Development of a Prototype Automated Self-Adjusting Arm with a Light for an Operation Theatre

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ABSTRACT

Most of the available surgical lighting systems in Sri Lanka are manually operated. This paper describes a development of a prototype automated self adjusting arm with a light for an operation theatre. The project consisted of two main parts. The first part was image processing. Image processing was done with the help of a computer and a camera to identify the site of surgery. Equipment with an infrared light emitting diode was used as an indicator of the surgery position. The second part was controlling the arm of the theatre light. The rotation of the arm was controlled by three small servo motors. Servo motor control was done using a microcontroller. The position data of the place of surgery was fed to the microcontroller via a communication link (RS232) between the computer and the microcontroller. The microcontroller controls the servo motors and focuses the surgical light to the identified area of surgery. The prototype was designed and constructed using components available in the local market, at low cost. Functionality of the prototype was tested and evaluated under laboratory conditions.

1. INTRODUCTION

Before 1850s, sun light from a window of the ceiling was used as the lighting source for operation theaters. But the difficulty was that doctors, nurses and equipments could easily block the illuminated area. Mirrors were then used in the corners of the ceiling to direct sunlight to the operating table, but the problems were not reduced very much.

Optical condenser in an indirect light was also tried to reduce the heating but without success. When the electric lights made their entrance into the operating room in the 1880s it also quickly showed problems. The light created was still moving and diffuse with great heat radiation. With new technology today, LEDs (light-emitting diodes) are now used to control heat radiation with greater control and brightness of light and a much higher efficiency [1].

A surgical light, which is referred to as an operating light or surgical light head is to assist medical personal during a surgical procedure by illuminating the local area or cavity of the patient. A group of many surgical lights together is referred to as a 'surgical lighting system'. With the help of such lights, it is ensured that the entire surgical procedure is carried out properly. Surgical lights are used in medical examinations and in the actual surgical procedures. Lighting is an important factor when working directly with patients either in surgical settings or in general patient rooms and

examination rooms. Without the right lighting it is possible to miss an important factor that can dramatically increase the chance of a misdiagnosis [2].
The field of electronics has now become an important partner of new technologies of medicine. Many researches are going on combining the two knowledge streams medicine and electronics for developing new technologies, making it easy to cure people and, lots of new medical equipment have been introduced to the field of medicine.

Building a robot is not only a passion but also a dream for most engineers. Automation has become a fast developing technology in the past four five decades in all the engineering applications. Robot arms are highly essential parts in automation. The goal of this work is to develop a prototype automated self adjusting arm with a light for an operation theatre. The program was designed to capture the position of an IR LEDs through a PC-based webcam using MATLAB software. The IR LED position was fed in to the microcontroller which controls servo motors of the robot arm focusing surgical lights on to the surgical area.

2. METHODOLOGY AND IMPLEMENTATION

The study mainly focuses on;

- Identification of the position of surgery.
- Focusing the surgical light on to the surgery area (Focusing light means the light equipped on the arm is spotted to the position of surgery).

For position identification, a device was designed with an IR LED and a push button. The operator first should operate the IR LED device keeping it just above the surgery place of the patient. The image of the IR LED is sent into the Personal Computer (PC) through a camera which was specially modified to identify IR signals. A specific *MATLAB* program which is continuously running in the PC will detect the coordinates of the position of the IR LED. This coordinate data is sent to a Programmable IC (PIC) via a RS232 communication. The PIC calibrated with position data identifies the position of the surgery with an acceptable accuracy. Thereafter, the PIC sends signals to the robot arm servo motors. The robot arm servo motors then rotate focusing light beam to the position of surgery. Figure 1 shows a diagram of the complete process.

