JOURNAL OF SCIECNCE TECHNOLOGY AND EDUCATION 9(1), MARCH, 2021
ISSN: 2277-0011; Journal homepage: www.atbuftejoste.com

Design and Development of an Inexpensive Footswitch Controlled Surgical Light Prototype for Low Resource Healthcare Setting

[1]Yusuf Kola Ahmed, [1,2]Sani Saminu, [1]Mustapha Opeyemi, [1]Zainab Ovayoza Balogun
[1] Department of Biomedical Engineering,
Faculty of Engineering and Technology,
University of Ilorin, P.M.B. 1515, Ilorin, Nigeria.
[2]School of Electrical Engineering,
Hebei University of Technology, Tianjin-China

ABSTRACT
Surgical procedures and patient examination activities have been identified as critical universal health care components by the 2015 world health assembly. These critical tasks often require adequate lighting supply for successful execution. However, surgical lightings are very expensive for rural health care centres in middle and low-income countries. Besides, the epileptic grid power supply has rendered the few available ones underutilized. Technically, most of these lighting designs' control mechanism tends to interfere with the concentration of the surgeon or supporting staff during procedures. Hence, an inexpensive surgical light with footswitch control and battery bank is proposed. The prototype was implemented using 85% locally sourced materials without compromising standards in line with sustainable development goals. The device passed the Chassis leakage test as well as mechanical stability tests. On illumination tests, the device performed seamless control tasks without distraction. It produces a luminosity of 8500lx and correlated colour temperature of 6000k at an average cost of 109 USD.

ARTICLE INFO
Article History
Received: August, 2020
Received in revised form: December, 2020
Accepted: January, 2021
Published online: April, 2021

KEYWORDS
Surgical light; footswitch control; luminous intensity; low resource setting; battery bank

INTRODUCTION

Several surgical procedures are carried out day-in-day-out, and an adequate lighting supply is integral to its success (IEC Subcommittee 62D, 2009; Knulst et al., 2019; Matern & Koneczny, 2007; Patkin, 2003). Hence, adequate illumination of the operating room has been an essential part of medical equipment research over the years. Surgical lights are artificial lights used in the operating room to optimize visualization of body cavities and low-contrast objects and or substances at various incision depths (Joseph, 2006; *Lights*, 2012). There are numerous surgical lighting designs on the market with comparative properties (Berman et al., 2015; Knulst et al., 2011, 2019). These light sources are usually single large light head or multiple light heads with satellite light source attached to a suspended arm that is ceiling or wall-mounted and sometimes a stand-alone system (Berman et al., 2015; Knulst et al., 2009, 2019).

However, surgical lights are costly for low resource health care settings to acquire. When acquired, it is rather more expensive to replace the surgical light bulbs when they expire as they are not locally available (Forrester et al., 2017). The typical light sources are the incandescent Xenon halogen lamps, quartz and tungsten lamps.

**Corresponding author: Ahmed, Y. K. ahmed.yk@unilorin.edu.ng Department of Biomedical Engineering, Faculty of Engineering and Technology, University of Ilorin.* *© 2019 Faculty of Techn. Educ., ATBU Bauchi. All rights reserved*

However, these sources often generate heat radiation problem and mercury pollution (Pan et al., 2014). To correct these drawbacks, light-emitting diodes (LED) surgical luminaire is fast gaining popularity as it offers low colour temperature, long life, cold light and enhanced colour rendering (Hardy et al., 2007; Pan et al., 2014; Zhao et al., 2019).

