddetini kontrol eden sensörler içeren bir fototerapi cihazı geliştirilmiştir. Sarılığa neden olan bilirubinin yok edilmesini sağlamak için mavi, yeşil ve beyaz 1 Watt LED ışık kaynakları kullanılmaktadır. Ayrıca ayak izini artırmak ve bilirubin yıkımını desteklemek için 3D yapı hedeflenmiştir. Bu çalışma ile kliniklerde sıklıkla karşılaşılan ciddi bir sorunu çözmek için yeni bir teknolojik gelişme sağlanmıştır. Cihazın etkin olup olmadığını görmek için farklı mesafelerde (20 cm, 30 cm) ve açılarda (90°, 135°, 180°) çıkış gücü ölçümü, bilirubin yıkım testi ve sıcaklık testleri yapılmıştır. Farklı mesafe ve açılarda ışık gücü ölçülmüş ve en yüksek değer olan 0.3370 mWatt'a ulaşılmıştır(20 cm, 180°). Cihazın bilirubin üzerindeki etkisi test edilmek istenmiştir ve hazırlanan bilirubin solusyonu plakalara yerleştirilmiştir. 30 dk boyunca farklı mesafe ve açılarda ışık bilirubin solusyonuna uygulanmıştır. Bilirubin testlerinde %7.6 başarı elde edilmiştir. Dikkate alınması gereken başka bir şey sıcaklık değişimidir. Işık 30 dk boyunca farklı açı ve mesafelerde uygulanmış ve sıcaklık artışı tespit edilmiştir. Termal kamera ve sıcaklık sensöründen veriler alınmış ve 20 cm'de yüksek sıcaklık artışı gözlemlenmiştir. En fazla 0.1°C sıcaklık artışı ölçülmüştür.

Cihaz mavi-yeşil-beyaz dalgaboylarını içermesi ve 3 boyutlu yapısı açısından özgün değere sahiptir. Yeşil renk bandı ile toksik özelliği az ve vucuttan atımı hızlı olan limuribin yapımı desteklenmiştir. Ayrıca 3D yapıdaki panel dizaynı ile ışık ayak izi arttırılmıştır. Işık yoğunluğu ve sıcaklık sensörleri ile istenmeyen veriler elde edildiğinde kullanıcının uyarılması sağlanmıştır. İleriki çalışmalarda cihazdan elde edilen ışık çıkış gücü arttırılmak istenmektedir. Bu çalışma ile kliniklerde sıklıkla karşılaşılan ciddi bir sorunun çözümü için yeni teknolojik gelişmeler sağlanacaktır.

Anahtar Kelimeler: Sarılık, bilirubin, LED, lumirubin, fototerapi

to my family and friends…

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Table of Contents

List of Figures

List of Tables

List of Abbreviations

TSB	Total Serum Bilirubin
RBC	Red Blood Cell
UCB	Unconjugated form bilirubin
DC	Direct Current
UGT1A1	Uridine-diphosphate glucuronosyltransferase 1A1
LED	Light emitting diode
mg	Milligram
3D	3 dimension
dl	Deciliter
h	Hour
nm	Nanometer
LDR	Light Dependent Resistor

List of Symbols

λ	Wavelength
E	Irradiance of light
Π	Pi
Ω	Ohm

Chapter 1

Introduction

Jaundice is a disease that requires medical attention. It is the most common illness in newborns. Jaundice is also denominated hyperbilirubinemia. Because it arises out of the accumulation of high bilirubin. Bilirubin is a yellow-orange bile pigment. It has the characteristic of toxic material. Deposition of bilirubin in tissue induces yellowing of the skin, mucous membranes, and sclera. When the level of Total Serum Bilirubin (TSB) is exceeded the 5 mg/dl limit value; this situation is considered jaundice. An increase in bilirubin is observed in at least 2/3 of newborns in the first week. This may be temporary or cause serious damage. The accumulated bilirubin attacks the tissues. It also disrupts basic functioning due to its toxic feature in the tissue. It causes severe brain damage, visual impairment, organ loss, and even death. This disease, which is caused by high bilirubin, should be treated and the patient should be observed. Exchange transfusion, pharmacological drugs, and phototherapy are used in the treatment of jaundice. The most effective treatment method after the exchange of blood is known as phototherapy [1, 2].

1.1 Bilirubin

Bilirubin, a potentially toxic substance, is produced as 4 mg/kg body weight daily in the human body. It is formed by the destruction of red blood cells. It is produced in the natural functioning of the body. It is an insoluble form in human blood, so it binds to albumin.

1.1.1 Bilirubin Mechanism

Bilirubin may be in the conjugated or unconjugated form. When senescent red blood cells are raptured, hemoglobin has erupted from dead cells. Heme and globin structures are breakdown products of hemoglobin. As a result of the reduction and oxidation reactions of heme, iron, carbon monoxide, and biliverdin structures are released. Then, a reduction reaction occurred between the reductase enzyme and biliverdin. At the end of this reaction, a bilirubin structure is produced. 80% of bilirubin is derived from the degradation of red blood cells. Another 20% of bilirubin came up with the breakdown of no hemoglobin proteins. Myoglobin, the cytochromes proteins release bilirubin. Produced bilirubin is an unconjugated form. It moves to the liver and is bound to albumin [1, 3].

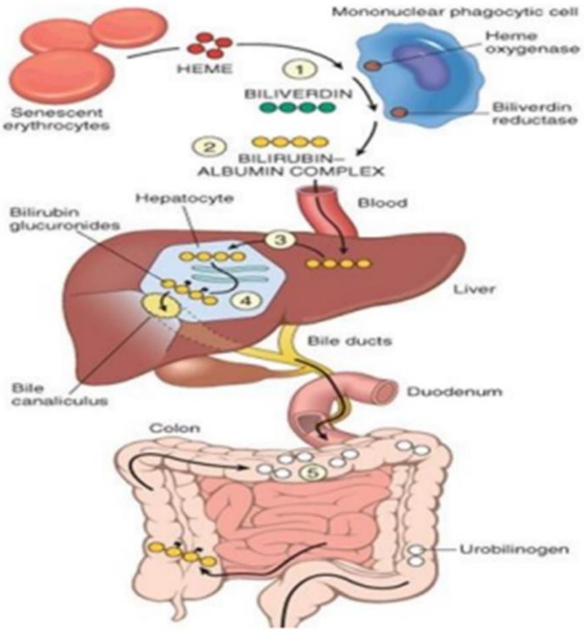


Figure 1.1: Basic mechanism of bilirubin [1]

Unconjugated bilirubin is filtered by the liver. When the bilirubin-albumin complex comes to the liver; three phases occur. Bilirubin enters inside the hepatocyte and unconjugated bilirubin is bound by a cytoplasmic protein (Figure 1.1).

Unconjugated bilirubin is conjugated with glucuronic acid by the uridine diphosphate–glucuronyl transferase enzyme. Hence bilirubin monoglucuronide (15%) and bilirubin diglucuronide (85%) are produced. These structures are water-soluble and conjugated form.

Then bilirubin releases from the hepatocyte and is excreted into the bile canaliculus. Bile moves to the biliary ductal collecting system. Bilirubin is converted into urobilinogen at the entrance of the ileum and colon. The intestine absorbs 20% of the urobilinogen, absorbed urobilinogen is excreted into bile or urine. Another 80% of the urobilinogen is converted to fecobilinogen, thrown out from the body by stool [1].

1.1.2 Bilirubin Mechanism in Jaundice

Problems or changes in the bilirubin transportation system can cause jaundice. It can be observable in adults, children, or neonatal patients. The most prevalent-observable reasons are race, genetic reason, change in enzyme activity, and Gilbert’s syndrome. Rise in production of bilirubin, an impaired liver system for unconjugated bilirubin filtering end removing, problems in conjugation bilirubin, etc. factors lead to jaundice. Unconjugated hyperbilirubinemia arises from these factors. Failures in the transport system, excretion, or biliary transport system are attributable to conjugated hyperbilirubinemia. Bilirubin transportation to the liver is supported by proteins that are encoded by the genes. Gilbert Syndrome arises from the mutation UGT1A1 gene that responds to uridine diphosphate glucuronosyltransferase (UGT1A1 enzyme). UGT1A1 is responsible for the conjugation of bilirubin. Bilirubin is unconjugated form when it is filtered by the liver. It gets conjugated with glucuronic acid in the hepatocyte. It develops an identity as water-soluble; hence it can excrete and transport in bile canaliculus. But this mechanism is interrupted in Gilbert Syndrome. Deficiency occurs in hepatic uptake. When the liver disease has occurred, the serum bilirubin levels are more than 17 μmol/l [1, 3].

There are two essential causes: The first factor is raised in a breakdown of red blood cell numbers. The second is inadequate enzyme activity in hepatocytes and insufficient binding protein in hepatocytes. Inadequate enzyme activity and binding protein in hepatocytes induce unconjugated form bilirubin accumulation.

For this reason, the amount of unconjugated form bilirubin increase, and excretion of bilirubin and other forms are restricted [4].

1.2 Types of Hyperbilirubinemia

The prevalence of neonatal jaundice has a serious ratio. The observed hyperbilirubinemia may be risk-free as well as life-threatening. There are several types of jaundice: physiological jaundice, pathological jaundice, jaundice due to breastfeeding, and hemolytic jaundice.

1.2.1 Physiological Jaundice

In the first week of birth, the amount of bilirubin can raise. Physiological jaundice is observed in 2/3 of newborns clinically. It has no serious effect on the newborn. This is a temporary situation. Bilirubin is the unconjugated form of physiological jaundice. Jaundice in physiological form is observed between 24-72 h of age and between 4th and -5th days. During this time, the bilirubin level reaches to peak level. It goes out of existence in 10-14 days. In general, serum total bilirubin (STB) level is less than 15 mg/dl. But 15 mg/dl value is not a term.

Determine physiological jaundice or pathological jaundice; is dependent on some criteria like risk, week, and STB level [5, 6, 7].

1.2.2 Breast Feeding-Breast Jaundice

Breast Feeding Jaundice is observed in the third week of infant life. This event prevailed in 2/3 of an infant. Hyperbilirubinemia is the unconjugated form in breast feeding related jaundice. According to a hypothesis; milk includes an inhibitor of hepatic glucuronyl transferase enzyme. This enzyme is responsible for the conjugation of bilirubin. When bilirubin enters inside the hepatocyte, bilirubin is conjugated with glucuronic acid. Hence bilirubin turns into a water-soluble structure. But inhibitor of hepatic glucuronyl transferase enzyme prevents conjugation. As a result of inhibitor existence, bilirubin cannot transport to bile canaliculus, unconjugated form bilirubin accumulation gets higher level [8].

The other approximation is the frequency of feeding dealing with the reason for jaundice. Early-Onset Breastfeeding Jaundice is originating from a deficiency in feeding. Formula-fed newborns have less risk than breastfeeding newborns. There can be less frequency in feeding or human breast milk can be less volume or less calorie value.

These factors initiate risk for early-onset breastfeeding jaundice. Because dehydration value will be in mild and meconium will be delayed. Rise in bilirubin level on meconium and meconium retardation induce to rise in bilirubin level. It's for this reason that infant formulae and follow-on formulae should be taken, and weight gain should be supported.

When Breastfeeding Jaundice is detected in a newborn, the breastfeeding period should be discontinued and the newborn should be supported with formula-fed. After the healing period is carried out, breastfeeding can continue. Increasing bilirubin levels in newborns attribute to insufficient breastfeeding in the first five days. Except for jaundice related to weight loss in the first five days, a rise in weight loses induce jaundice even permanent disease in the newborn in the upcoming days [8, 9].

1.2.3 Pathological Jaundice

STB levels deviates from a normal range of STB in pathological jaundice. But etiologies of physiological jaundice are assessed as pathological. While physiological jaundice is considered as temporary, pathological jaundice is assessed as prolonged disease.

Also, it has a fatal effect. In full term newborn (not premature), STB level pass over 17 mg/dl. The rate of the increase exceeds the limit of the normal rate; it increases by 5 mg/dl per day [7, 9].

As a result, at least 2/3 of the newborns have an increase in bilirubin in the first week. This impermanent hyperbilirubinemia is called physiological jaundice. For physiological jaundice, STB is expected to be below 12.9 mg/dl and this value does not have a serious effect on the newborn.

It is usually observed at the 24th and 72nd hours of birth, and the highest bilirubin amount is reached on the 7th day. Physiological jaundice disappears between 10 and 14 days in total. Another type of jaundice is defined as pathological jaundice. Situations where STB value exceeds 5 mg/dl /day and longer period than physiological jaundice are considered as pathological jaundice and it is required treatment. Pathological jaundice causes very serious damage to the newborn [6, 7].

1.3 Bilirubin Toxicity/Side Effects of Jaundice

Raise in bilirubin levels can be transient or permanent; it can create different effects on the newborn. Their efficiency can harmful or mild. Bilirubin is a toxic substance. As a result of bilirubin accumulation in the body, irreversible tissue organ loss can occur. Bilirubin accumulates in the circulatory system and accumulates in the organs. It can lead to brain damage, visual impairment, kidney loss, respiratory impairment, and hearing loss.

Protein/peptide phosphorylation has a critical role in the human body. It has roles in cell growth, signal transduction, and regulation of the cell cycle. It adjusts the protein mechanism. Bilirubin has an inhibitory mechanism on protein/peptide phosphorylation.

On nerve transmission, bilirubin has a negative effect on phosphorylation of synapsin I that have responsibility for vesicle moving regulation, neural transmitter kinetic, and exocytosis. For this reason, it has an inhibitory effect on the brain [10].

Unconjugated form bilirubin (UCB) binds to the cell membrane and it can change cell membrane structure, potential, transport, and enzymatic activity. UCB can bind to the erythrocyte. So UCB is assessed as toxic to cellular structure. Erythrocyte is called a Red Blood Cell (RCB) and includes hemoglobin and iron.

Erythrocyte is responsible for carrying oxygen and CO_2. So UCB and erythrocyte interaction point out different diseases like anemia. Between liver diseases and anemia, the connection has existed a source of blood loss. When UCB bound erythrocyte, phospholipids break from the cell membrane. This lipid is binding site of UCB.

Hence UCB can easily enter and accumulate within in cell membrane. UCB entrance and accumulation incline degradation, and destruction of RBC (haemolyses).

Haemolyses are seen on RCB when there is a high concentration of bilirubin. There is no show haemolyses 1x10^{-5} mole/l of bilirubin, but haemolyses are shown in 1x10^{-4} mole/l bilirubin Hence the biological system is affected by bilirubin [11].

1.4 Treatment Methods Used in Jaundice

There are different treatment methods available for the treatment of jaundice. Such as exchange transfusion, drug therapy, and phototherapy. Phototherapy is first applied to the newborn with jaundice for 6 hours. It includes the need to eliminate the neurotoxic effect of jaundice and eliminate the need for exchange transfusion. When the amount of increase in STB value is above 0.2 mg/dl per hour, a risk situation occurs. This situation requires intensive phototherapy. Afterward, a blood transfusion may be needed. Because bilirubin can be found in the blood in the form bound to albumin or in free form. In cases where the amount of albumin falls below 3 g/dl, it indicates excess free bilirubin. Free bilirubin crosses the brain barrier more easily than when bound to albumin. This increases the risk of neurotoxicity. In other words, the bilirubin-albumin ratio is an element that supports blood exchange. Although this method is routinely applied, exchange transfusion is applied in cases that require urgent intervention with the increase in the progression of the disease [2, 7].