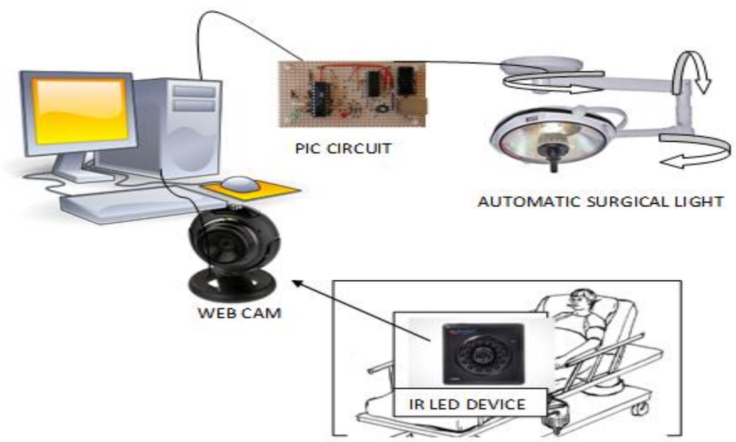

Figure 1: Diagram of the detection process

2.1 Identification of the Position of Surgery

A visual-based positioning method (Using an optical sensors-camera) was selected since, other available methods such as a GPS or a similar electro-magnetic wave signal methods are suitable for very large areas (equipment cost also very high). Instead, low cost, small web camera and a computer are enough for image processing (visual-based positioning method) [3].

Initially, it was decided to check the possibility of giving a colour to the glove of the surgeon, so that the system recognizes the colour of glove. But when the surgeon turns to get surgical instruments, the surgical light will also be turned to that side. Therefore, it was essential to introduce an advanced type of glove which the surgeon can trigger a specific feature. The price of that glove would be high. Normally, a surgeon changes glove several times during a surgery. Therefore, it was decided to introduce a small device which was equipped with a press-button and a LED. It can be easily be used to position the surgical light before the surgery is started. But, coloured LED adds colour to the environment and may be a disturbance to the surgery. Therefore, an IR LED was used. To avoid the disturbance from other lights an IR pass filter was added to the camera eye [4].

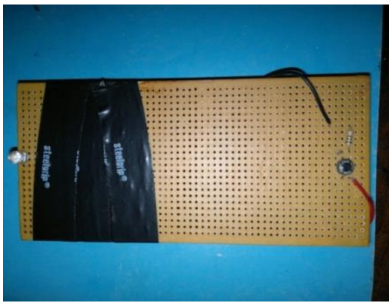

Figure 2: Device with an IR LED and Push-button

The position of IR LED was identified using the image segmentation method. Image segmentation is the process of dividing an image into multiple parts. This is typically used to identify objects or other relevant information in digital images. There the MATLAB software calculates coordinates of the IR LED very precisely. The data was fed to PIC via RS232 connection.

2.1.1 MATLAB Program and Identification of Coordinates of IR Light

A MATLAB program was coded to identify the white colour in the camera input [5]. Since, the lens was covered with an IR pass filter no visible light hits the camera. Therefore, an IR light signal comes in to the camera and identifies it as a white light. The MATLAB program takes the middle of the camera image as (325, 240) position and outer corners as (10, 14), (642, 14), (642,460) and (10,460) [6].

When the push button of the IR LED device was pressed the image and the coordinates are given by the program. An image of the camera output was shown in Figure 3.

The coordinates were extracted and send to the PIC via RS232 communication by the MATLAB program. USB PC camera is high quality powerful and inexpensive camera which can be installing easily. The resolution of web camera is 1280 × 960 pixels.

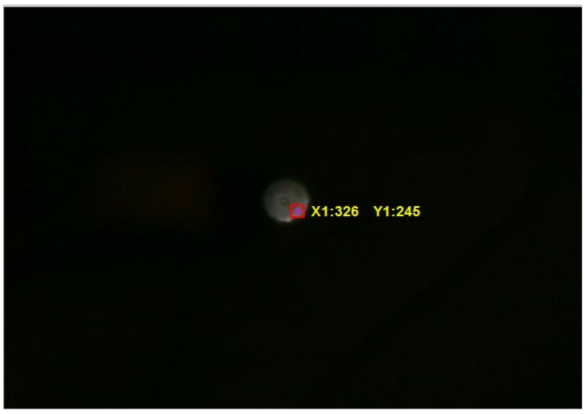

Figure 3: Output of the web camera after modification

2.1.2 Calibration of the positions

It is necessary to calibrate the positions of the surgery field after installation for better accuracy. Therefore, the following steps were followed to calibrate the positions and the data were stored in the PIC.