The suspended arm range of motion determines the shape and properties of the projected light field, distance of the projected light to the surgical area, the shape of the beam and surface area of the LED reflecting board (Knulst et al., 2019). The position and intensity of most conventional surgical lights are manually controlled either by the physician or the assisting Nursing officer.These control buttons are often positioned on the surgical light head above the surgeons head which constitute ergonomic discormfort (i.e hand has to go over and above the head). This action often requires a disruption of attention on the patient and the procedure being carried out. Besides, the control knob of the light source is open to potential infection when touched by either the surgeon or the nurse as 50% of supposed sterile light handles were found to be bacteria infected in (Schweitzer et al., 2015) hip replacement surgery report. Hence a better manipulation mechanism is needed for the surgical luminaire with minimum distraction. Besides, there as been reports of eye fatigue and difficulty in control of light head from surgeons and burns from patients (Curlin et al., 2020)

Recent works include the design and development of an intelligent surgical light using MATLAB Sim mechanic and embedded sensor networks by (Roshan et al., 2016). However, the design is computationally complex and could cause distraction and obstruction as the sensor for the surgical light positioning is worn on the surgeon's hand. Another design by (Pan et al., 2014) developed a stack elliptic shadowless LED surgical lamp using an optical tracing algorithm. The design achieved shadowless illumination, but no improvement was carried out on the luminaire's position and intensity control. Knulst et al. (2019) came up with an adaptive light field surgical light that could automatically adjust intensity and focus area to reduce reflection from non-essential areas close to the operating field to reduce visual discomfort during the procedure. The system is computationally complex, and further research is needed to validate its applicability in operating room luminaire design. Dietz et al. (2016) also proposed a Contactless Surgical Light Control with 3D Gesture Recognition. The design uses Microsoft Kinect 3D sensor for picking the surgeons hand gesture to control the lighting parameters. However, the design is costly and require intensive training to master the guestures.

With recent recognition of surgery as a component of critical universal health care by the 2015 world health assembly, inadequate electricity supply and hospital lightings were highlighted as limiting factors in middle and low-income countries (deVries & Rosenberg, 2016). According to a survey by (Henry et al., 2012) in rural southern Nigeria clinics, only 50.3% of all hospitals have access to electricity through the power grid. Some reports also indicated a gross shortage of medical equipment (Henry et al., 2012; Oyekale, 2017). In light of this, an inexpensive surgical light system with power bank would be a sustainable alternative. This study seeks to design and develop a prototype footswitch controlled, stand-alone surgical light with an efficient battery bank to promote the smooth running of surgical procedures and eliminate downtime during a grid power outage.

*Corresponding author: Ahmed, Y. K. ahmed.yk@unilorin.edu.ng Department of Biomedical Engineering, Faculty of Engineering and Technology, University of Ilorin. © 2019 Faculty of Techn. Educ., ATBU Bauchi. All rights reserved

Theoretical Background

Light constitute a part of the wide electromagnetic spectrum. The human eye responds to light within a particular wavelength characteristics of 380 nm – 780 nm (Knulst, 2017). However, due to differences in human nature, eye sensitivity to light varies for each wavelength. Hence, a relative spectral sensitivity curve which depends on the individual difference and visual condition is used to evaluate human eye response to electromagnetic radiation. For different visual conditions, a standard set of observers V(λ) has been proposed. These standards, using the relative spectral sensitivity enables for conversion between photometric data (e.g luminous flux (lm)) and radiometric data (e.g. radiant flux (W)). The rods and cones are the light sensors in the human visual system (three cone and one rods) (Knulst, 2017). In light colour representation, three main colour matching functions x(λ), y(λ) and z(λ) are used to convert electromagnetic spectrum in to the equivalent imaginary primary colours x, y and z such that mathematically:

$$x + y + z = 1 \quad \ldots\ldots\ldots\ldots \quad (1)$$

x, y and z are the colour coordinates. In this CIE1931 standard, only two coordinates are required to determine the chromaticity of light. Other standards includes correlated CIE General Colour Rendering Index (CRI) and colour temperature (CCT) which are simpler metrics.

MATERIALS AND METHOD

Materials

Inexpensive construction materials such as mild steel sheet and pipes were sourced locally without compromising standards (Ahmed, Zubair et al., 2020). Durability, strength and ease of manufacturing were also considered in the material selection (Ahmed et al., 2020; Ibitoye et al., 2019). These factors were considered in other to meet the engineering characteristics of the selected materials. Table 1 depicts the relative advantage of the selected materials, while Table 2 gives a cost summary of the design.