1.4.1 Exchange Transfusion

Exchange transfusion is the replacement of newborn babies with high bilirubin levels with donor blood containing normal bilirubin levels. It was possible to remove bilirubin and hemolytic antibodies from the environment. However, transfusion should be considered as an alternative to intensive phototherapy. Phototherapy is also required before and after transfusion. An umbilical catheter is used for blood exchange; the amount of blood to be taken and given is at most 5 ml/kg and takes about 2 hours. Blood transfusion also brings some complications. Cardiovascular and respiratory problems are serious complications. Sudden shocks may occur due to bleeding or incomplete blood draw. Also, blood clots obstructing the catheter can be observed.

The ion balance of the blood sent to the body may be disturbed; there may be an increase or deficiency in potassium, calcium, or glucose levels. Ph change is also possible. Exchange transfusion can also bring about various allergic effects. Septic shock due to sudden changes in the body can be observed. Changes in blood pressure may be observed. Therefore, it is necessary to apply phototherapy beforehand. Air embolism, infection even death can be seen in this treatment technique as a complication. Therefore, it is necessary to apply phototherapy beforehand [2, 6].

1.4.2 Phototherapy

For the treatment of newborn jaundice, phototherapy is the most often utilized method. In the treatment of jaundice with phototherapy, different light sources are employed in different ways.

The main aim in the phototheraphy, to send light to penetrate skin, to break down bilirubin. Photo isomers are formed by degradation of bilirubin. Configurational E,Z/Z,E-isomers(photobilirubin) and lumirubin is formed. Photobilirubin excreted thanks to their water soluable structure. But this reaction is reversible. When there is not light is turn to bilirubin. Photobilirubin excretion from the body is realized slowly. Lumirubin structures are water soluble. This photochemical reaction is irreversible. They can excreted from body easily. It was discovered in 1975 that sunlight affects jaundice. As a result of later research, bilirubin absorbs blue light in the visible region and developed a blue light emitting phototherapy device. In Japan, blue fluorescence close to the UV wavelength was used in phototherapy studies, but it was found that short wavelengths cause damage to cells.

Various light sources such as halogen spotlight, metal halide gas discharge tube, fluorescent lamp and LED are used in phototherapy treatment. Although light sources provide advantages in certain situations, they can have drawbacks [5, 12].

1.5 Spectral Characteristics of the Light Sources Used for the Treatment of Jaundice

The main purpose of phototherapy is to allow light to penetrate the skin, interact with bilirubin, break it down, and be excreted from the body through feces. For phototherapy to be efficient and to take place without harming the patient, the phototherapy gadget must possess several essential characteristics. These characteristics were chosen in a way that is safe for both the infant and the user. Factors to be considered when deciding on the dose of phototherapy (Figure 1.2).

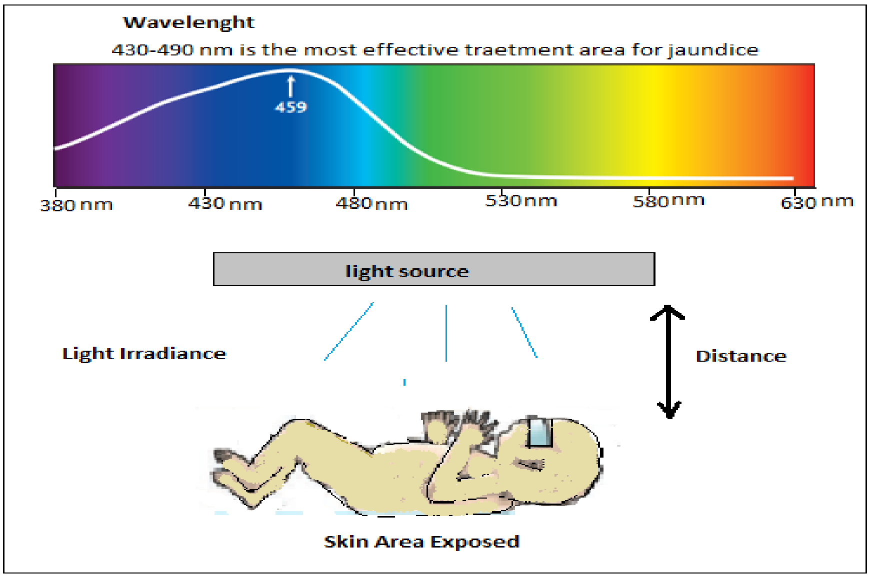


Figure 1.2: Characteristic properties of light [13]

1.5.1 Wavelengths

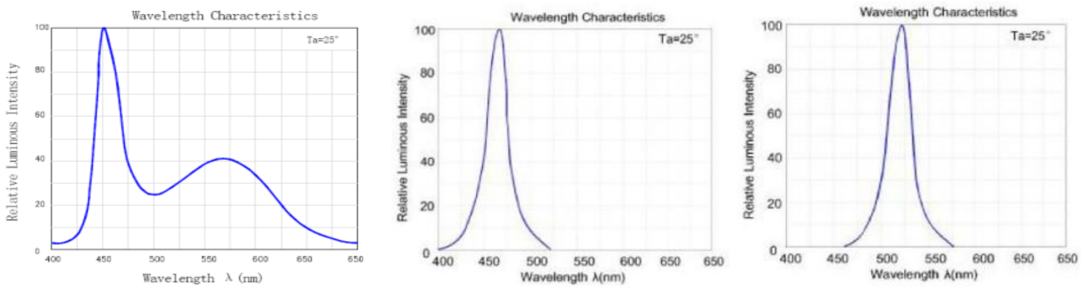
One of the most important criteria during phototherapy is the wavelength. Phototherapy has a higher effect in the visible region between 460 and 490 nanometers. This wavelength represents blue-green light in the visible region.

LEDs containing gallium nitride are used to obtain blue wavelength light. Blue, green, and white 1Watt LEDs are used in the light source in this study.

When the blue light is used alone in phototherapy, the baby's skin color cannot be detected. In addition, it was determined that it caused dizziness in the personnel around. For this reason, blue light is not used alone. Light with blue and white wavelengths is used together.

To prevent this disadvantage, white light was also used in the study. The specific wavelength (λ) was determined as 460±10 nm [14, 15, 16].

For effective phototherapy, it is necessary for the light to affect the bilirubin in the maximum amount and to break down the bilirubin. Hemoglobin, which is abundant in the body, also absorbs blue light. This, in turn, adversely affects the absorption of light by bilirubin and the destruction of bilirubin. In addition, although blue LEDs are more convenient than traditional light sources in terms of DNA destruction, mutation, and changing chromatin threads and do not cause them; It has side effects such as hypothermia, rash, and loss of water in the body. Therefore, it is thought that the use of green light, which is more tolerable than blue light, together with blue light will be effective. Although it is said that blue light is more effective than green light in the destruction of bilirubin when the studies are examined, in the study of Vreman et al., 500 ± 10 nm was found to be the optimum value in bilirubin destruction. This information supports the green light we will use next to the blue light. Palavskii et al. support the use of blue light and green light for bilirubin degradation in their study. Light at 505 nm supports the formation of lumirubin. Limuribin is a substance that is rapidly excreted from the body. This study also supports blue light and green light.



(a) (b) (c)

Figure 1.3: Representation of wavelength characteristic in different colour of LEDs (a) White colour LED; (b) Blue colour LED; (c) Green colour LED [1]

Unlike other studies, blue-green-white light was used together in this study. Wavelength characteristic is shown. Blue LEDs wavelength is between 400- 500 nm; and green light around 450-550 nm; white LEDs have widely wavelength area. LEDs have 25-30 nm bandwidth (Figure 1.3). Thus, more effective treatment was obtained and the disadvantages were minimized [1, 16, 17, 18].

1.5.2 Light Intensity (Radiance)

Light intensity (radiance); is the number of photons exposed per square centimeter of body surface. It is an important factor that increases the rate of decrease in bilirubin levels. The unit of light intensity is $W/cm^2/nm$. It can be measured with a spectral radiometer. Intensive phototherapy requires spectral irradiation at least 30 $\mu W/cm^2/nm$. Generally, approximately 10 $\mu W/cm^2/nm$ light intensity is applied in phototherapy. Also light intensity should not pass 65 $\mu W/cm^2/nm$ value, because there is harmful effect on newborn [13].

1.5.3 The Distance Between the Target and the Light Source

The distance between the light source and the baby's skin from the light source affects the light intensity. It is important in this regard. There is also an inverse relationship between light intensity and distance. Light intensity is expected to be high for effective treatment. However, there should be a distance between the light source and the surface to prevent the baby from being affected by heat and the risk of burns.

This distance should be between 35-40 cm in fluorescence and halogen light source. It is determined as 20 cm for LED therapy devices [7, 13].

1.5.4 Footprint

The area that can be processed by a particular light source is expressed as the light footprint size. The phototherapy device needs to be designed so that the irradiated surface area is the highest. If the surface area to which the phototherapy light is transmitted is expanded, the amount of degraded bilirubin will also increase. Also, the light intensity is highest in the center and decreases towards the periphery.

1.6 Types of the Light Sources Used in Phototherapy

There are many light sources used for therapeutic purposes in phototherapy from past to present: fluorescent lamps, halogen spot light, and LED light sources. The most important criterion in choosing a light source is the wavelength. Another important criterion in the selection of a light source is that it has a fixed wavelength, the heat accumulation it creates on the surface is low, and it does not cause any negative biological effects [14].

1.6.1 Fluorescent Lamps

It is important to remember, though, that not all fluorescent tubes are created equal. The irradiance generated by different types of fluorescent bulbs differs significantly. There are various results within the same wavelength range of 425 to 475 nm. Fluorescent Lamps have wider bandwidth than LEDs. To be successful, fluorescent tube units are frequently placed too far away from the newborn. It can heat on the surface of the newborn. This heat can cause skin burns [14].

1.6.2 Halogen Spot Light

Halogen spotlight provides sufficient radiation for treatment. But the light intensity at the surface is much higher at the center. This feature increases the risk of heat-based complications in the patient.

More distance should be maintained between the light source and the baby to prevent burns. It is necessary to run a fan next to it. Its brittleness increases at high temperature level [14].

1.6.3 LED Light Sources

LED lights are now favored over other types of lamps in phototherapy equipment. They have more limited bandwidth. They create less heat on the surface yet have a higher light intensity. Thanks to the low production of heat, side effects such as burns to the newborn are minimized.

With newborns, lamps are placed closer together when we use LEDs. LEDs are non-fragile and consume little electricity. Also, these lamps are rather tiny. The light stability of these lights is excellent for long-term use. Their light intensity is not becoming less. In this study, LEDs are used as the light sources for preventing the negative side effects of other light sources [14]. Comparison of light source is given (Table 1.1).

Table 1.1: Comparison of light source

	Light emitting diode (LED)	Fluorescent Tube	Halogen spotlight
Lifespan	✓	✓	x
Cost	✓	x	x
Heat Output	✓	x	x
Efficiency	✓	x	x
Comfort	✓	x	x
Material(hazardous-mercury)	✓	x	✓

There are also different studies on the selection of different wavelengths and light sources. Addi et al. [19] develop an automatic phototherapy garment for newborns. They use blue LEDs and an Arduino microcontroller. In this paper; the advantages of bilirubin degradation are presented as a reason for choosing LEDs instead of conventional phototherapy light sources. This study points out that bilirubin degradation reaches 44% and 30% in vitro and in vivo.

But bilirubin degradation results fall down 35% and 16% for in vitro and in vivo in the usage of conventional light sources. Addi et al. [19] design wearable phototherapy devices; they regard them as alternative therapy.

Because wearable devices have the opportunity for continuous breastfeeding period. But rising temperature on the surface is a disadvantage in this technic. In this study, two phototherapy light sources efficiency are compared. 20-Watt fluorescent light is chosen as conventional phototherapy. Fluorescent light wavelength is between 400-500 nm and it has a peak value of 450 nm. LEDs wavelengths are changing from 465 to 470 nm.

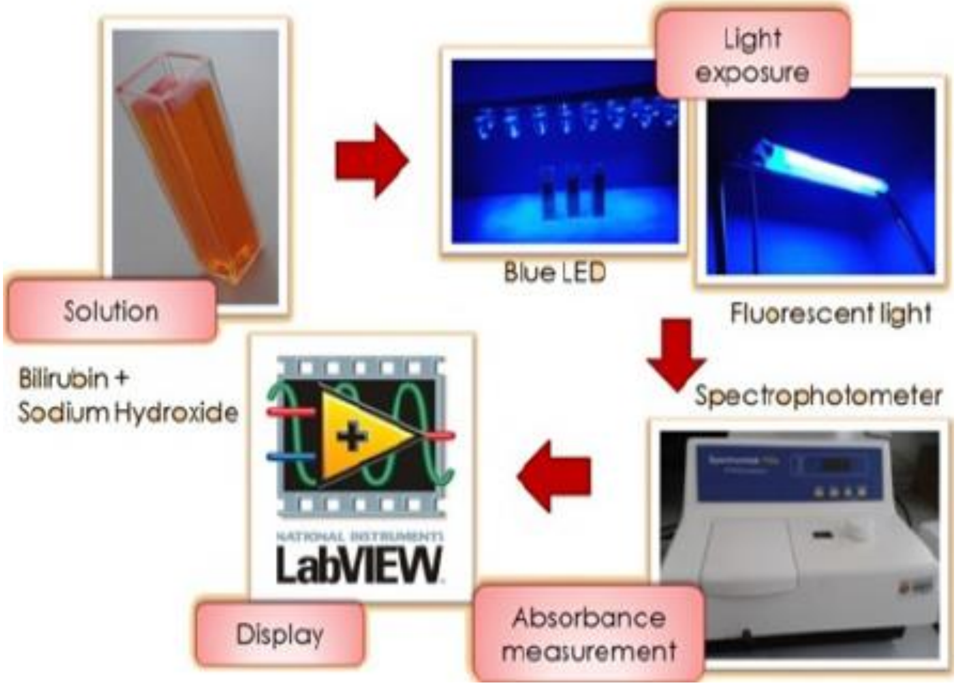


Figure 1.4: Steps of the phototherapy bilirubin test [19]

Bilirubin test steps of the study are shown. Firstly, a bilirubin solution is prepared. 50 mg/dl to 500 mg/dl bilirubin solution is prepared by mixing 5 mg of bilirubin and 10 ml of a 0.05 molar sodium hydroxide. In the next step, fluorescent light and LEDs lights are applied to bilirubin at different time intervals. These time intervals are determined as 10, 30 minutes; 1, 2, and 3 hours. When bilirubin concentration is measured after the light application, bilirubin degradation has a greater results using LEDs. In the ten minutes, there is not any change in bilirubin concentration using fluorescent light; but bilirubin degradation is 0.87% using LEDs. As a result of bilirubin degradation in 30 minutes; the bilirubin degradation value is measured at 10.62 % and 0.87 applying LEDs and fluorescent light respectively (Figure 1.4).

When LEDs application is compared with the fluorescent light application; LEDs have a higher degradation value in all five-interval times. The efficiency of blue LEDs are proven as counter to conventional phototherapy technics.