The frame captured by the camera is divided into twenty five points. The positions of the IR LED were plotted as described in Figure 4,

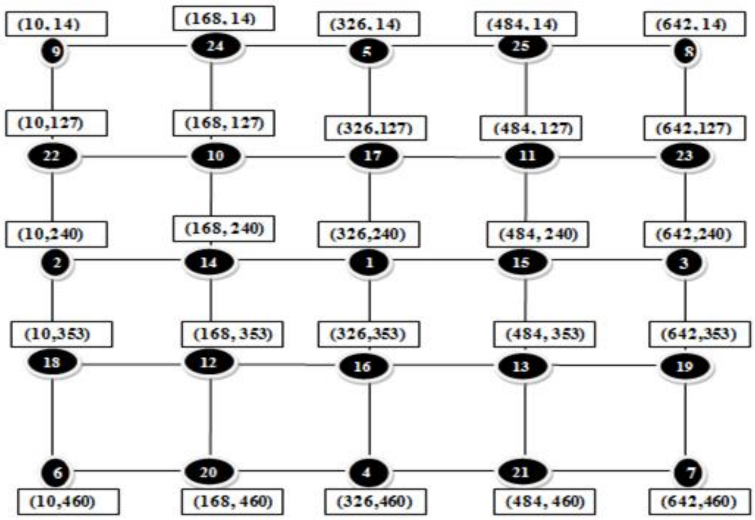

Figure 4: The Frame Captured by the camera

Various conditions for detecting the position of the IR LED are,

(1) If the IR LED is at the point 1, 2, 3, 4, 5, 6... 24 and 25, the surgical light should be moved at these points.

(2) If the IR LED does not coincide with any of the pre-defined coordinate points, the surgical light should be moved to the nearest point.

When, the push-button was pressed, the computer processes the image of the IR LED and sends twenty five different data sets through its serial comport. The data depends on the location of the IR LED as captured by the camera.

2.2 Focusing the Surgical Light on to the Position of Surgical Area

For a 3D space, there should be at least three degrees of freedom in the robot arm. With more degrees of freedom, the movements would be fast and smooth but controlling would be complex. For convenience it was decided to use a robot arm with three degrees of freedom. The surgical light with the robotic arm is shown in Figure 5.

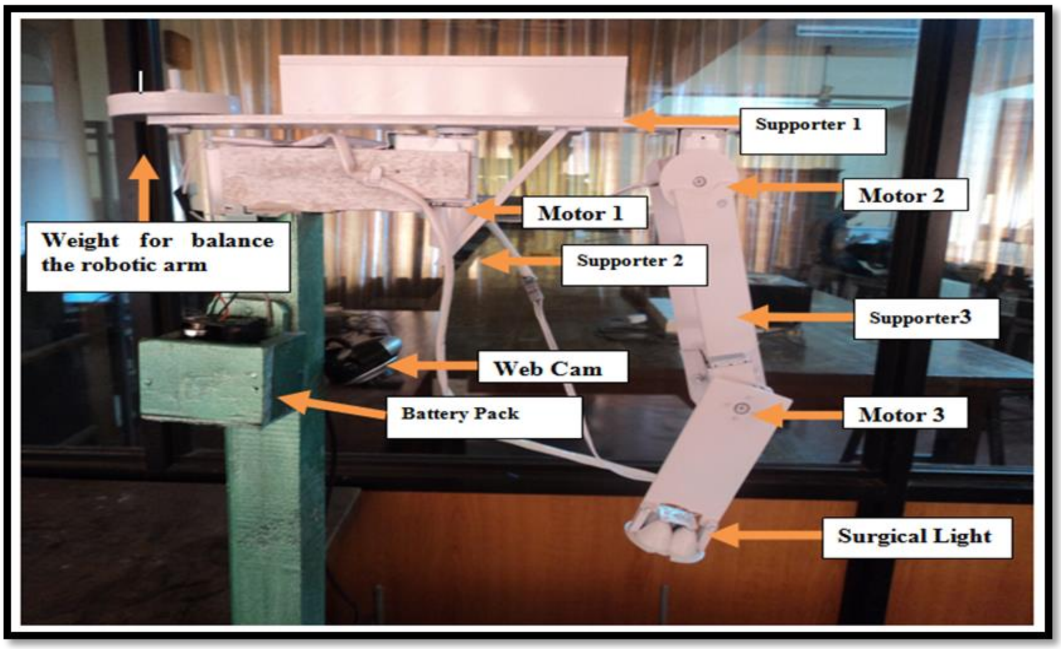

Figure 5: Robotic Arm for Controlling the Surgical Light

Considering the ease of controllability and low power consumption, three small robotic servo motors were used [7]. According to the above figure, three servo motors were used to control the surgical light. The surgical light can be focused through the rotation of the servo motors as required.