Table 1: List of materials selected and their properties

S/N	Materials	Properties
1	Mild steel sheet and pipes	It has high mechanical strength, ductility, elasticity, affordable and readily available.
2	Arduino unoR3	It is simple to programme and readily available.
3	Footswitch	It has highly durable, inexpensive and easy to install.
4	Auto T10 cold white LED (12v)	It is light in weight, inexpensive, and durable.
5	Charge controller module	It has good sensitivity, easy to install and robust.
6	Stainless steel	Corrosion resistance, heat resistance and easy to fabricate
7	Lockable rubber castor	It has high mechanical strength to support the weight of the device.

*Corresponding author: Ahmed, Y. K. ahmed.yk@unilorin.edu.ng Department of Biomedical Engineering, Faculty of Engineering and Technology, University of Ilorin. © 2019 Faculty of Techn. Educ., ATBU Bauchi. All rights reserved

Table 2: Cost summary of the designed surgical light

S/N	Item	Quantity	Unit price (USD)	Total price (USD)
1	Mild steel sheet $(2000\ mm \times 1000\ mm \times 0.09\ mm)$	1	10.41	10.41
2	Mild steel pipe $(1000\ mm\ long, 3.4\ mm\ thick\ and\ 32\ mm\ \emptyset)$	1	6.51	6.51
3	Mild steel pipe $(1100\ mm\ long, 3.4\ mm \times 28\ mm\ \emptyset)$	1	5.21	5.21
4	Lockable rubber castor	4	2.60	10.40
5	Stainless steel sheet $(700\ mm \times 360\ mm \times 1\ mm)$	1	7.81	7.81
6	Footswitch/pedal	1	9.11	9.11
7	Arduino uno R3	1	7.81	7.81
8	Angle iron $(6100\ mm\ by\ 2mm)$	1	10.41	10.41
9	Vero board	2	0.52	1.04
10	Bridge rectifier KBU1010	2	1.04	2.08
11	Auto T10 (W5W/194) Cold white LEDs	32	0.65	20.83
12	(12V/50mA)	1	7.81	7.81
13	Battery (12v/7.2Ah)	1	0.39	0.39
14	IC (LM7815)	1	5.20	5.20
15	Transformer (220v/15v 2A)	1	3.90	3.90
16	Connecting Wire pack	1	2.60	2.60
17	Plug and socket (220V-240V)	1	0.52	0.52
	Miscellaneous including transport	-	-	13.51
	Total			108.63

System Design and Description

The design is modularized into (i) control module (ii) lighting module and (iii) battery bank and charge controller module. They all work together to provide adequate illumination and a robust system. The block diagram in Fig. 1 showed the interconnection of the main components of the system.

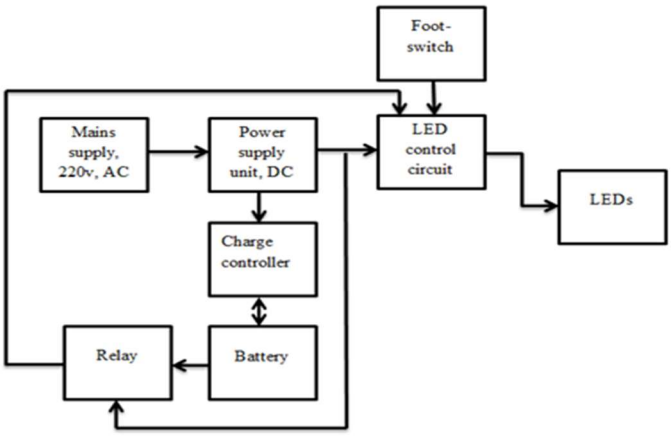


Fig. 1: Block diagram of the device modules.