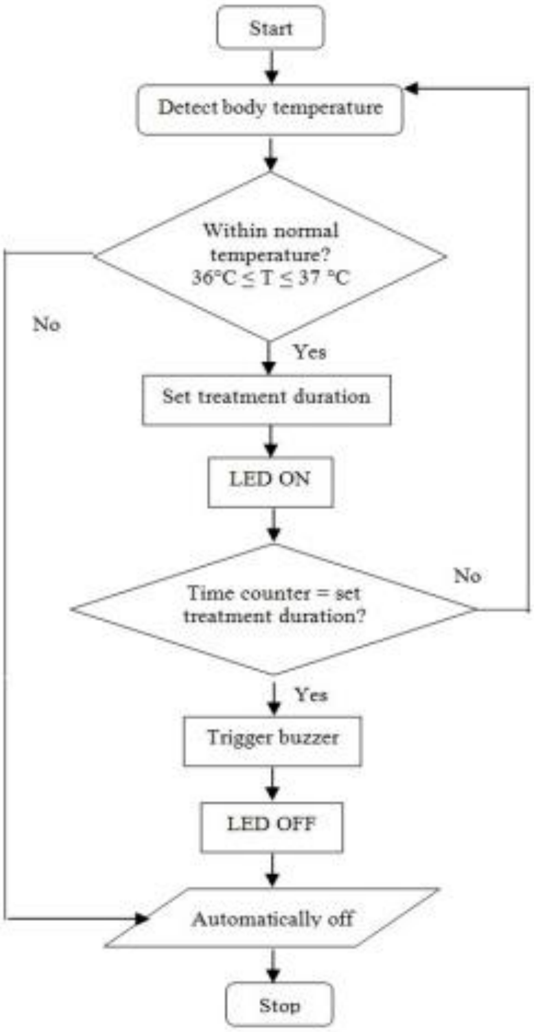


Figure 1.5: Phototherapy device algorithm [19]

Also, there is the risk of rising body temperature; so the system has a temperature controlling system. The temperature sensor is attached to a wearable system, and temperature is measured momentarily. Results are shown on the LCD screen and the system is blocked, when body temperature results digress from normal value.

The system is controlled by an Arduino controller and the application is completed; users are informed by the alarm (Figure 1.5).

In the study of Addie at al. [19]; blue LEDs efficiency is proven with a bilirubin experiment. Hence bilirubin degradation is determined greater using blue LEDs than fluorescent light. Also, an automatic, time and the temperature-controlled system are improved [19].

Ajiwiguna et al. [20] developed a phototherapy device using blue LEDs as a light source. Ajiwiguna et al. [20] emphasizes that 60% of a newborn be jaundice in the first week. Also, different therapy technics are pointed out:

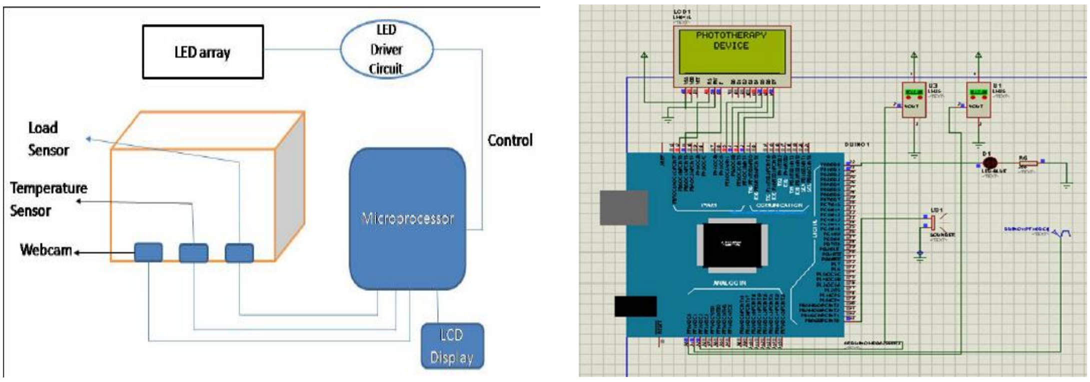
Phototherapy is applied to a newborn, when their bilirubin value is between 12 mg/dl, and 25 mg/dl. If the bilirubin level pass over 25 mg/dl blood transfusion technics is applied. The product consists of a fan, a heat sink for controlling system temperature. Hence heating of LED can embarrass. The light source includes eight LEDs.

LED Package has 32 mm x 30 mm in length. 40 cm x 70 cm field is brightened by the light source. 80 cm length is determined between the light source and target area. Also, each LED packages have 4.3 Volt and 1.2 Ampere values. 9 different points are a remark on the 40 cm x 70 cm target area. Light intensity was measured at all of the points. 0.3 W/m^2 value is established. The effectiveness and durability of LEDs were also measured in order to assess the light source's efficiency. The luminous flux was measured as 0.3 W/m^2 (it was measured by lux-meter). The light intensity was measured as 0.3 W/m^2 at 460 nm wavelength. Luminous efficacy is the ratio of luminous flux to light intensity. It was calculated 60 lumen/Watt.

Optical calculation and measurement are done at the different time intervals. The test duration was determined as 8 hours. The light intensity was measured at 1-hour intervals. Phototherapy devices have 0.3 W/m^2 light intensity during 8 hours. Considering the results, the device was suitable for use in terms of light intensity and durability [20].

Akşahin [21] has a study that Multifunctional Phototherapy Device Design.

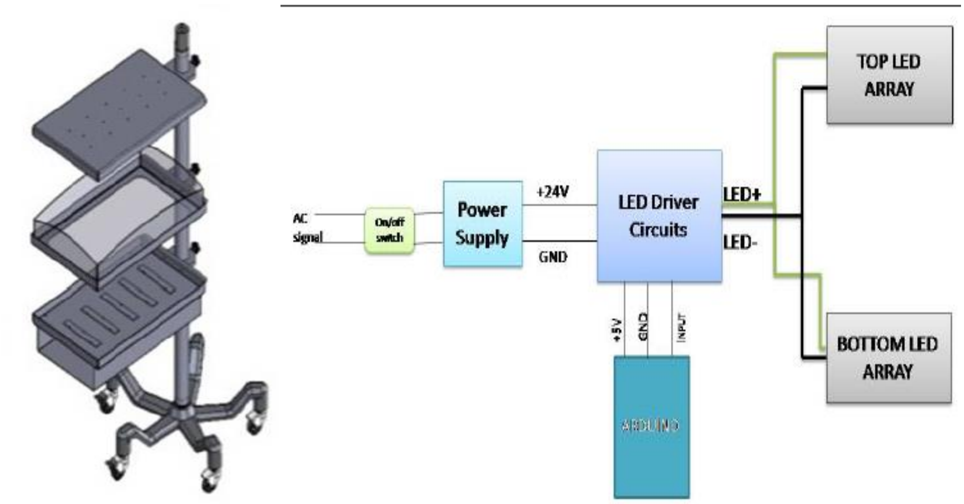
In this research, Akşahin [21] develops a radically new conceptual phototherapy system prototype. This study was created to fix the flaws in current commercial systems developing a new design.



(a) (b)

Figure 1.6: System design, (a) General part of the system, (b) Electronic design [21]

In Figure 1.6; the general study mechanism and Proteus drawings are shown. The system is controlled by Arduino Mega. The presence of the newborn in the system is detected using a load sensor. The sensor produces an output voltage when there is any pressure is applied it. Hence microcontroller can open or close the system automatically. The optical temperature sensor was used to make an instantaneous calculation of the target temperature. The computer issues audible and written warnings at the end of the time limit (Figure 1.6).



(a) (b)

Figure 1.7: System design, (a) Device schematic, (b) Electronic diagram [21]

The light source is placed on the bottom and top side of the device to increase the footprint. LEDs are placed on a plate 6x5 matrix (Figure 1.7.a).

6 LEDs are connected serially.5 LEDs strips are connected parallel. Hence LED array is completed. Light panels take their energy source from mains voltage. After LEDs Driver regulate voltage; current transfer to two LEDs arrays like in Figure 1.5.b. 350 mA current is conducted to one LED strip. Also, each Power LED has 3.2 V. For focusing light; a 45º lens was used. This process minimizes the device's cost and power usage, while also lowering the number of LEDs decided during the preliminary work. Hence improving the design of phototherapy devices, a more effective technic is achieved [21].

Cabacungan et al. [22] work on a low-cost phototherapy system. The system wanted to be fewer prices and be more efficient.

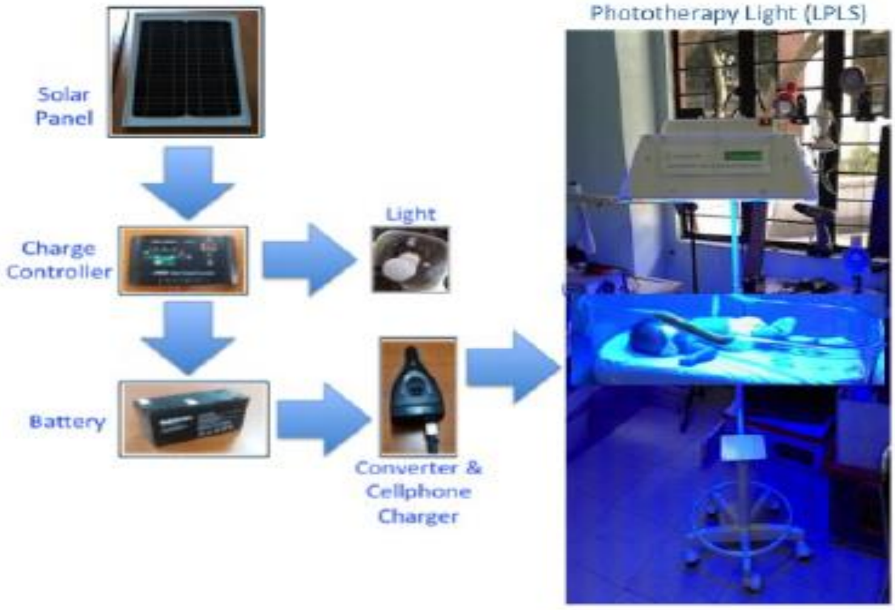


Figure 1.8: LPLS system [22]

Low-cost phototherapy light system (LPLS) system diagram is shown. A solar panel is used as the power source (Figure 1.8).

Light-dependent resistors (LDR), temperature and humidity sensors, microcontrollers, audio-visual System, and internet are used in this low-cost phototherapy system, an intelligent system is constituted. The light source has a peak wavelength at 447.68 nm. 20 LEDs (3 Watt) are used as a light source. Stand is used and it is length adjustable. Also a computer fan is used for the cooling system. Then the system is put through a stress test by running it nonstop for 72 hours. Monitoring, wavelength, irradiance, and power usage are observed.

In the next step; a low-cost phototherapy system is developed using some sensor and monitoring systems. Using sensors and monitor, some clinical needs is aimed to iron out. Also, in this system, 7-watt LEDs are used as a light source. These 7-watt LEDs are stronger than 3-watt LEDs. The irradiance level of the Improved Low-cost Phototherapy Light System (ILPLS) is measured and the results are showing us, the ILPLS system is higher 3 times than the first system. 8-bulb unit is placed on the light source, there is 13 cm between all LEDs. Two ventilation fans are used for the cooling system.

A microphone and a camera are added to the system for sending audio or voice information. Using a monitor, irradiance accuracy is determined. Durability tests are done and there is not any significant changing.

If we compare these two systems and products used for commercial purposes; the ILPLS system has 90 $\mu Wcm^{-2}nm^{-1}$ irradiances, the LPLS system has 80 $\mu Wcm^{-2}nm^{-1}$ irradiances, the commercial unit has 70 $\mu Wcm^{-2}nm^{-1}$ irradiances at 30 cm distance between a light source and target area. Power consumptions are 75 watts, 90 watts, and 400 Watts respectively in LPLS systems, ILPLS systems and commercial units. Also, ILPLS has the advantage for having a sensor and monitoring system [22].

The home type phototherapy unit was designed by Yilmaz et al. [23]. They use Light-emitting-diode as the light source. This design was created to be used as a supplement to traditional methods. The aim of this study was to develop a minimum-cost, laborless transportable, reduction in weight phototherapy system called a "home-type phototherapy system" and compare it to conventional phototherapy systems. Also, after the design unit, the clinical trial is done and the efficiency of the home-type phototherapy unit is determined.

Figure 1.9: The home-type phototherapy [23]

Design of the home-type phototherapy unit is seen. 6 m flexible LED light strips are getting off the shelf; LEDs strip is set on the tube (Figure 1.9).

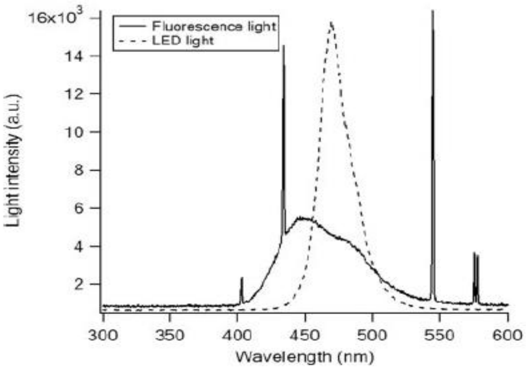


Figure 1.10: Light intensity wavelength diagram [23]

A wavelength range of 450–500 nm is supported by the system and it emits light with a maximum intensity of 470 nm as seen (Figure 1.10). The tunnel measures 50 cm in circumference, 34 cm in width, and 36 cm in height, with a gross illuminated area of 1700 cm^2.

The irradiance distribution in the tunnel is determined by calculating light intensity at 20 distinct points in the tunnel. The tunnel's intensity was highest in the middle and lowest at the top.

The irradiance of home-type phototherapy is measured and it is found 16–20 μWcm^{-2}nm^{-1}range. Irradiance value is change between 16 and 20 μWcm^{-2}nm^{-1}; variation is less than 20%.

The unit is a recent concept, and the overall cost of the unit in the manufacturing stage is estimated to be less than $90. A distance is 25 cm between the newborn and the light source, and the irradiance of traditional fluorescence phototherapy units was tested at various locations. Irradiance is found to vary between 7–12 watts.

To compare home-type phototherapy and conventional fluorescence phototherapy, the conventional fluorescence phototherapy unit was used on 25 of the 50 neonates, while the home-type phototherapy unit was used on 25. There were no phototherapy-related complications in either technique. Then the rate of decreased in bilirubin is measured. Success percentages were obtained by the ratio of bilirubin concentration difference before and after light application to the total time.

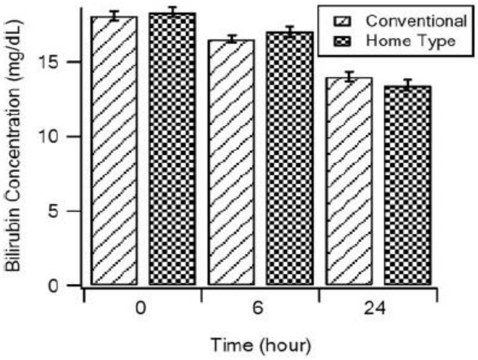


Figure 1.11: Comparison of traditional and home-type devices [23]

Phototherapy is applied during 24 hours. At the end of 6 hours, bilirubin measurement is done. The rate of initial bilirubin level decrease for the first 6 hours of phototherapy. Conventional fluorescence phototherapy has a greater result than the home-type phototherapy unit. The overall rate of decrease for the home-type phototherapy unit is greater than the conventional fluorescence phototherapy unit at the end of the 24-hour period. Different bilirubin concentration is prepared at the initial time, after 6 hours, and after 24 hours (Figure 1.11). The home type has a good result at the end of the phototherapy [23].

