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Design and Development of Simple and Low-cost Light Source for Laparoscopic Surgery

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ABSTRACT

Background: The existing medical light source device used in laparoscopy surgery is very costly and is not yet developed in Nepal. This study aimed to build a light source device that is cost-effective and passes all the testing parameters like Light Emitting Diode illumination, color, and heat.

Methods: A method of constructing a light source comprises the steps of designing, assembling the system, and undergoing device testing. The design of the device was done through Sketchup software. The dual switched-mode power supply of 3-4 Voltage to the Light Emitting Diode and 12 Voltage to the rest of the system with cooling technology were used.

Results: The Light emitted from the Light Emitting Diode focuses the light directly at the fiber optic cable through the coupler. Moreover, the testing of the device concludes that the increment temperature of the device for 1 hour is 1 degree Celsius whereas the maximum increment temperature was found to be 3 degrees. Additionally, the fiber optic illumination at the port is found to be >50000. Also, the color of the Light Emitting Diode is cool white light having a color temperature of 5700 Kelvin and a color rending index of 92.

Conclusions:The developed device is four times cheaper than a similar device available in the Nepalese market. Also, this device has been developed first of its kind in Nepal.

Keywords: Light emitting diode; light source; low-cost

INTRODUCTION

Medical Light Source assists in creating a simulated micro-surgical image in laparoscopic surgery by illuminating the area that needs to be examined.[1] The number of light source that must be used in hospitals has grown as the number of minimally invasive surgery has increased. As a result, the development of low-cost medical light sources in developing nations such as ours should increase. The built light source should not only have sufficient luminous fluxes and high color temperatures, but they must also be functional and safe.

However, the light source available in Nepal is worth NPR Rs. 1.5 lakh or more so the aim of this study is to design and develop simple and low-cost light source for laparoscopic surgery.

METHODS

This device was completed in eight months' duration from 23rd January, 2020 till 25th September, 2020. Prior to beginning the study, our protocol was approved by the College of Biomedical Engineering and Applied Sciences. The technique of constructing a light source includes the steps of designing, assembling the system, and testing the device. Firstly, the device was designed using a 3D CAD software called sketch up.[2] Following the completion of the design, a thorough examination of the LED and power driver was carried out. Then, in accordance with the specifications, LED was chosen. In addition, a thorough examination of the Switched Mode Power Supply was performed to confirm that the required current and voltage were met. This precaution was taken to guarantee that the LED wouldn't get damaged.

The first phase of mechanical assembly began with calibration, validation, and specification. The LED was initially installed on the heat sink with proper thermal contact between the LED and the heat sink. Following that, suitable electrical connections were made. The LED

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was then connected to the coupler once the electrical connection was completed. Following the installation of the LED to the coupler, the other components were joined using connectors and a hot glue gun. And for the next step, outer covering for the device was designed. For the outer covering, the metal sheet was cut according to the required dimension i.e., the width/ length is 30cm and height is 10.5 cm and then wielded and folded to get a square shape. The outlook of the device can be seen in figure 3. Finally, when all of the components and materials were properly constructed, the device underwent different tests.

Device testing was completed in 3 months' duration from 15^{th} July, 2020 till 10^{th} September, 2020. Firstly, color temperature was analyzed. The color temperature of a light source is the temperature of an ideal black-body radiator that radiates light of comparable hue to that light source.[3] The polynomial formula for corrected color temperature (CCT) T is,[4]

$T = -437n^3 + 3601n^2 - 6861n + 5514.31$[3] with inverse line slope n, $n = \frac{(x-0.3320)}{(y-0.1858)}$ [5] where (x, y) is the chromaticity coordinates. The chromaticity coordinates is based on standard tristimulus (X, Y, Z), defined by the International Commission on Illumination (CIE). The transformation from RGB to CIE color space (X, Y, Z) is,

$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} 2.7689 & 1.7517 & 1.1302 \\ 1 & 4.5907 & 0.0601 \\ 0 & 0.0565 & 5.5943 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$[6]. The transformation from (X, Y, Z) to chromaticity coordinates is $X = \frac{X}{X+y+Z}$ and $Y = \frac{Y}{X+Y+Z}$. Hence, the CCT of the LED used in light source was analyzed to be white daylight color having the color temperature of 5700K. The color rendering index refers to how closely a light shows the true color of what it is illuminating, it should be in the range of 85-100.[7] And, the color rendering index of the LED (CBT 90) of the light source was analyzed to be 92.