*Corresponding author: Ahmed, Y. K. ahmed.yk@unilorin.edu.ng Department of Biomedical Engineering, Faculty of Engineering and Technology, University of Ilorin. © 2019 Faculty of Techn. Educ., ATBU Bauchi. All rights reserved

The AC mains supply gets rectified and regulated in the power supply unit (PSU) which feeds both the charge controller and the control circuit for the T10 LED light. The charge controller in Fig. 2 is equipped with a digital display of the battery's current voltage level. The controller is used to monitor and control the charging and discharging phase of the battery automatically to avoid overcharging and consuming the battery energy below 70%. This mechanism helps to increase the battery's useful life span and cut cost on its maintenance and replacement.

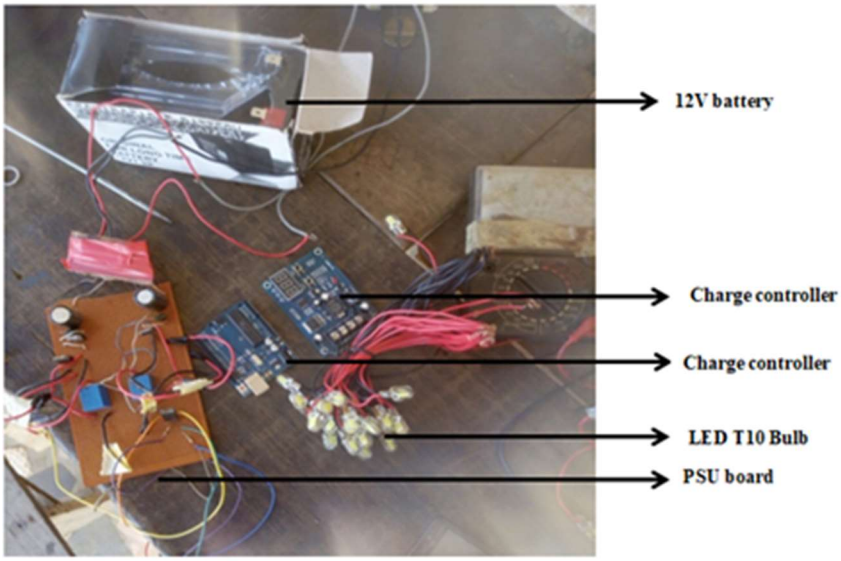


Fig. 2: Main components of the device.

The LED control circuit which consist of Arduino unoR3 board with Atmega 328p, LED indicators, the power ON/OFF switch with a foot pedal (switch) connected to it. The foot pedal (Fig. 3) is programmed to seamlessly control the surgical light intensity on pressing it with either right or left foot. This footswitch is such that one do not have to press several times to change the light intensity but rather keep the pedal pressed until ones desired intensity is achieved then lift ones foot off it.



Fig. 3: Footswitch

*Corresponding author: Ahmed, Y. K. ahmed.yk@unilorin.edu.ng Department of Biomedical Engineering, Faculty of Engineering and Technology, University of Ilorin. © 2019 Faculty of Techn. Educ., ATBU Bauchi. All rights reserved

JOURNAL OF SCIECNCE TECHNOLOGY AND EDUCATION 9(1), MARCH, 2021
ISSN: 2277-0011; Journal homepage: www.atbuftejoste.com

This mechanism would avoid fatigue, and unnecessary distraction, as no sound would be made while carrying out this process. On switching ON the device, the illumination is maximum and decreases to a minimum on continual long press on the foot pedal for an average of 7secs. The LED array circuit is shown in Fig. 4 consist of a thirty (30) Auto T10 (W5W/194) cold white LEDs' connected in parallel. Each LED is 1 watt, 3200 lumens and has an in built current limiting resistor. On the Arduino unoR3 board, one leg of the footswitch is connected while the other leg is linked to pin D2 of the Arduino board. A 10kΩ resistor (R3) is connected between pin D2 and ground. Another 10kΩ resistor (R4) is connected between pin D9 and the gate of the MOSFET. The source terminal of the MOSFET is connected to the ground pin and the negative leg of the LED array. In normally closed configuration, the relay block is used to change over to battery supply when AC mains are not available and vice versa. On completion of the design's hardware prototype, the orthographic and Isometric views of the system are developed as in Fig. 5 (a).