Shirzadfar et al. [24] developed an automatic and portable phototherapy device. The product is designed as wearable instead of the conventional method. By putting the baby in a cover that looks like the baby's clothes, the portable wearable phototherapy system will help decrease neonatal bilirubin levels. In the conventional devices, the mother and baby are to be admitted to the hospital and the baby is to be separated from the mother during care. Thanks to this unit, mothers can check their babies' condition at home and safely breastfeed without having to take them to the hospital's pediatric ward.

LEDs are used in this work for their durability, and lower power consumption. Also, LEDs produce less heat than other light source. Then irradiance is calculated as 51.28 $\mu W/cm^2/nm$. This value is above 30 $\mu W/cm^2/nm$, which the American Academy of Pediatrics has set a limit for intensive phototherapy. Maximum power dissipation is 80mW and wavelength is changed between 385 nm – 395 nm, the peak wavelength is taken as 390 nm.

The LM35 temperature sensor is used to detect are there any increase in heat. Relays are used for the management system. When the temperature is reached out of wanted result; the relay is moved by the system. It is a real-time electrical key. The system will be stopped when there is a critic situation. LM35 sensor is commonly used and the price is lower.

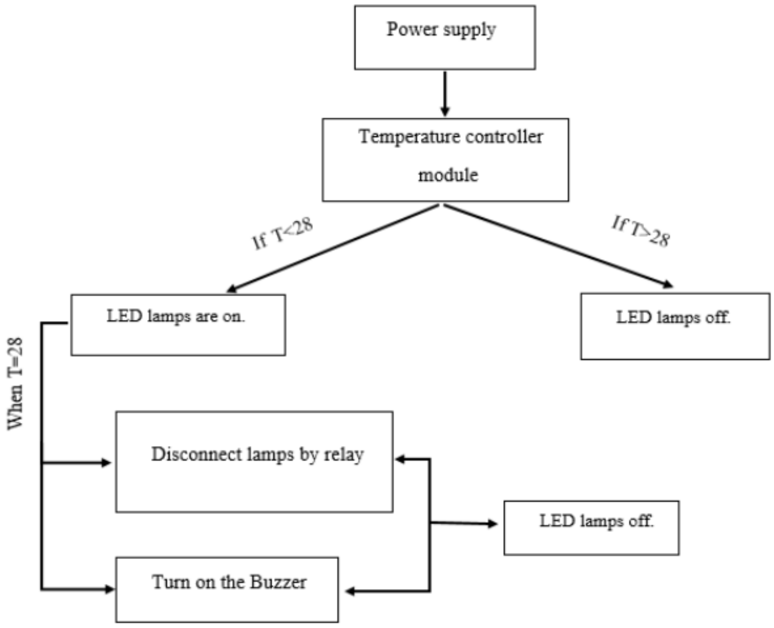


Figure 1.12: Study diagram of phototherapy device [24]

The study diagram of the system is seen basically (Figure 1.12). 28° C is determined as the critic value. The system can control automatically. In this study, a wearable system is developed and temperature is controlled by the system automatically. Light source LEDs are attached on the clothes. The temperature level of the newborn is monitored and the alarm system is ready for warning. Thanks to the wearable system, treatment is can continue without leaving the baby and mother during the breastfeeding period [24].

Nabizath et al. [25] want to develop a device that came up with a solution for trouble-shoot lack side of existing phototherapy devices.

Exposure of radiation can cause some problems on the surrounding of the device. For protecting the surrounding staff, the device is designed like in Figure 1.13. Using this barrier, the passage of light is prevented to a certain extent. Also, the dispersion of the LEDs is shown in the Figure. Light is sent to the body top of the device. The system includes 10 blue LEDs, and 2 white LEDs. Blue LEDs are symbolized with black colored dots, and white LEDs are symbolized with white colored (Figure 1.13).

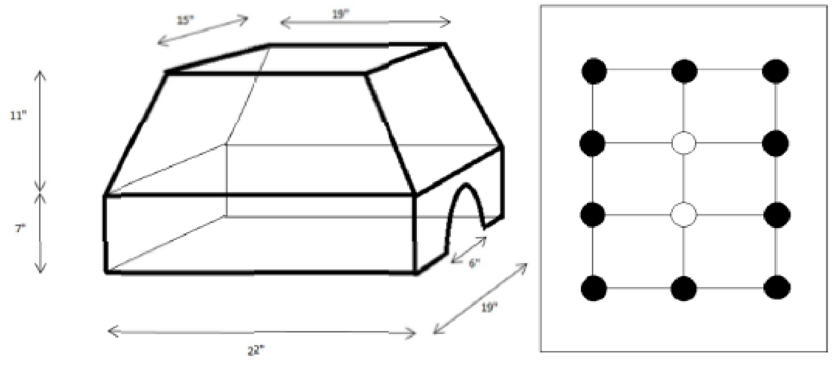


Figure 1.13: Device schematic [25]

The system has an LED driver circuit. The intensity of the light is can be changed, LDR is used for detect to light intensity levels. A timer is used on the system; hence doctor or nurse can organize time formerly, prearranged time is filled, the device is closed automatically.

Yellowish pigmentation is produced on the skin because of bilirubin accumulation. Normally, pigmentation decreases, after the treatment is completed. In this study, image analysis is done, and skin images of neonates are compared. Hence phototherapy efficiency is determined using this image. Also, there is no need to take blood. This stage is achieved non-invasively.

A MATLAB program is used for image analysis. The input image is taken and their size is regulated. Then it is converted to a WAVE file, and this file is converted to a spectrogram. Spectrogram values are compared with a normal image.

Nabizath et al. [25] have completed a system that prevents the adverse effects of light on the people around and determines the treatment efficacy by image processing [25].

Jimenez et al. [26] approached the subject from a different perspective. They have created a new design called kangaroo mother care so that the baby and the mother are not separated during the treatment. The newborn has either preterm birth or a low weight. It will not be able to regulate the body temperature sufficiently.

The newborn in this situation is kept in the incubator and the stability of the body temperature of the newborn is ensured. The contact between the mother and the baby is more functional than the incubator for the balance of the body temperature of the baby. For this reason, Jimenez et al developed the device in the Kangaroo type mother model. While developing the device, they evaluated the heat increase caused by the light source. SMD5050 type, 450nm, blue LEDs were used as the light source in the developed device. LEDs are mounted on a flexible LED strip. DC supply voltage of 12 V was used. The LED strip was cut at 12 cm intervals and each piece has 3 SMD5050 LEDs. 5 LED strips are connected in series. 5 LED strips in series were connected in parallel. The array of 5x5 LEDs was obtained. A transparent plastic package was prepared for LED arrays. The package is made of polyethylene plastic film. The LED mattress uses 0.98-Watt power. The visual of the LED mattress is shown in the Figure 1.14.a.


(a) (b)

Figure1.14: (a) phototherapy device, (b) Kangaroo type mother model [26]

Then the analysis of thermal conditions is realized. Mannequins with temperature sensors are used (Figure 1.14.a). Several heating systems for newborns are thermally analyzed using a neonate mannequin. Heat balance is used to analyze heat transfer. An electrical heater or resistance inside the mannequin is used to mimic metabolic rate. Thermal energy from LEDs that has been transmitted to a neonate and is analyzed. Temperature-controlled tests have been used to measure. Mannequins are figurines that are used to represent people. The results show that 0.395 W is present on a 250 cm^2 surface. This data is useful. As a result, it is assumed that it provides a low thermal threat to a newborn. Three rechargeable lithium-ion batteries are used for the power supply LED mattresses. Batteries are connected in series within a tiny belt bag. A charge controller and a data recorder are also included in this bag for keeping track of phototherapy sessions. The waist bag and the clothes are designed for the LED mistress [26].

In this thesis, the development of the multicolor LED-based light sources with 3D design was aimed. The blue-green-white color LEDs were used for preventing negative side effects of blue light. The conversion of bilirubin to lumirubin was achieved with the use of green light. Lumirubin is not a toxic structure and its elimination from the body is faster than the photoisomers of bilirubin. The use of blue-white-green LED makes the study different from its counterparts in the literature. For example, Palavskii et al. [18] used green-blue light in their work. Nabizath et al. [25] used a light source in the white-blue color band. A foldable light panel was designed to adjusting light transmission. Hence side surfaces of the baby could be taken enough light. The denser light intensity with a perpendicular angle would be sent on the baby surface. There are different multidirectional studies in the literature. For example, Akşahin et al. [21] design tunnel type device, and in the work of Yılmaz et al. [23], LED array is placed on top and bottom of the device. 3D maintains its difference with its foldable panel structure. In this way, the light footprint will increase and bilirubin degradation will increase. More economical, adjustable light intensity and adjustable exposed area by light were aimed. An automatically self-control system has been developed to prevent the possible negative effects of phototherapy devices. There are different studies where the sensors are available and the user is warned in unsuitable situations. For example, in work of Shirzadfar et al. [24], the system is controlled using temperature sensor. Thus, the risks of burns, hypothermia and hyperthermia that may occur in the baby are prevented. Because of this reason, temperature sensor is used in this study. In this study, it was aimed to use 3 different wavelengths (blue, green, white), 3D foldable light source design and various light intensity measurements, bilirubin tests and temperature rise measurements [21,23,24,25].

Chapter 2

Materials and Methods

2.1 Materials

In this study, 5 red, 10 green, and 12 blue power LED was used for lighting purposes. A ready-made plate was used for fixing the LEDs. Humidity, light intensity, and temperature sensors were used to obtain data. Arduino microcontroller was used to process the data and control the system. The obtained data was printed on the LCD screen. In cases where the system needs to be turned off, the Arduino was programmed to turn the relay on and off. The power supply was used for the energy need and different light intensity was achieved in the system with a DC-DC regulator. Mechanical designs were made on SOLIDWORKS and using a 3D printer. Acrylonitrile butadiene styrene (ABS) was used as material of filament. A fixable hinge was used between the panels for the mobility of the panels and to be adjusted at the desired angle.

After the device construction was completed, light intensity, bilirubin, and temperature tests were performed. A light power meter was used to measure light intensity. There is bilirubin, NaOH, and distilled water in the solution prepared to investigate the effect of the device on bilirubin. Absorbance values were obtained with a multimode device before and after the application. A thermal camera was used for temperature measurements.

2.2 Electronic-Mechanical Design and Production

It covers the electronic and mechanical designs of the device and the implementation of the designs. At this stage,

- designing the arrangement of the LEDs in the Proteus program,
- making connections of sensors with Arduino microcontroller,
- power supply and DC-DC regulator connections,
- mechanical design of the system and 3D printer stages are completed.

The electrical and mechanical design and production stages were listed below.

2.2.1 Electronic Circuit Drawing

The placement of 1 Watt LEDs on LED panel in the system was completed using the Proteus program.

The light source contains 3 panels. Each panel has 9 LEDs. 1Watt LEDs are connected in series in 3 rows. 1Watt LEDs in a series of three were connected in parallel to each other. 1 Watt LEDs with green, white, and blue wavelengths were homogenized in the drawing.

2.2.2 The Production of System Control Card

Arduino: Arduino is a very widely used microcontroller board. Arduino nano was used in this study. It is smaller than other versions. It is easy to use with a breadboard, and it is designed in harmony. It is also easy to use with other electronic components. It is easy to use and has open-source hardware and software. It is available in different versions, including the Atmel ATmega168 and ATmega 328. There are analog and digital pins on the Arduino. In this way, analog and digital pins are processed. It contains 14 digital pins. Pins can be used for input and output purposes and work at 5V operating voltage. 40 mA current can be output from the pins. It has also been used in different studies on medical devices. For example, in the study of Dhirendra et al. [27], the device developed for knee joint health was used as a microcontroller [27].

LDR: LDR is a photoresistor and a passive component. As the incident light increases, the LDR resistance decreases. In this way, the light intensity in the environment can be estimated according to the LDR data [28].

DHT11: DHT11 is a temperature and humidity sensor, with high reliability. It gives different digital output according to changing temperature-humidity values. These values are read by the Arduino. It has also been used in different studies on medical devices. For example, in the study of Zeng Chen et al. [29], it was used as a sensor for Covid-19 detection [29].

All components to be used in the construction of the control card were connected to each other and soldered. The materials used in the construction of the control card are listed in Table 2.1.

Table 2.1: Materials used in the control card

Material	Number
light intensity sensor-LDR	1
humidity sensor-DHT 11	1
temperature sensor	1
LCD	1
Relay	1
Buzzer	1
dc-dc regulator	1
power supply	1
Arduino nano	1

Jumper cable and solder were used to complete the connections between components. First of all, the sensors and the buzzer were connected to the Arduino. Attention was paid to the ports. The digital pins where the sensors are controlled are noted. Then the LCD screen and Arduino microcontroller were connected. Energy would be taken from the city grid and sent to the power supply. The wires of a plug were connected to the positive, negative, and GND ports respectively on the power supply. Thus, the voltage from the city grid was reduced to 12 volts. The connection of the power supply with the DC-DC regulator has been established.

The minus of the DC-DC regulator was connected to the negative pole of the LEDs on the panel.

The positive connection point at the output of the DC-DC regulator and the COM of the relay are connected with a cable. It was then achieved by connecting the NC of the relay with the positive pole of the LEDs. Then the relay connection was completed to control it with the Arduino microcontroller. All components to be used in the construction of the control card were soldered. The basic design is schematized (Figure 2.1).

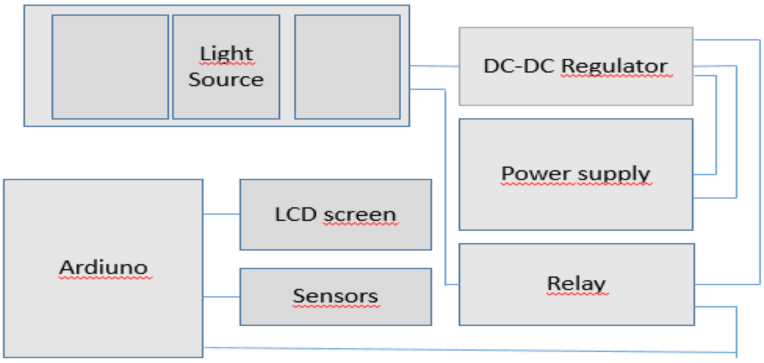


Figure 2.1: Design of system

2.2.3 Optic Design of Prototype

The area illuminated by a single LED was calculated. The angle of the lenses are 45°. This value was taken into account when calculations were made. The power of the light from a single LED used in subsequent calculations. The light intensity generated by a single LED was then calculated as the ratio of power to area. To find the total light intensity, the total number of LEDs to be used was multiplied by the light intensity produced by a single LED. The value obtained was divided by the bandwidth to obtain the desired unit value for jaundice.

The lens radius and the distance of the LEDs from each other when placed on the panel were determined. By making use of the luminous area created by a single LED, the area to be illuminated by all LEDs was designed. Drawings were made with the principle that the center points of the lenses and the centers of the circles illuminated by the LEDs are of equal length. The total illuminated area was calculated and the points with the highest light intensity were indicated.

2.2.4 The Production of LED Panel

1 Watt power LEDs are used for enlightenment in this study. Green, blue and white color LEDs is used (Table 2.2).

1 Watt LEDs: Light which has a narrow range spectrum is emitted by power LEDs. They have a better thermal effect and durability than the other light sources. It has a positive and negative terminal, likely other LEDs. It hasn’t ultraviolet radiation. Also, PWM can use with LEDs. It needs to be 3.0 and 3.5 Volt.