Secondly, white balance of the light source was done. The white balance was done by placing the laparoscope in front of the camera. The camera sensed that white object as a reference and then adjusted its all-primary color (red, blue, green) to make pure natural white color.

Thirdly, the heat testing was performed with the help of infrared thermometer. The light source was kept in different intensities in different time duration and the infrared thermometer was placed near the laparoscope and tested in different intensities with variable time duration (Table 1).

Fourthly, the illumination testing was performed with the help of Luxmeter. The testing was performed in a dark room by passing the light to the luxmeter at different intensities and values were taking by placing the measuring scale at a distance of 5cm and 10cm. Also, the power of the whole system was calculated through a power meter.

All the data collected from the above testing were entered into Microsoft excel and statistical analysis were done to find the results. Descriptive statistics were calculated using mean and standard deviation for illumination testing. The mean and standard deviation values of fiber optic cable at the end of the port in distance 10 cm and 5 cm (in Lux) at different levels were then calculated (table 2 and 3). Then, through statistical analysis the illumination, heat, color temperature and color balance of the devices were found.

RESULTS

Seven different intensities of data were collected for heat testing (Table 1), and the least increment temperature at one-hour time period was determined to be 1 degree, while the highest increase temperature was found to be 3 degrees. Since the increment is very less so, we may conclude that no heat-related concerns were identified.

Table 1. The value of the calculated heat with variable time duration (in degree Celsius).

Time	Intensity	Heat in Celsius
15 minutes	10	23℃
15 minutes	20	24.5℃
Initial	40	23.5℃
30 minutes	40	25.0℃
45 minutes	40	24.5℃
60 minutes	40	24.4℃
15 minutes	100	26.8℃

Table 2. Mean and Standard deviation values of the end of the cable (in Lux).

Level	mean(10cm) [in Lux]	mean(5cm) [in Lux]	sd(10cm) [in Lux]	sd(5cm) [in Lux]
10	127	365	21.65	69.2
20	548	1137	73.9	65.52
30	969	3106	233.1	252.97
40	1513	4640	232.48	163.3
50	2065	5332	179.9	1266.2
60	2582	7614	386.7	1314.9
70	2864	7638	302	654.6
80	3786	10672	264	1008.5
90	4362	12726	413	1176.2
100	5482	16214	638	1864.2

Similarly, ten (level) of intensities were measured at the end of the cable and the port and the mean illumination at the end of the cable at 5cm distance was found to be 16,214 Lux and the mean illumination at the end of the port at 5cm distance was found to be 60.225 Lux (Table 2 and 3). As a result, the optical loss caused by the fiber optic cable is 44,011 Lux.

Table 3. Mean and Standard deviation values of the end of the port (in Lux).

Level	mean(10cm)	mean(5cm)	sd(10cm)	sd(5cm)
10	598	1632	24.25	172
20	2592	7008	51.23	147
30	4567	12320	97.7	733.62
40	6497	17658	41.12	605.71
50	8582	24275	91.05	1683.99
60	10732	30625	167	2819.42
70	12827	35925	148	2478.4
80	15187	41100	194	1874.3
90	17175	48755	266.89	4550.7
100	24050	60225	2641	4998.2

Likewise, power consumption of ten (level) of intensities were measured at the initial phase and after one hour. The total power of the whole system at the intensity of 60 was found to be approximately 20 watts. After an hour, the power consumption increased only slightly after 70 intensities (Figure 1 and 2).

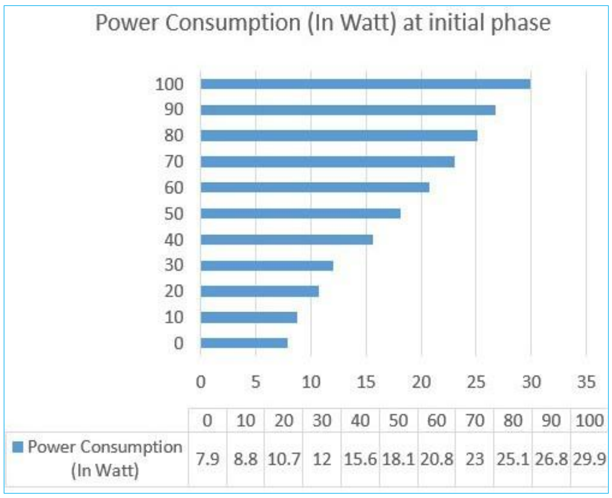

Figure 1. Power Consumption at initial phase.