The stem of the lamp is made of metal pipes of two different diameters (the pipe with a smaller diameter is suspended in the bigger diameter pipe) such that the adjusting can control the length of the stem by the knob in Fig. 5 (b). The lamp's base is made of a box 610 mm × 300 mm to allow for future expansion of the battery bank and provide a rigid base with a high centre of gravity to ensure stability. Lockable castor wheels are attached to the base to allow for easy movement and positioning – the lock is used to keep it in a particular desired position.

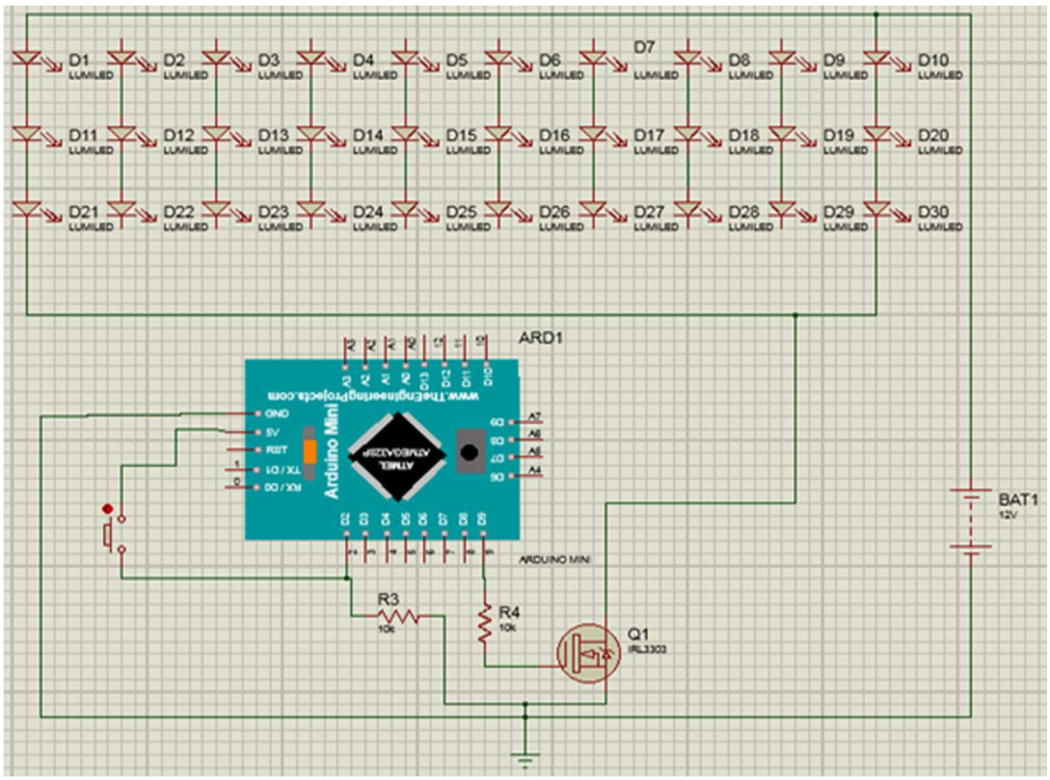
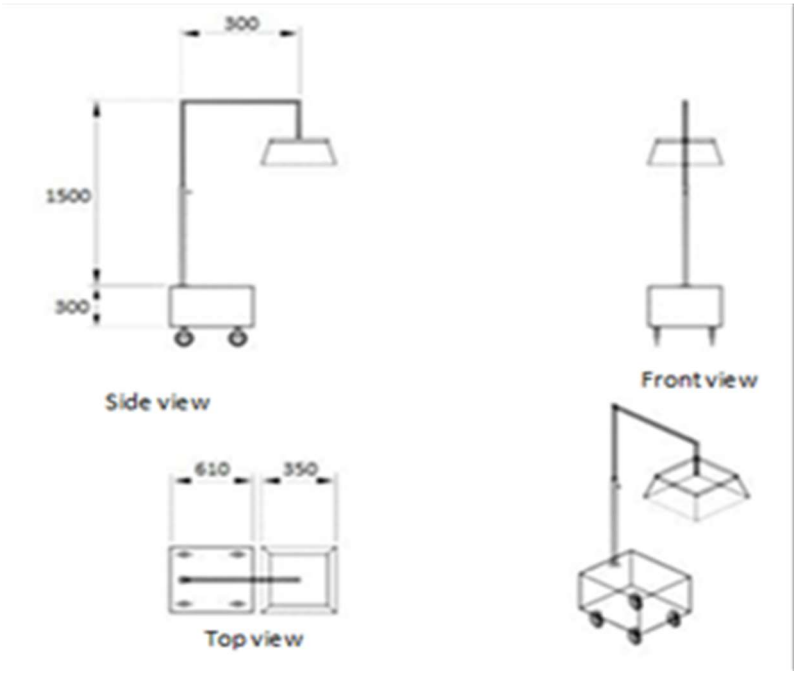