Table 2.2: Materials used in LED panel

Material	Number
1-watt green power LEDs	12
1-watt white power LEDs	9
1-watt blue power LEDs	5
LEDs plate	

Materials used in LED panel is shown on Table 2.2. The plate is taken ready for fixing the LEDs. The plate is designed with 3 LEDs connected in series. First of all, the plate was heated with a blown soldering iron and cut into pieces with a guillotine to make it suitable for the desired design. Thus, three separate identical plates were obtained for fixing the LEDs. Stability checks and plus-minus poles of 1 Watt LEDs were determined with a multimeter. Defective LEDs detected. Thermal paste was applied to the back surface of the 1Watt LEDs for cooling purposes. Soldering on the plate was carried out.

2.2.5 SOLIDWORKS Drawing of the System

3D drawings of the LED panel case and the stand of the prototype were designed using the SOLIDWORKS (EDU Edition 2012-2013) program. SOLIDWORKS is a program that provides 3D drawing, analysis, and simulation of the model. First, the dimensions of the model to be designed were determined. Drawings were made in SOLIDWORKS. Then the drawings were saved in SLDPRT format.

Then SLDPRT format was transformed to an STL file. This file is used in the CAD program. Then STL file was transformed to G-code. G-code is used in 3D printer devices.

The stand is designed as adjustable in height. The light source consists of three separate foldable panels. The foldable structure of the panel allows the light to be concentrated in a single area. A separate box is drawn for equipment controlling the system. Arduino, DC-DC regulator, relay, and LCD will be placed in the box. Holes have been created on the surface of the box so that the cables connecting with the sensors can pass. In addition, many holes were created in the box walls to minimize the heat that may occur in this part.

2.2.6 3D printing of the System

The designed materials were obtained using a 3D printer. SLDPRT format files convert to STL format files. For the 3D printer process, this file converts to G-Code.

The 3D printer filament for the case and panel is determined as acrylonitrile butadiene styrene (ABS), which has high material strength. ABS is a heat resistant material. It is widely used in 3D writing. It is also used in biomedical projects. Hence the panel, case, and cover of the system are printed using a 3D printer.

2.2.7 Production of the Mechanical Parts of the System

The justification of the 3D panel was intended for the assembly of the light source in the system. A light source consisting of 3 separate panels was designed. To have a fixable and variable angle between the panels. It was deemed appropriate to use 360° rotating fixable hinges. In this way, the user can adjust the panels to the desired angle and there will be no need for any support between the panels.

During the construction of the project, a need was determined for a plane where the hinges would be fixed and the LED plates would be placed. The material of this plane was determined to be aluminum. In this way, the heating situation on the plate will also be solved by the aluminum plate, and the aluminum surface will dissipate the heat. Overheating in the system will be prevented.

Aluminum plates were cut with a grinding machine. 3 coplanar dimensions of 82x104 mm were created. The hinges were fixed between 3 Aluminum plates using a drill.

Since the weight of the panel has increased due to the aluminum plates, it was obtained by using metal material instead of a stationary 3D printer to carry the panel. A cylindrical pipe with a length of 300 mm was obtained by cutting using a grinding machine. After cutting a fixable plate on the floor, welded vertically with the cylinder pipe we obtained. Afterward, sliding support (clamp) was installed on the pipe to adjust the height of the panels and keep them at a constant distance.

2.3 Prototype Assembly and Control Software

2.3.1 Control of the System with Arduino and Card Production

First, the necessary libraries to use the sensors were installed on the Arduino. The DHT11 and temperature sensor library are also available online at Arduino. After the libraries were downloaded, the sample codes uploaded to the Arduino were tried and data were obtained from the sensors. The obtained values were printed on the computer screen and checked. The library of the LCD screen was also installed on the Arduino and the received values were printed on the LCD screen. Then the buzzer attached to the system was checked. A temperature range in which phototherapy will continue has been determined. If the value received from the sensor is between these values, normal values are written on the screen. When the values went out of the determined range, control software was done to write a warning text on the screen. In addition, the buzzer was enabled to be active during the warning. Then, 'high' and 'low' commands were sent to the relay independently of the data received from the sensors. The relay was controlled with Arduino and it was done on and off. In the high command, the current from the DC-DC regulator is sent to the LED panel. Then, the high and low commands sent to the relay were adapted according to the data from the sensors. If the data received from the sensor is within the predetermined range, the high command is sent to the relay, and if it is out of range, the low command is sent. In other words, the flashing of the LEDs was adjusted with the data received from the sensors.

2.3.2 Assembly

After the electronic control software and mechanical parts of the system were completed, the assembly phase was started. First of all, the led panels were glued on the previously obtained plates and LCD sensors, and microcontroller regulator, are placed in the box, which was previously printed by a 3D printer. A resistor is soldered to main cable of LED panel. The stand screw into the led panel. Finally, the system is complete. Lastly, total current, voltage is measured using an multimeter.

2.4 Tests

2.4.1 Light Intensity Measurement Test

The output power of the light sent from the device was measured using a power meter at different angles (180°, 135°, 90°), and at different distances (0, 20 cm, 30 cm). Output power measurements were completed by using the power meter available in İzmir Katip Çelebi University Biomedical Optics and Laser Applications Laboratory. For power measurements, PM100D Optical Power Meter was used. The filter size that measures the light power of the device is 1 cm^2. It contains a photodiode and measures the power of light at certain wavelengths. It has different sensitivity according to wavelengths. The sensor can measure the wavelength of light between 185 nm and 20000 nm. Therefore, the wavelength information used before the measurement is set into the device.

It was determined at which wavelength the output power of the blue and green LEDs had a peak value. The device was tuned to different wavelengths and the output power was measured. The wavelength with the highest output power was determined separately for green and blue LEDs. These values have been determined for the purpose of finding the wavelength at which the power meter will be adjusted in the measurements to be made with the power meter.

The output power of each LED on the panel was measured separately with a power meter. During the process, no distance was left between the sensor and the LED, and the system was set to the highest light power.

While measuring the output power of blue LEDs, the power meter is set to 460 nm; In the measurement of the output power of the green, white LEDs, the power meter is set to 530 nm.

7 different points were determined on the potentiometer. By turning the potentiometer to 7 different points, the device can be adjusted to different light output power values. The power meter was set at 430 nm. The distance between the sensor and light panel is adjusted as 30 cm. Light panel angle between the panels is adjusted to 180°, 135°, and 90°. The output power is measured at 7 different values for these three angles separately. Then the same application is repeated changing distance as 20 cm. The power meter is adjusted to 530 nm and the measurement is repeated. Lastly, light intensity is calculated for maximum output power. The unit of light intensity is given in different nm. However, some discrepancies were noticed in the studies in the literature while calculating the output power. For example, in the study of Addi et al. [19], light with a wavelength of 460 nm was used. Output power/area is divided by wavelength (460 nm). However, such a calculation cannot be considered correct. In the calculation of $Wxcm^{-2}/nm^{-1}$, cm and nm are two separate units of length and it is illogical. The power/$4\pi r^2$ formula was used in the study of Akşahin et al. [21]. The value $4\pi r^2$ used as the area is known as the area of sphere. For this reason, we considered the nm value as the bandwidth in our study and accepted it as power/ πr^2/nm (bandwidth).

2.4.2 Biological Applications of the Prototype on Bilirubin Solution

To determine the effectiveness of the device, light at different light intensities, angles and distances will be applied to the bilirubin solution. A bilirubin solution was prepared beforehand. A 0.05 molar, 10 ml NaOH solution was prepared.20 mg NaOH solution is weighted and solved on 10 ml distilled water. Bilirubin solutions with concentration values of 0.0025 mg/ml, 0.005 mg/ml, 0.01 mg/ml, 0.025 mg/ml, 0.05 mg/ml were prepared, respectively.

Absorbance measurements of the prepared bilirubin solutions were made at microplate reader device and a calibration graph was obtained. The formula on the graph was used to obtain bilirubin concentrations over absorbance.

A bilirubin solution at a concentration of 0.01 mg/ml was used to apply phototherapy at different angles and distances. The angle between the panels was changed to 90, 135, 180, and 6 different measurements were made at 30 cm, 20 cm distances. A solution of 0.01 mg/ml bilirubin was pipetted into 3 wells on the plate with 200 ml. The phototherapy application took 30 minutes for each measurement. Absorbance measurements were made at 460 nm before and after each application. Bilirubin concentrations were obtained by using the absorbance values obtained and the formula in the previous calibration curve. The average of the bilirubin concentrations obtained from the 3 wells on the plate was used in the procedures. Success percentages were calculated to show the effectiveness of the device. Success percentages are ratio is the percentage of the difference in bilirubin concentration before and after irradiation to the bilirubin concentration before irradiation. The percentage of success for each application was calculated. Efficacy comparisons between applications were made.

In each application, the bilirubin solution was placed in 3 different wells on the plate. Standard deviations of 3 different bilirubin concentrations obtained from the applications were calculated.

The temperature raise on the surface was recorded before and after the bilirubin application. Temperatures were determined using the device's LDR and calibrated thermal camera. The thermal camera (Testo 882, Melrose, USA) is located in İzmir Katip Çelebi University Electrical and Electronics Department. In addition, differences between LDR and thermal camera values were observed.

Chapter 3

3. Result

3.1 Electronic Circuit Drawing

In order to design the light source of the system, the electronic drawing was completed using the Proteus program. 1Watt LEDs are connected in series in 3 rows 1 Watt LEDs are connected in parallel to each other in series of 3 LEDs. 9 parallel LED arrays are obtained. 1 Watt LEDs with green, white, and blue wavelengths were homogenized in the drawing. The Proteus drawing of 12 blue, 5 white, 10 green 1 Watt power LEDs (Figure 3.1).

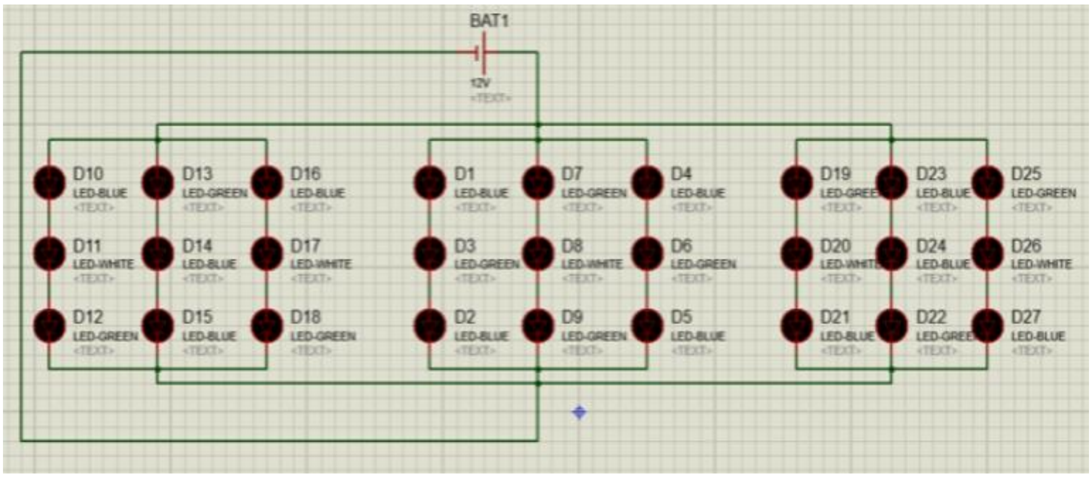


Figure 3.1: Drawing with the layout of 1Watt LEDs.

3.2 The Production of System Control Card

The connections of the Arduino microprocessor, the sensor, the buzzer, and the LCD screen have been completed. The power supply was chosen to reduce the voltage in the city network to 12 Volts, and the connection was completed in a way that transmits the voltage in the power supply to the DC-DC regulator. The positive port of the DC-DC regulator is connected to the COM of the relay. The NC of the relay is connected to the negative pole of the LEDs on the panel. Basically, these links are complete. All components in the system design were connected and necessary soldering was done. The result obtained is shown (Figure 3.2).

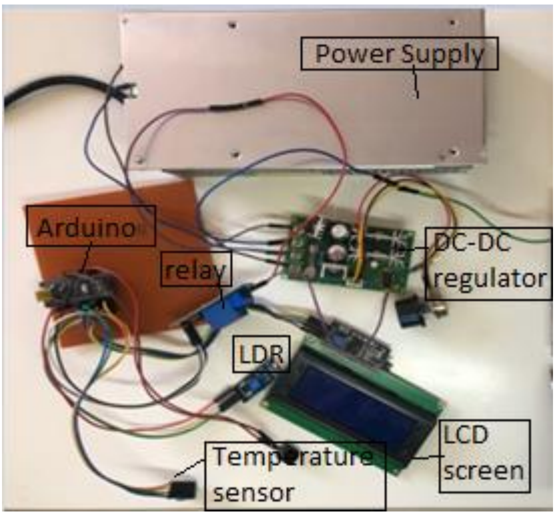


Figure 3.2: Electronic design

3.3 Optic Design of System

First, the optical design of the system was made. The light intensity of the system was calculated. As indicated in the image, the light power from a single LED was calculated as 1.792 mWatt. In Figure, the LED is placed at point A and data is given for the calculation of the area to be illuminated by the light (Figure 3.3).

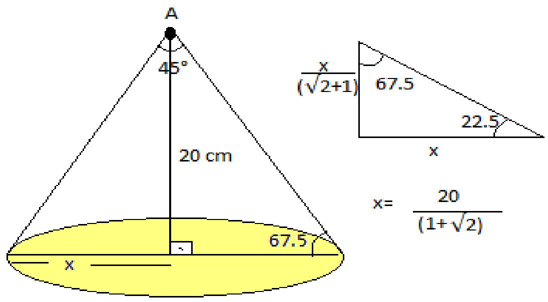


Figure 3.3: Illuminated area by 1 Watt LED

Illuminated area: The area of the circle given the radius r= is calculated from πr^2. The area illuminated by a single LED is 215.6 cm^2.

Light intensity calculation (W/cm^2 /nm): The ratio of the power of a single LED to the total area is 8.31 W/cm^2 . A total of 27 LEDs will be used. By multiplying the values of 27 and 8.31 μW/cm^2 /nm, 3105 μW/cm^2 /nm is gained. It is given as μW/cm^2 /nm. the desired unit of light intensity for jaundice. For this reason, ratio of power to area divided by bandwidth of used LEDs. Bandwidth is 25. Accordingly, the estimated light intensity to be obtained is 8.31 μW/cm^2 /nm.

In addition, the placement of the LEDs on the panels and the distance between them are designed as shown (Figure 3.4).