Motor 1 servo motor was rotated along vertical axis and Motor 2 and Motor 3 servo motors were rotated along horizontal axes. The left side weight was used to balance the robotic arm and as a result, the torque of the Motor-1 was reduced. Supporter 2 and supporter 3 were used to minimize the weight of the rotating wheels so that, the Motor-1 and Motor-2 torques were reduced. Supporter-1 was used to avoid bending of the robotic arm.

Perspex was used to make the robotic arm because it is light in weight, low in price, and easy to fix to the servo motors. The web camera fixes the robotic arm and it was focused on the midpoint of the surgical area. Therefore, the web cam was angled at 45° to negative side of horizontal axis and with an angle of -45° to positive side of vertical axis.

The robotic arm controlled using a microcontroller with respect to the image processing part data output is sent through serial COM port. The microcontroller identifies the positions and control three servo motors to the correct position. The microcontroller identifies the positions using the following codes in the decision table.

Table 1: Decision Table with Angles of Three Servo Motors

Points	Key	Servo 1	Servo 2	Servo 3
Point-1	a	90°	90°	90°
Point-2	b	45°	45°	135°
Point-3	c	135°	45°	135°
Point-4	d	90°	45°	135°
Point-5	e	90°	135°	45°
Point-6	f	110°	30°	150°
Point-7	g	70°	30°	150°
Point-8	h	0°	90°	90°
Point-9	i	180°	90°	90°
Point-10	j	135°	115°	65°
Point-11	k	45°	115°	65°
Point-12	l	120°	70°	110°
Point-13	m	60°	70°	110°
Point-14	n	135°	90°	90°
Point-15	o	45°	90°	90°
Point-16	p	90°	75°	105°
Point-17	q	90°	105°	75°
Point-18	r	125°	60°	120°
Point-19	s	55°	60°	120°
Point-20	t	105°	30°	150°
Point-21	u	75°	30°	150°
Point-22	v	160°	80°	100°
Point-23	w	20°	80°	100°
Point-24	x	180°	70°	110°
Point-25	y	0°	70°	110°

When the push-button is pressed at the point1, the serial port sends key ‘a’ to the microcontroller and the microcontroller controls three servo motors to the correct position. That means servo motor1; motor2 and motor3 are individually rotated by 90 degree.

When considering point 4, the serial port sends key ‘d’ to the microcontroller and microcontroller controls three servo motors to the point 4. That means servo motor1 is rotated by 90 degree, servo motor 2 is rotated by 45 degree and servo motor 3 is rotated by 135 degree.

2.2.1 PIC Inter-circuit

The PIC inter-circuit was designed with one PIC16F877a microcontroller, one MAX 232, 7805 regulator, one Serial port, LEDs, resistors, capacitors and connectors. Eagle5.8 software was used to draw the schematic diagram and design the PCB layout of the circuit [8].

The board required a 5.5 V (minimum voltage) to 10 V (maximum voltage) DC supply input and 6 V supply was used. The ideal voltage for a PIC16F877a is 5 V. It should not be higher than 5.5 V because, otherwise the PIC would be burnt. It also should not be less than 2 V because; if so the PIC would not operate. Therefore, LM7805 regulator was used. LM7805 would step down larger input voltage (maximum 10 V) to 5 V. The max 232 was used to convert 12 V supply because; the output signal of PIC16F877a is in TTL level from 0 V to 5 V. The COM ports of the PC need both positive and negative voltage levels. Therefore, a RS232 level is necessary to perform +12 V and -12 V. A LED connected to the pin-A0 was used to give visual indication when the control circuit is at ON state or OFF state. An indicator LED has been used to identify ON state or OFF state of the circuit. The three servo motors were controlled using Pins RB1, RB2 and RB3. Here only three pins were needed to connect to the servo motors, but extra connectors were added for future usage.