Fig. 4: LED array circuit

*Corresponding author: Ahmed, Y. K. ahmed.yk@unilorin.edu.ng Department of Biomedical Engineering, Faculty of Engineering and Technology, University of Ilorin. © 2019 Faculty of Techn. Educ., ATBU Bauchi. All rights reserved



(a) Orthographic and Isometric drawings

Fig. 5: Software drawings



(b) Image of the surgical light device

Fig. 6: Image of the surgical light design.

*Corresponding author: Ahmed, Y. K. ahmed.yk@unilorin.edu.ng Department of Biomedical Engineering, Faculty of Engineering and Technology, University of Ilorin. © 2019 Faculty of Techn. Educ., ATBU Bauchi. All rights reserved

Two consecutive hinge joints are installed: one at the end of the stem while the second one is placed at the end of the 300 mm long, 3.4 mm thick and 28 mmØ pipe. The light head, 100 mm × 350 mm (outer length) is attached to the third hinge at the end of 500 mm long, 3.4 mm thick and 28 mmØ pipe. This light head is made of stainless steel reflectors with angle 45 ^{o} to ensure that the light rays are focused downward to the operating area.

RESULT

Several tests were carried out on the device to ensure its compliance with electrical, mechanical and optical standards. The device passed the load-bearing test as it did not topple over on attaching the light head and swirled around for two minutes.

Electrical Tests

Tests such as continuity test were carried out to ensure no open circuit problem with the device. An electrical safety test, such as short circuit test, was also done and there was no leakage current to the chassis that could cause an electric shock to users. To ensure the right battery size for adequate input voltage for maximum illumination intensity, a variable PSU with model no M10-AD370-6 (MCP® Lab Electronics, China) was used. The test revealed that a voltage of 13V gives a high and save intensity without burning out the LED bulbs.

Optical Test

According to IEC 2000, section 60601 - 2 - 41, the quality of illumination for surgical light ranges from 40,000 – 160,000 lux (IEC Subcommittee 62D, 2009). The central illumination E_c and the correlated colour temperature (CCT) were 8500lx and 6000K, respectively. The measurements were taken by benetech® Illuminometer (Shenzen, China). All tests were conducted in the instrumentation laboratory of the Department of Biomedical Engineering, University of Ilorin, Nigeria.