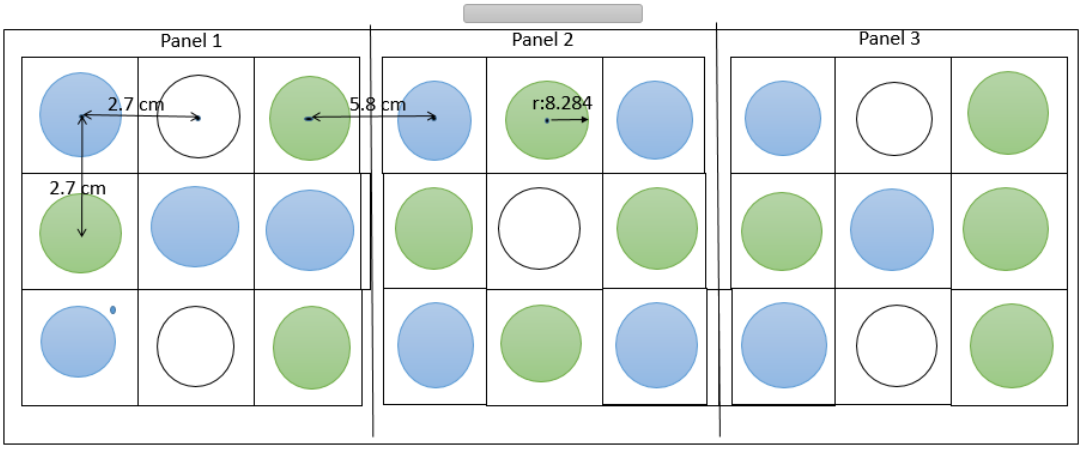
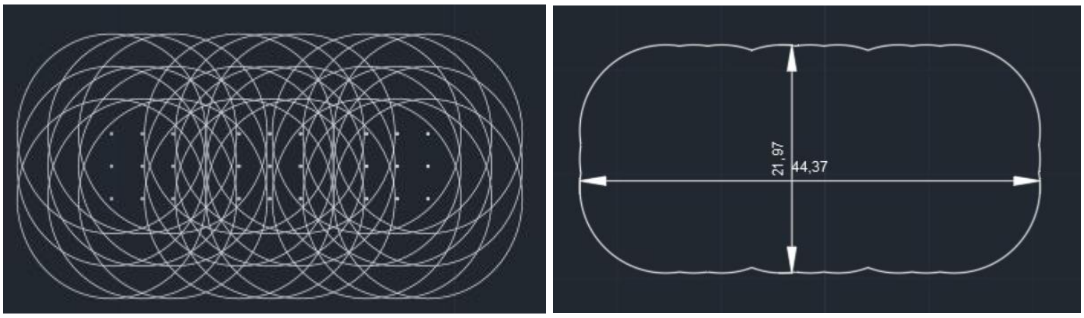


Figure 3.4: LED placement on the panel

The total area illuminated according to the designed LED design is shown in the Figure. Figure 13(b) shows the total illuminated area. The total area where the light is transmitted is 910 cm^2. Not all points in this area are of equal density.

The total area illuminated by each LED is given separately in the figure 3.5. It will be possible to detect the points with the highest density from this visual (Figure 3.5.a).



(a) (b)

Figure 3.5: Illuminated area, (a) Separate display of the area illuminated by the LEDs, (b) total illuminated area

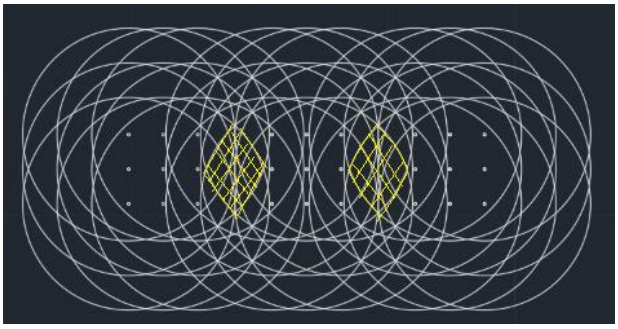


Figure 3.6: Design of system

The areas where the light is estimated to be the most intense are marked. It was determined as a total area of 34 cm^2 (Figure 3.6). AutoCAD program was used for drawing and area calculations.

3.4 The Production of LED Panel

Blue-green-white LEDs are homogenously distributed on the LED plate. First of all, a thermal paste was applied to the LEDs. 3 LEDs are connected in series. 9 x 3 series LEDs are soldered. Finally, all serial LED strings are connected in parallel to each other (Figure 3.7).

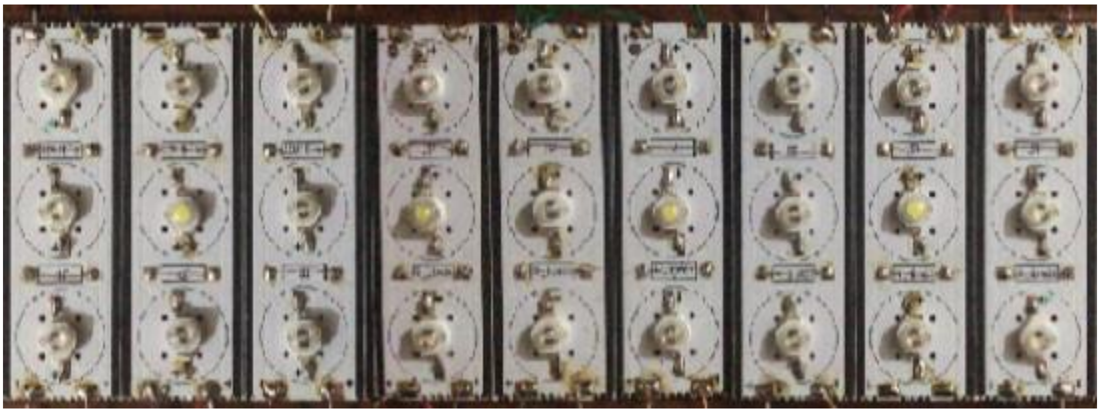


Figure 3.7: Soldered LED plate

3.5 SOLIDWORKS Drawing of the System

SOLIDWORKS drawings of the mechanical parts of the system have been completed. The panel and stand of the device are shown as assembled in Figure 3.4 (a, b, c). The box with Arduino, DC-DC regulator, relay, LCD screen, and connection cables is also available (Figure 3.8. d, e, f).

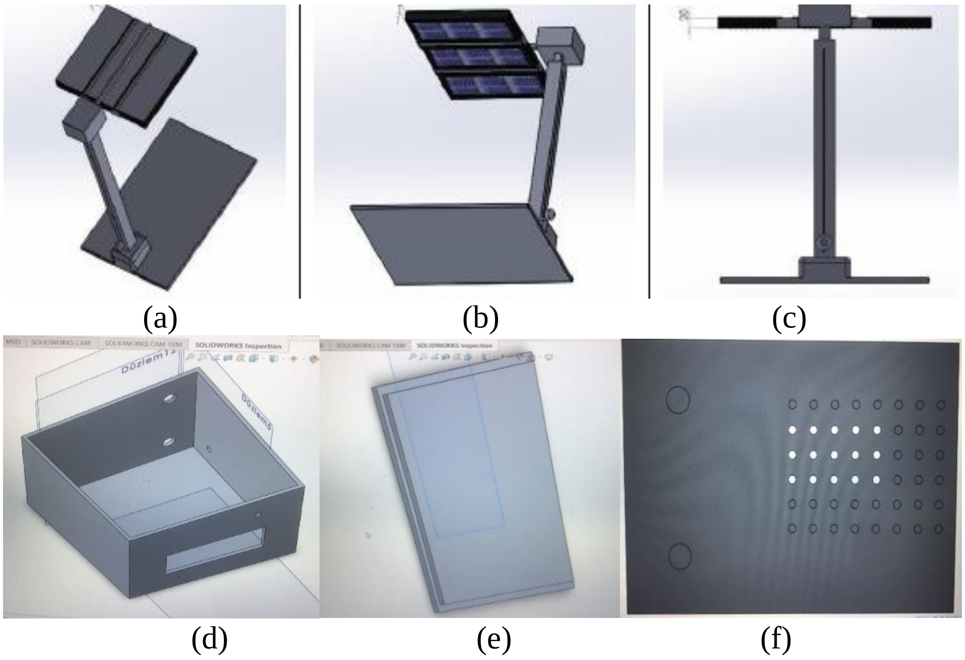


Figure 3.8: SOLIDWORKS design of system; light panel, (a) top, (b) side, (c) back; (d) control box, (e) cover, (f) side part of box

3.6 3D Printing of the System

The file in STL format has been converted to G-code that can be used by the 3D printer device. The products were obtained by using acrylonitrile butadiene styrene (ABS) filament. For the panel where the light source is located, 3 separate cases and control boxes were printed with a 3D printer (Figure 3.9).

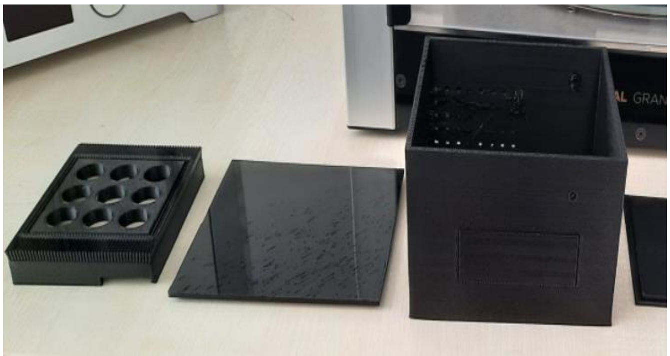


Figure 3.9: 3D printer product

3.7 Production of the Mechanical Parts of the System

Some of the mechanical parts of the system were printed with a 3D printer. The plate of the panel and stand is made of metal material in terms of durability. The plates on which the light source is made of aluminum. The homogeneous distribution of heat is supported. 3D movement of the panels is provided with a fixed hinge (Figure 3.10).

Figure 3.10: Foldable panel plate

The length-adjustable stand is 300 mm long. It can be adjusted to the desired length. The stand and the sliding support are obtained (Figure 3.11).

Figure 3.11: Stand of the prototype

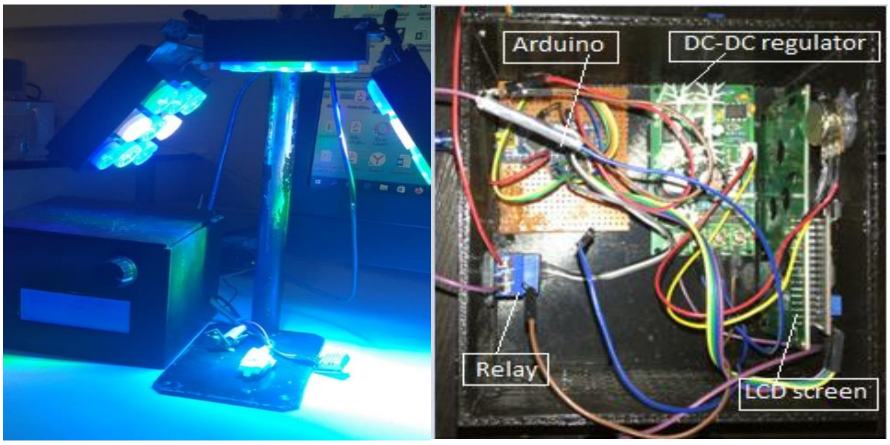
3.8 Control of the System with Arduino and Card Production

Control Software was done with an Arduino microcontroller. The data (temperature and light intensity) received from the sensors were written to the LDC screen with a microcontroller. The system is enabled to turn itself off in undesirable value ranges. The LED panel was controlled by controlling the relay with Arduino. The control software that makes this function is complete.

3.9 Assembly

All mechanical and electronic parts of the system were combined. Arduino, DC-DC regulator, LCD screen, and relay were placed in the control box. After the LEDs were passed into the panel box, they were mounted on the static panel. All cable connections were completed. A 0.130 kΩ resistor was placed on the main wire of the LEDs.

This process was done to reduce the light intensity. The visuals of the phototherapy device and control box are shown (Figure 3.13).



(a) (b)

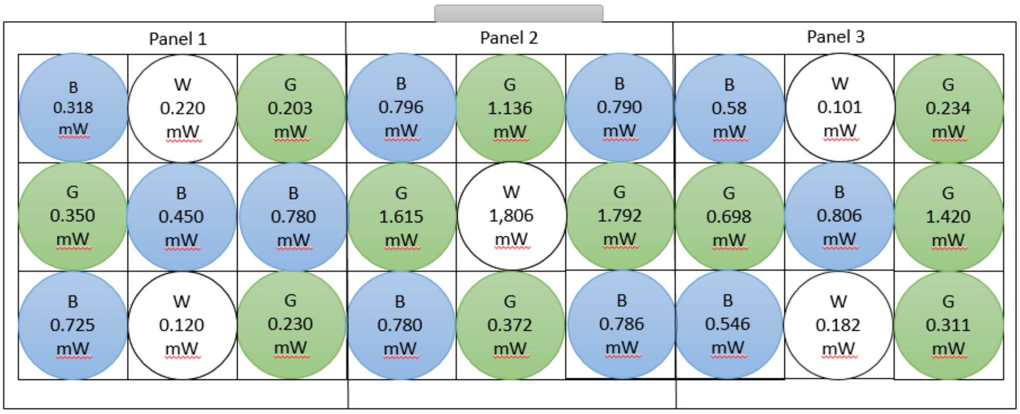
Figure 3.12: Component of Prototype (a) Phototherapy device, (b) Control box

The visual of the final state of the system is in Figure 3.10. The total current is measured as 27.8 mA. Total voltage on the LEDs is measured as 48.786 mV. The total power on the LEDs is 0.00135 Watts.

3.10 Tests

3.10.1 Light Intensity Measurement Test

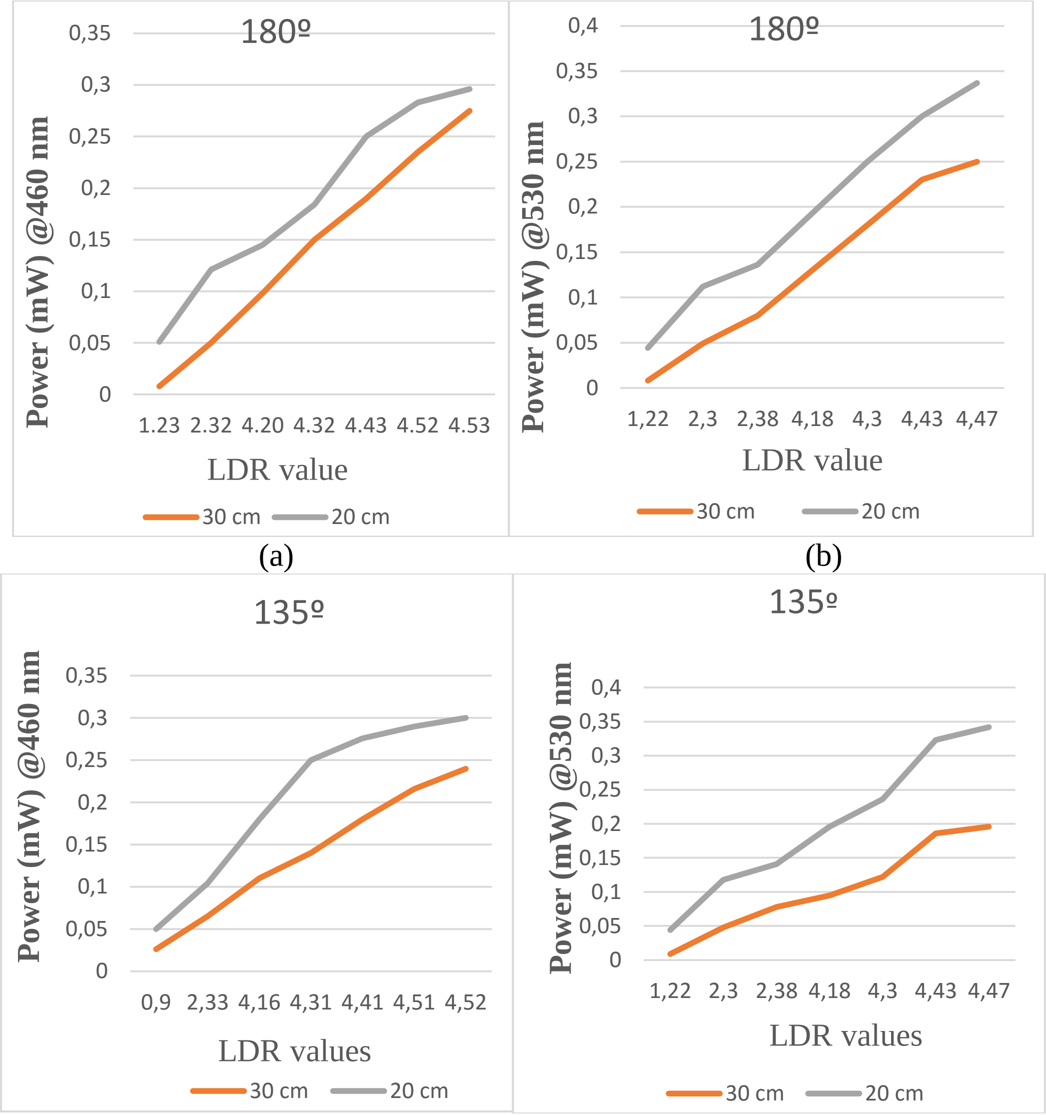
The wavelength with the highest output power was determined separately for green and blue LEDs. The wavelength was determined as 460 nm for blue LEDs and 530 nm for green-white LEDs.