Hence, the maximum power of the Light Source at 100 intensities after an hour is 34.3 watt and the luminous efficacy of CBT-90 LED at intensity of 60 was seen to be 408.51 Lm/ watt. The final result or the device/product specification can be seen in the device specification below:

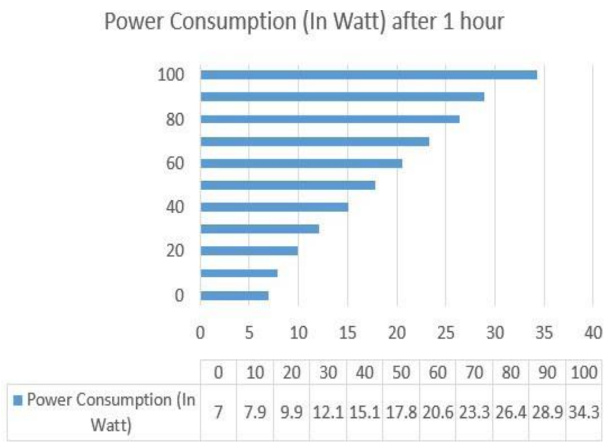

Figure 2. Power Consumption after 1 hour.

Product Specifications

Color index	92
Light bulb	Led
Fiber optic illumination (at the port)	>50000
Brightness	Adjustable (0-100%)
Bulb power	60W
Bulb life	60,000 hours
Bulb color temperature	5700K close to sunlight
Voltage	3-4V
Spectral range	380-780mm
Product size (L*W*H)	30.5* 30.5*10.8cm
Net weight	5kg

Figure 3. Final outlook of the Light source at 10 intensity.

DISCUSSION

The lamp or bulb used in the light source plays a vital role in providing appropriate lighting during surgery. But existing medical light source used in laparoscopic surgery are quite expensive so this invention was created to alleviate this problem.

Several modern types of light sources are currently available on the market. These light sources mainly differ in the types of bulbs used. The lamps that are used most recently are Quartz halogen, Incandescent bulbs, Xenon, and halogen and, Metal halite vapor arc lamp and LEDs. LED bulbs are the latest addition to the medical lighting field as it offers improved color and clarity as compared to incandescent bulbs. They are energy-efficient, small, durable, and also their spectral emission in the visible range can be tuned. However, there are other elements influencing these decisions such as color temperature, color rendition, illumination and light output, energy efficiency, longevity and, heat.[8]

The LED light that is being used in the device produces 5700 Kelvin which in comparison gives a very good daylight white color.[9] The designed light source produces the CRI of 92 which is similar to the light source of other companies, it can be considered to have a good color rendition.[9,10]

Power uses of the device also plays an important role to make the light source an ideal one. Generally, the power usage varies by the surgical light model. Usually, a LED light uses up to 50%-75% less electricity than halogen lights.[11] As the light source which we have built is also using CBT-90 LED hence, it uses up to 50%-70% less electricity which is similar to the light sources that is commercially available in the market.[11] Light longevity is also extremely important because the surgical team does not want a light going out during a surgical procedure. LED lights are rated much higher, a good LED surgical light has an estimated 50,000-hour rating. The LED that is being used in the device has 60,000- hours estimated rating.[9]

The heat dissipated by the LED also plays a crucial role during the surgery. The maximum heat generated by our device was 27 degrees which is much similar to other commercially available light sources and thus it produces no harms to the surgeons and patients as the core temperature of internal organs is 28 degrees.[12]

Another crucial part that is not to be neglected is the illumination which is provided by the light source. A good LED surgical light can produce over 120,000 Lux which is similar to our device.[9]

The designed light source also provides a brilliant, noise-free inspection while consuming extremely little energy. In addition, important consideration was given for the design of exterior and interior parts for the easy handling of the device. Instead of the complex expensive microcontroller system, a simple controlling solution is presented using a PWM dimmer to control the brightness.

CONCLUSIONS

So to conclude, as per the objective of the project, low- cost light device for laparoscopic surgery was built at NPR Rs 47,500 which is much cheaper than that of the market price i.e. approximately NPR Rs 1.5 lakh or more which fulfills the ultimate objective of building a cheaper yet efficient model. It features good color temperature, and CRI. It also features a user-friendly design and is simple to use.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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