DISCUSSION

An inexpensive surgical light device is presented in this study for low resource health care centres. Being a prototype, the design did not meet the IEC 2000 standards of minimum 40,000 lux due to limited number of LED used, which can simply be increased to meet the standard. However, recent research such as Hemphälä et al.(2020) didn't support "the more the intensity the better" theory of IEC 2000. His study of varying light intensity among various subjects revealed that fatigue and subjective discomfort glare are increased with high luminosity. Therefore, his research concluded that a value of 5500lx on operating table is better, which is even below the luminous intensity value of our prototype reading. While providing seamless intensity control without distraction from the on-going procedure, this prototype could also be used for other purposes such as examination, diagnostic and even treatment light, requiring minimum illumination of 1000 lux (Mehrotra et al., 2015). Although this device would still require the surgeon to touch the light head handle for position change, it has greatly reduced the frequency of touchs, hence reduced probability of distraction and infection.

The estimated cost of the designed surgical light is 109 USD which is extremely cheap compared to the market price range of 2000 – 37000 USD for incandescent light and 12000 – 89000 USD for LED light (depending on the number of light heads) as given by WHO (*Lights*, 2012). Other costs include shipping, installation and training costs. Besides, the incorporated charge Controller would further cut on maintenance cost by increasing the healthy life span of the battery bank. Therefore, it is expected that this device would replace

*Corresponding author: Ahmed, Y. K. ahmed.yk@unilorin.edu.ng Department of Biomedical Engineering, Faculty of Engineering and Technology, University of Ilorin. © 2019 Faculty of Techn. Educ., ATBU Bauchi. All rights reserved

touch lights often used during surgical operations and deliveries in the rural clinics. However, it is recommended that subsequent design adopt a parabolic light head to ensure adequate convergence and, hence, higher intensity on the operating table.

REFERENCES

Ahmed, Yusuf K and Zubair, Abdul R and Sani, Saminu and Akande, Kareem A and Afolayan, Mubarak A and Afonja, A. A. (2020). Design and Construction of a Portable Electronic Sleep Inducer for Low Resource Settings. *FUOYE Journal of Engineering and Technology*, *5*(2), 84–88. https://doi.org/http://dx.doi.org/10.46792/fuoyejet.v5i2.475

Ahmed, Y. K., Ibitoye, M. O., Zubair, A. R., Oladejo, J. M., Yahaya, S. A., Abdulsalam, S. O., & Ajibola, R. O. (2020). Low-cost biofuel-powered autoclaving machine for use in rural health care centres. *Journal of Medical Engineering & Technology*, 1–9.

Berman, J., Leiter, R. B., & Fong, Y. (2015). Lighting in the operating room: current technologies and considerations. In *Imaging and Visualization in The Modern Operating Room* (pp. 3–15). Springer.

Curlin, Jahnavi and Herman, C. K. (2020). Current state of surgical lighting. *The Surgery Journal*, *6*(2), e87.

deVries, C. R., & Rosenberg, J. S. (2016). Global surgical ecosystems: a need for systems strengthening. *Annals of Global Health*, *82*(4), 605–613.

Dietz, Armin and Schröder, Stephan and Pösch, Andreas and Frank, Klaus and Reithmeier, E. (2016). Contactless Surgery Light Control based on 3D Gesture Recognition. *GCAI*, 138–146.

Forrester, J. A., Boyd, N. J., Fitzgerald, J. E. F., Wilson, I. H., Bekele, A., & Weiser, T. G. (2017). Impact of surgical lighting on intraoperative safety in low-resource settings: a cross-sectional survey of surgical providers. *World Journal of Surgery*, *41*(12), 3055–3065.

Hardy, K. R., Olsson, M. S., Sanderson, J. R., Steeves, K. A., Lakin, B. P., Simmons, J. E., & Weber, P. A. (2007). High brightness light emitting diodes for ocean applications. *OCEANS 2007*, 1–4.

Henry, J. A., Windapo, O., Kushner, A. L., Groen, R. S., & Nwomeh, B. C. (2012). A survey of surgical capacity in rural southern Nigeria: opportunities for change. *World Journal of Surgery*, *36*(12), 2811–2818.