Panel 1			Panel 2			Panel 3		
B 0.318 mW	W 0.220 mW	G 0.203 mW	B 0.796 mW	G 1.136 mW	B 0.790 mW	B 0.58 mW	W 0.101 mW	G 0.234 mW
G 0.350 mW	B 0.450 mW	B 0.780 mW	G 1.615 mW	W 1,806 mW	G 1.792 mW	G 0.698 mW	B 0.806 mW	G 1.420 mW
B 0.725 mW	W 0.120 mW	G 0.230 mW	B 0.780 mW	G 0.372 mW	B 0.786 mW	B 0.546 mW	W 0.182 mW	G 0.311 mW

Figure 3.13: Output power and color display of LEDs on the panel (B: Blue, G: Green, W: White)

The output power of the blue, white and green power LEDs was measured by setting the device to 460 nm and 530 nm, respectively. This measurement was made for each LED separately and without any distance. The result of this measurement is shown (Figure 3.14).

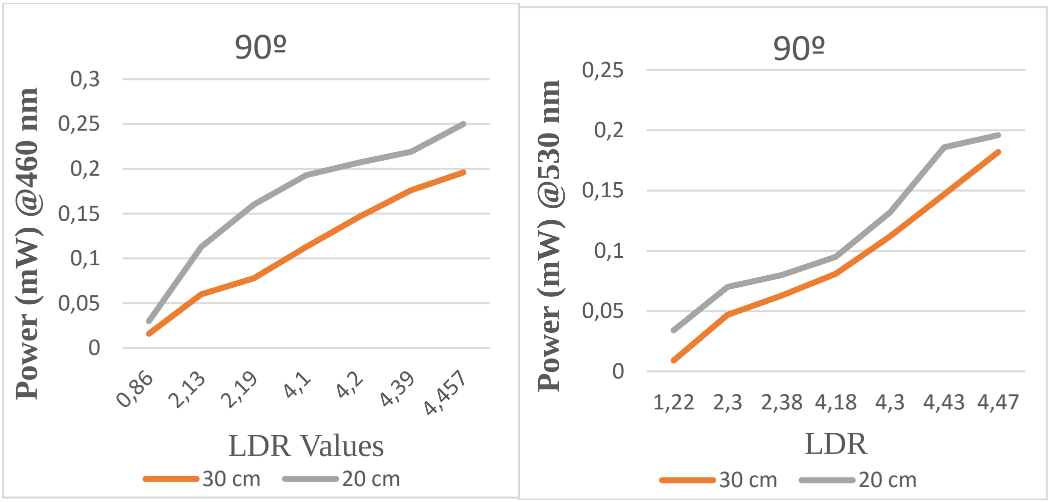


(a) (b)

(c) (d)

Figure 3.14: Output power measurement results of light at different angles, distance (a) measurement result at 180°, 460 nm; (b) measurement result at 180°, 530 nm; (c) measurement result at 135°, 460 nm; (d) measurement result at 135°, 530 nm; (e) measurement result at 90°, 460 nm; (f) measurement result at 90°, 530 nm

Figure 3.14 (continued)



(e) (f)

Figure 3.14: Output power measurement results of light at different angles, distance (a) measurement result at 180°, 460 nm; (b) measurement result at 180°, 530 nm; (c) measurement result at 135°, 460 nm; (d) measurement result at 135°, 530 nm; (e) measurement result at 90°, 460 nm; (f) measurement result at 90°, 530 nm

The average values of the measurement values obtained by adjusting the device at different distances and angles are shown (Figure 3.15). Light intensity is measured for 0,3370 mWatt at 20 cm, 180°, 530 nm.

$$E = \frac{0.337\ x\ 1000}{\mathrm{nm(bandwidth)}} = \frac{0.45\mathrm{x}1000}{25} = 13.48\mu\mathrm{Watt/cm^2/nm} \qquad (3.1)$$

3.10.2 Biological Applications of the Prototype on Bilirubin Solution

The absorbance value of the prepared bilirubin solution with different concentrations was measured at 460 nm in microplate reader (Multimode Microplate Reader Biotek Synergy HTX, Biotec). The calibration curve is obtained (Figure 3.16).

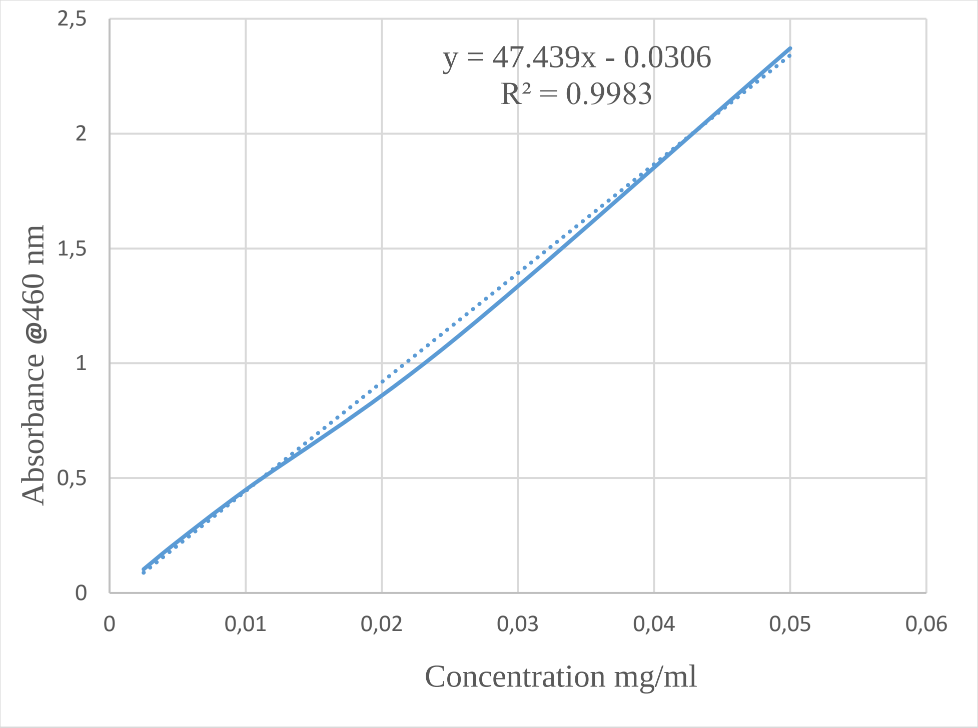


Figure 3.15: Absorbance and concentration calibration curve

The bilirubin concentrations obtained by the formula in the calibration curve are shown ($y = 47.439x - 0.0306$ at 460 nm). The y value represents the absorbance value in the formula. 5 different x value was found by entering the absorbance values instead of y in the formula. The concentration of bilirubin was obtained with the values x (Table 3.1).

Table 3.1: Absorbance value at different concentration

Bilirubin concentration(mg/ml)	**Absorbance @460nm**
0.0025	0.103
0.005	0.223666667
0.01	0.449
0.025	1.087666667
0.05	2.371666667

Applications lasting 30 minutes were made to the bilirubin solution with a concentration of 0.01 mg/ml at different angles and distances.

The average value and success percentages of different bilirubin concentrations that obtained before and after the application data (Table 3.2).

Table 3.2: Bilirubin concentration before light application, bilirubin concentration after light application, bilirubin breakdown success rates obtained from bilirubin tests performed at different angles and distances

Distance	Angle	Before (mg/ml)	After(mg/ml)	% Decrease
30 cm	**180°**	0.002127645	0.002050352	3.6
	135°	0.009210425	0.00883099	4.1
	90°	0.008711538	0.008444529	3
20 cm	**180°**	0.002457893	0.002303309	7.3
	135°	0.002226017	0.002106565	7.6
	90°	0.002324389	0.002211963	4.8

After 30 minutes of light application, a decrease in bilirubin levels was observed. While the highest drop is observed at a distance of 20 cm, 135°. The lowest bilirubin decrease was observed at 30 cm, 90°. In order to see the decrease in bilirubin solutions, 3 different wells were filled on the plate and the average values of these values were taken. Standard deviation was calculated to see at which values the concentration amount could change.

The standard deviations are shown on the success percentages of the decrease in bilirubin concentration (Figure 3.17).

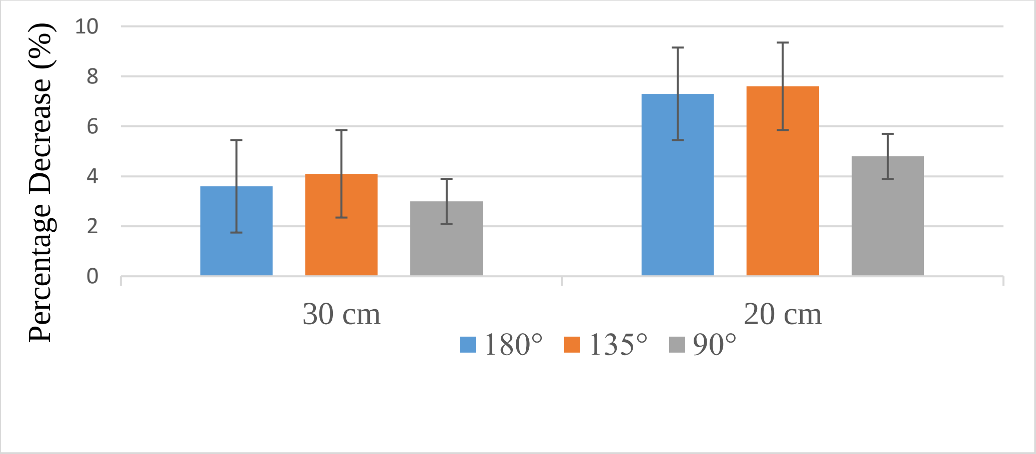


Figure 3.16: Bilirubin degradation success percentages obtained from bilirubin tests performed at different angles and distances

Finally, the temperature rise caused by the light on the surface was investigated. The data of 6 different applications at different distances (20 cm, 30 cm) and angles (90°, 135°, 180°) are shown. Data were obtained from the device's LDR and thermal camera simultaneously before and after light applications. Temperature rise was determined after the light application (Figure 3.18).

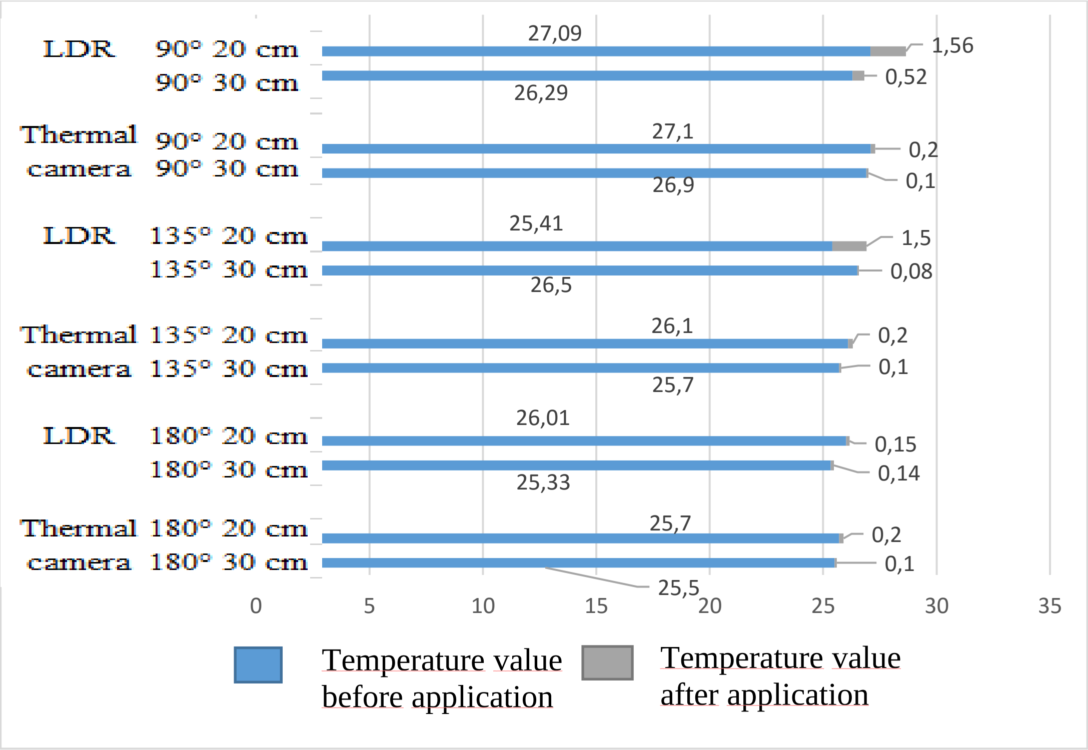


Figure 3.17: Temperature (°C) changes during applications

Chapter 4

4. Discussion

In this project, a phototherapy device was aimed to be developed for the treatment of jaundice. LEDs were used as the light source. Blue wavelength LEDs and white and green wavelength LEDs were used together for raise the efficiency of the application by reducing the negative side effects of treatment on the patient. In addition, the effects area of phototherapy was increased with the foldable panel system. The device is containing sensors that control the temperature and light intensity to alert the user with an alarm in non-ideal data.

Halogen Spotlight, fluorescent Lamps, and LEDs are light sources used in phototherapy. In this project, power LEDs were used as a light source. LEDs have many advantages over other light sources. They are simpler and lower cost. They create less heat on the surface than other light sources. In this way, they generate less heat even when operating at a high light intensity, and the possibility of skin burns is reduced. Because of their low heat generation, the light source can be applied more closely to the patient. As the distance decreases, the rate of degradation of bilirubin will increase. In addition, LEDs have a narrow emission band compared to other light sources. Emission bands are around 50 nm. Their lifetime is longer than other light sources, over 100,000 h [13,30,31].

In this study, LEDs in 3 different colors as blue, green, and white were used. According to the studies, the range of values where bilirubin absorbs light best has been determined as 430-490 nm. It has a peak value at 460 nm wavelength. These wavelengths represent blue light in visible light.