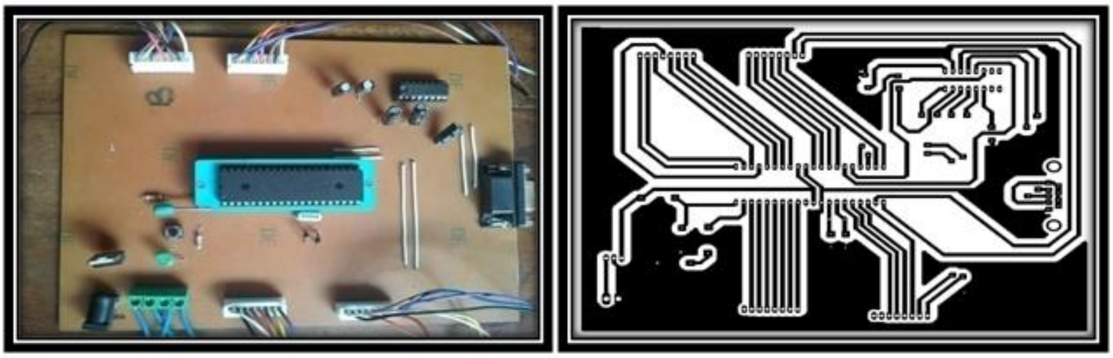

Figure 6: Constructed Circuit and PCB layout

3. RESULTS AND DISCUSSION

When it was pressed the push-button of IR LED device is pressed keeping it at the positions of the surgical area, surgical light was rotated to the correct positions.

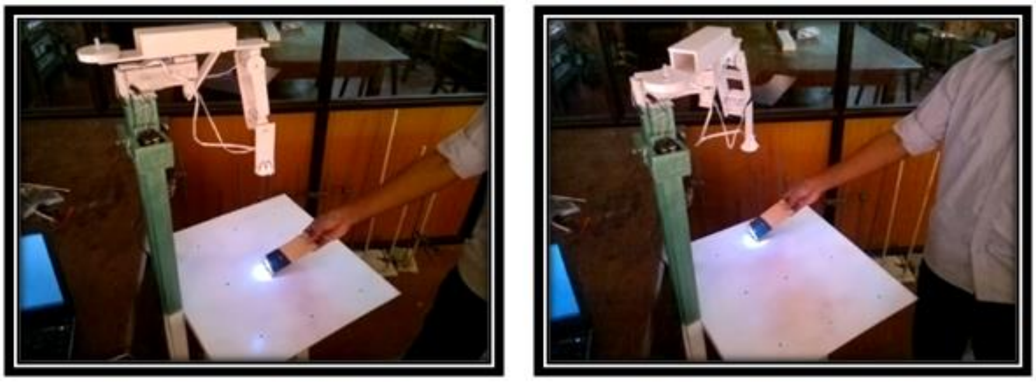

Figure 7: Surgical Light Rotates to the Correct Positions

The time taken for the rotation of the light from one point to another point was measured and it was found that time taken to rotate from one point to another point is less than one second.

This automated surgical light system was calibrated in such a way that, the surgical light is focused to a fixed 25 points to make it easy for the coding for the prototype (It is possible to code as rotating to any point). Therefore, if the IR LED is activated at the points 1, 2, 3, 4, 5, 6... 24 and 25, the surgical light will move to the exact locations of the points. If the IR LED does not coincide with any of the pre-defined coordinate points, the surgical light should be moved to the nearest point. Therefore, maximum error between two points is ± 1.25 cm. This can be made negligible by increasing number of points.

4. CONCLUSION

The prototype of automated self-adjusting arm with a light was designed and constructed and its functionality was tested in laboratory. It functioned successfully to the expected level. The reliability and accuracy of operation was very high.

The techniques used in this prototype can be developed to the commercial level using servomotors with higher power levels, bearings, mobile processors, quality manufacturing processes and etc. This will be an achievement of trusted, efficient and very accurate theatre lighting system than existing theatre lighting systems.

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