Ibitoye, M. O., Raji, A. O., & Nafiu, S. O. (2019). Inexpensive automated medication dispenser for persons with neurodegenerative illnesses in low resource settings. *Journal of Medical Engineering & Technology*, *43*(8), 451–456.

IEC Subcommittee 62D, E. E. I. 60601-2-41 E. 2. (2009). *Medical Electrical Equipment, Part 2-41: Particular Requirements for the Safety of Surgical Luminaires and Luminaires for Diagnosis*.

Joseph, A. (2006). *The impact of light on outcomes in healthcare settings*. Center for Health Design.

Knulst, Andries Jacob. (2017). *Surgical lighting*. Delft University of Technology.

Knulst, Arjan J, Kunst, J., & Dankelman, J. (2019). Lightfield adaptable surgical luminaire concept. *Journal of Medical Engineering & Technology*, *43*(6), 378–386.

Knulst, Arjan J, Mooijweer, R., Jansen, F. W., Stassen, L. P. S., & Dankelman, J. (2011). Indicating shortcomings in surgical lighting systems. *Minimally Invasive Therapy & Allied*

*Corresponding author: Ahmed, Y. K. ahmed.yk@unilorin.edu.ng Department of Biomedical Engineering, Faculty of Engineering and Technology, University of Ilorin. © 2019 Faculty of Techn. Educ., ATBU Bauchi. All rights reserved

Technologies, *20*(5), 267–275.

Knulst, Arjan J, Stassen, L. P. S., Grimbergen, C. A., & Dankelman, J. (2009). Standards and performance indicators for surgical luminaires. *Leukos*, *6*(1), 37–49.

Lights , surgical Hospital medical equipment - general information. (2012).

Matern, U., & Koneczny, S. (2007). Safety, hazards and ergonomics in the operating room. *Surgical Endoscopy*, *21*(11), 1965–1969.

Mehrotra, S., Basukala, S., Devarakonda, S., & others. (2015). Effective lighting design standards impacting patient care: a systems approach. *Journal of Biosciences and Medicines*, *3*(11), 54–61.

Oyekale, A. S. (2017). Assessment of primary health care facilities' service readiness in Nigeria. *BMC Health Services Research*, *17*(1), 172.

Pan, C.-T., Chen, Y.-C., Yang, T.-L., Lin, P.-H., Lin, P.-H., & Hsieh, C. C. (2014). Design of elliptic reflective LED surgical shadowless lamps using mathematical optical tracing algorithms. *Mathematical Problems in Engineering*, 1–7. https://doi.org/doi.org/10.1155/2014/535703

Patkin, M. (2003). What surgeons want in operating rooms. *Minimally Invasive Therapy & Allied Technologies*, *12*(6), 256–262.

Roshan, T. A. U., Sachinthana, L. M. N., Senarathna, P., Welgama, W. J. W. P. D., & Amarasinghe, Y. W. R. (2016). *Design and Development of an Intelligent Lighting System for Operation Theatres*.

Schweitzer, Daniel and Klaber, Ianiv and Fischman, Daniel and Wozniak, Aniela and Botello, Eduardo and Amenabar, P. P. (2015). Surgical light handles: a source of contamination in the surgical field. *Acta Orthopaedica et Traumatologica Turcica*, *49*(4), 421–425.

Zhao, Q., Miao, J., Zhou, S., Gui, C., Tang, B., Liu, M., Wan, H., & Hu, J. (2019). High-Power GaN-Based Vertical Light-Emitting Diodes on 4-Inch Silicon Substrate. *Nanomaterials*, *9*(8), 1178.

**Corresponding author: Ahmed, Y. K. ahmed.yk@unilorin.edu.ng Department of Biomedical Engineering, Faculty of Engineering and Technology, University of Ilorin.* *© 2019 Faculty of Techn. Educ., ATBU Bauchi. All rights reserved*