Bilirubin does not only absorb light in the blue spectrum but also has a therapeutic effect in the 480-530 nm spectrum. In the spectral range optimization studies in the literature, it has been emphasized that the green light band is advantageous in converting bilirubin into different forms and removing it from the body. Bilirubin is converted to lumirubin in the green light band. Lumirubin is a highly hydrophilic structure and irreversible product. It also has low toxicity and can be quickly eliminated from the body. Since supporting the formation of lumirubin is advantageous in terms of toxicity and excretion rate, the use of a green light band with high lumirubin formation was found appropriate. For this reason, the light source had a green light beside the blue light. In the study of Nabizath and his colleagues used green light in addition to blue light in the system they developed. Thus, the efficacy of the phototherapy was increased with their design. In addition, white light was used in addition to blue light in the studies. With this, it was aimed to better observe the change in skin color, while reducing the side effects of blue light such as dizziness and nausea. The use of 3 different color bands in this study made it unique from other studies in the literature [15,18,25,31].

The 2014 guideline of the Turkish Neonatology Society emphasized the effect of the angle of incidence of light on bilirubin destruction. When the light angle was 45°, it creates a low effect compared to 90°. Even the light intensity drops by 40%. For this reason, a foldable, 3D panel was developed to adjust the angle of the light coming to the side surfaces of the baby. In addition, in this way, the light coming to the side surfaces was increased and it was aimed to increase the light footprint. For this 3D structure, a fixable hinged was placed between the same size aluminum plates. In this way, the angle between the panels could be changed by the user. When other studies in the literature were examined by Cabacungan and his colleagues, a cost-effective system was designed. However, single wavelength was used and the light was transmitted only from one direction in their study. Akşahin et al. used two separate light sources from the top and bottom to increase the light footprint in their study called Multifunctional Phototherapy Device Design. They made adifferent design [7, 21, 22].

Arduino microcontrollers were used in the device. Arduino is a simpler and more economical microcontroller to program. No external programming need, a program is already installed on the microcontroller.

Online libraries are available. For these reasons, the Arduino microcontroller was preferred in the device. LDR, temperature, and humidity sensors were used in the device.

With the temperature sensor, temperature changes on the surface were instantly printed on the LCD screen. It was aimed to warn the user when the values taken are out of the predetermined values and to prevent negative effects that may occur on the baby.

With light exposure, an increase in temperature occurs in the tissue. Heat accumulation occurs in the tissue where the light is absorbed. Even if the heat exchange only occurs on the surface where the light is sent, this heat will be transferred to the organs in the living thing due to the blood flow. In order to minimize the thermal damage to the tissues, the temperature increase on the surface must be controlled during the phototherapy process. In this way, the least possible necrosis is obtained. Also, phototherapy can have some side effects on the skin. Tanning, erythema (rash on skin), etc. In addition, skin burns and excessive dry skin conditions may occur with the increased heat created by the light on the skin. Normal body temperature is between 36 and 37.5 °C. In addition, temperature loss can be observed, since the baby's clothes are also removed during phototherapy. 2.75°C temperature rise is acceptable, but it shouldn’t be higher than 4 °C. Phototherapy can lead to hypothermia or hyperthermia. Temperature sensors are used in the system to control temperature-based problems. There are also different studies in the literature in which temperature was used for control purposes. In the study of Aksahin et al. [21] the digital temperature sensor DS18B20 was used to measure the body temperature of a baby. In this study, temperature control was also provided phototherapy [21, 26, 31].

Light intensity was measured with the LDR sensor. The LDR gave a value between 0 and 5 depending on the increasing light intensity. In addition, the data obtained from LDR and power meters were compared. The current power meter measures only at a single wavelength. Therefore, 460 nm and 530 nm were taken as a basis for the measurements for the power meter. In intensive phototherapy, a light intensity of 30 $\mu W/cm^2/nm$ is applied. In standard phototherapy, 10 $\mu W/cm^2/nm$ is applied. According to the data received, these data could not be accessed on the device.

In the light intensity measurements, the distance between the powermeter and the light source was determined as 0, 20 cm, 30 cm. Output power difference between LEDs was observed in measurements with 0 cm. 20 cm is determined as the lowest distance for LED light sources. 30 cm is used to observe the change of light intensity at a higher distance. Light intensity measurements were made at different distances (20 cm, and 30 cm) and at inter-panel angles (90°,135°,180°) as seen in Figure 4.1. The highest output power is at 20 cm, and 30 cm respectively. When the results obtained were compared, the highest value of 0.337 mWatt has been reached. This value was obtained when the distance between the panel and the sensor was 20 cm and the angle between the panels was 180°. According to the data obtained, the highest output power values were obtained at a distance of 20 cm. Because the light power will change inversely with the distance.

A comparison based on the angle could not be made clearly. No clear results could be obtained, increasing or decreasing as the angle changes. Considering the 3D structure of the baby, the angle between the panels will have a positive effect on bilirubin degradation.

The degradation percentages of bilirubin at different distances and angles are shown in Table 3.2. Since the output power is high at a low distance, the rate of bilirubin degradation has also increased. In this table showing bilirubin degradation, the highest efficiency was observed at 20 cm. When angle dependent change in bilirubin was examined, there was the highest bilirubin destruction at 135°. The destruction percentages of bilirubin at different distances and angles are shown in the table above. The output power is high at a low distance. The most efficient results were obtained at 20 cm 135° in the applications. Bilirubin degradation was 7.6%. When the study of Addi et al. [19] was examined, a decrease of 19.61% was reached. Less success was achieved in this study. Because 13.48 μWatt/cm^2 /nm value has been reached. This value is in the range that can be applied for an effective phototherapy. In addition, it is less than 65 μWatt/cm^2 /nm which is inconvenient to apply. The highest standard deviation value of 4.69 was obtained. While performing the bilirubin degradation test, bilirubin was placed in 3 wells to check its accuracy. The mean value obtained is used in the table showing bilirubin breakdown. In other words, there may be a change in the rate of standard deviations in bilirubin breakdown.

This may be due to the fact that every point where the device transmits light does not receive light with equal intensity and angle, or the device does not work stably.

In the last of the study, the temperature increase on the surface was investigated. The temperature rise test was verified with a thermal camera and data was obtained with the temperature sensor of the device. When the obtained data were examined, the highest temperature increase was observed at 20 cm. The highest value taken at 20 cm is 0.2°C. The temperature changes between the LDR and the thermal camera show parallelism. The temperature rise test was performed on a white surface. Different results can be obtained from living.

Chapter 5

5. Conclusion

In this study, 3 different color bands were studied. Blue-green-white1 Watt LEDs were used. With the different wavelengths used, both the excretion of bilirubin from the body was accelerated and the effects of blue light on the user and the patient were sought to be reduced. It was desired to develop a device that includes 3 foldable panels. It is aimed to increase the light footprint and to bring light to the skin close to right angles to the side surfaces. With the wavelengths and 3D structure used, it preserves its originality from other studies in the literature. In addition, an autonomous system is aimed with the sensors used. It is aimed to warn the user and the safety of the newborn when unwanted data comes from the sensors. In order to see the effectiveness of the device, light output power, bilirubin destruction, and temperature rise tests were performed.

The highest value of 0.337 mWatt was reached in the light power measurement at 20 cm 180°. An increase in the output power of the light was observed as the distance decreased. The light intensity value of 13.48 µWatt/cm^2 /nm has been reached. It is a suitable value for phototherapy. It is desired to increase this value in future studies. In future studies, the resistor value used to reduce the voltage on the LED panel and reduce the light intensity can be lowered. In future studies, a system will be created in which the LEDs will be turned off and on according to the color separation. %7.6 bilirubin degradation was reached at 20 cm 135°. When the light intensity is increased so that it does not exceed 65 µWatt/cm^2/n, the amount of degraded bilirubin will also increase. In the future study, this value will be aimed to increase.

During the system design, the optical design of the system was designed. The light intensity is considered to be 8.31 $\mu\mathrm{Watt/cm^2/n}$. In the light intensity measurements, the value of 13.48 $\mu\mathrm{Watt/cm^2/n}$ was reached. The designed and achieved values show parallelism. In addition, the highest value of 0.2 C was reached in the temperature rise tests performed with the thermal camera. The data from the thermal camera show parallelism with the temperature sensor.

Briefly, in this study, three different wavelengths were studied, namely blue, green and white. In addition; a 3D, angle changeable panel was designed. With these features, it originality from other studies in the literature was preserved. The safety of the user and the newborn was ensured by stopping the device in case of unwanted data. The effectiveness of the device was evaluated by light intensity, bilirubin and temperature tests.

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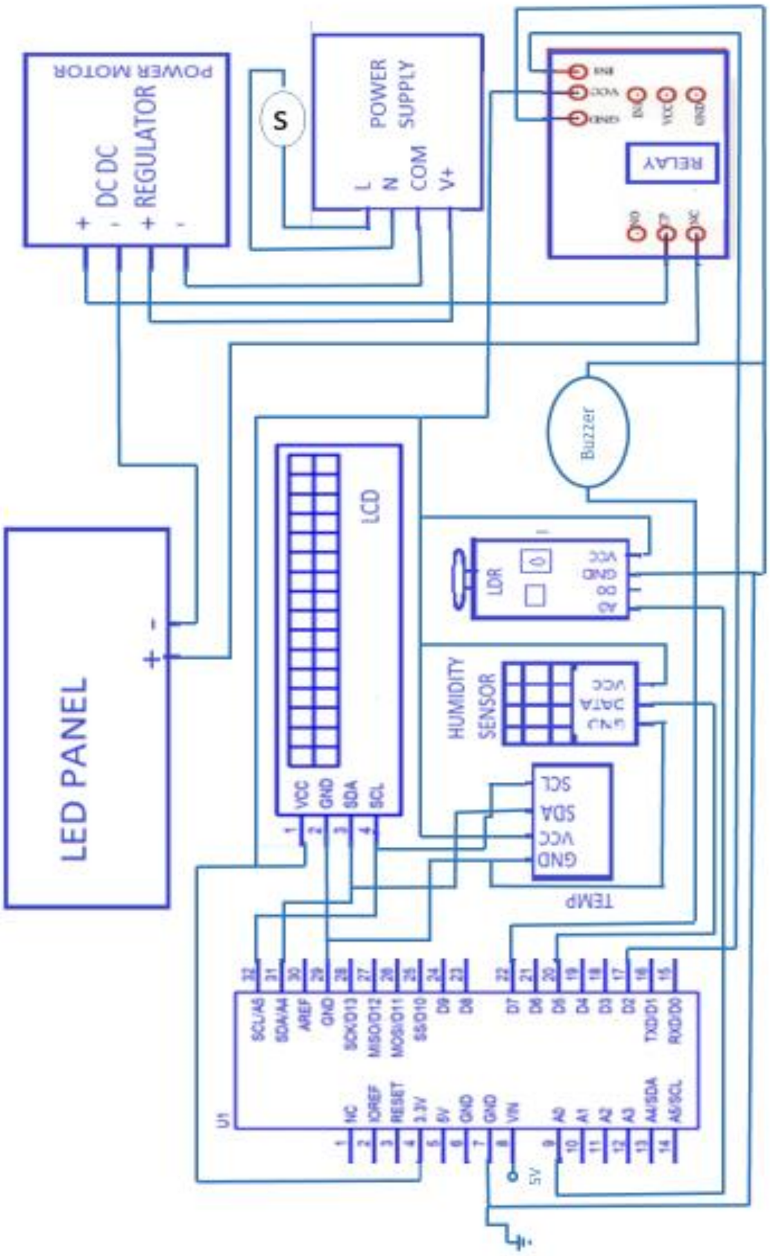
Appendices

Appendix A



Appendix A: Electronic Schematic of System

Appendix B

```
#define role 2
#include <Wire.h>
#include <Adafruit_MLX90614.h>
#include <LiquidCrystal_I2C.h>
#include "DHT.h"
#define DHTPIN 5
#define DHTTYPE DHT11
// Set the LCD address to 0x27 for a 16 chars and 2 line display
LiquidCrystal_I2C lcd(0x27,20,4);
int buzzerPin=7;
int LDR_Pin = A0;
int isik_degeri;
Adafruit_MLX90614 mlx = Adafruit_MLX90614();
float temperature;
DHT dht(DHTPIN, DHTTYPE);
void setup() {
  Serial.begin(9600);
// initialize the LCD
  lcd.begin();
  // Turn on the blacklight and print a message.
  lcd.backlight();
  Serial.println("Adafruit MLX90614 test");
  mlx.begin();
  pinMode(4, OUTPUT);
  pinMode(LDR_Pin, INPUT);
   pinMode(role,OUTPUT);
   Serial.println("DHTxx test!");
  dht.begin();
```

```
}
void loop() {
  pinMode(buzzerPin,OUTPUT);
  int Lvalue = analogRead(LDR_Pin);// read the light
  int mVolt = map(Lvalue,0, 1023, 0, 5000);// map analogue reading to 5000mV
  float volt =(double)mVolt/1000;// convert millivolt to volt
  float v1olt=5-volt;
  float m1Volt =5-mVolt;
  temperature = mlx.readObjectTempC();
  float h = dht.readHumidity();
  // Read temperature as Celsius (the default)
  float t = dht.readTemperature();
  // Read temperature as Fahrenheit (isFahrenheit = true)
  float f = dht.readTemperature(true);
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("phototheraphy device");
  lcd.setCursor(0, 1);
  lcd.print("temp=");
  lcd.setCursor(5, 1);
  lcd.print(temperature);
  lcd.setCursor(10, 1);
  lcd.print("*C");
    lcd.setCursor(20, 1);
  lcd.print(v1olt);
  Serial.print("Humidity: ");
  Serial.print(h);
  Serial.print(m1Volt);// print millivolt
  Serial.print( "mV ");
  Serial.print(m1Volt,3);// print volts with 3 decimal places
  Serial.println( "V ");
  delay(1000);// wait for 1000 milliseconds
   if (temperature < 20) {
      lcd.setCursor(4, 3);
  lcd.print("!1!ILNESSES!!!");
```

```
  digitalWrite(buzzerPin,LOW);
   lcd.setCursor(0, 2);
  lcd.print("LIGHTINTENSITY=MODE5");
 digitalWrite(role,HIGH);
delay(2000);
}
  if (temperature > 34) {
   Serial.print("Ambient = "); Serial.print(mlx.readAmbientTempC());
  Serial.print("*C\tObject = "); Serial.print("illnesses:)"); Serial.println("*C");
  Serial.print("Ambient = "); Serial.print(mlx.readAmbientTempF());
  Serial.print("*F\tObject = "); Serial.print(mlx.readObjectTempF());
Serial.println("*F");
  digitalWrite(role,HIGH);
  delay(5000);
} else {
   Serial.print("okey");
//   digitalWrite(role,HIGH);
//  delay(5000);
  digitalWrite(role,LOW);
  delay(5000);
}
  Serial.println();
  delay(500);
}
```

Publications from the Thesis

Conference Papers

1. Multicolor LED-Based Phototherapy Device with a Novel 3D Design 3 Boyutlu Özgün Tasarımı ile Çok Renkli LED-Tabanlı Fototerapi Cihazı Üretimi 4.Uluslararasi Tibbi Cihazlar Konferansi 2021 (ICMD'2021) Bildiri Özetleri Kitabi

Projects

1. Yeni Bir LED Tabanlı Fototerapi Cihazının Tasarımı, Üretimi ve Uygulamaları; Bilimsel Araştırma Projeleri BAP-2020-TYL-FEBE-0005-BY

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Publications (if any):

1. Büşra Yaşar, Yalçın İşler, Nermin Topaloğlu, Manufacturing Multicolor LED-Based Phototherapy Device with a Novel 3D Design 3 Boyutlu Özgün Tasarımı ile Çok Renkli LED-Tabanlı Fototerapi Cihazı Üretimi 4. Uluslararasi Tibbi Cihazlar Konferansı 2021 (ICMD’2021) Bildiri Özetleri Kitabi