Design and Implementation of Intelligent Desk Lamp

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Abstract—**In this paper, we proposed a FPGA based intelligent desk lamp system with a camera, two servo motors and LEDs. The proposed lamp can trace a moving book by automatic pan/tilt control. Thus, the user can read book with enough light for eye care. The architecture of the intelligent desk lamp system includes vision system and servo motors control system. The position data of the book can be obtained by the image processing module. According to the position data of the book, the pan and tilt angles of the desk lamp can be adjusted by two servo motors automatically. The adjustable ranges for pan/tilt are 60/30 degrees. The processing modules are implemented by hardware in FPGA. We use Verilog HDL to implement this system on Altera DE0-Nano kit with Cyclone® IV EP4CE22F17C6N FPGA.**

***Keywords* – FPGA; Intelligent Desk Lamp; Image Processing; Servo Motor Control**

I. Introduction

Intelligent lighting usually refers to stage lighting that has automated or mechanical abilities beyond those of traditional, stationary illumination. Mercedes-Benz also unveils the Intelligent light system, the adaptive car headlamps. These adapt to the prevailing driving and weather conditions, thereby significantly enhancing safety. The intelligent lighting systems as mention above need a sensory system that can monitor the environment in real time. In this work, we proposed an intelligent desk lamp system which can trace the book based on vision system and adjust the pan/tilt angle of the desk lamp automatically. Real-time image processing is used in the proposed system. Moreover, the power of desk lamp is turn on when user seat on the chair to ensure sufficient ambient lighting in the room for eye care by the intelligent chair system. We can take care of eyes by following the rule that the head of your desk lamp should be installed above your line of vision to avoid direct glare. Hence, the desk lamp of the proposed system can be adjusted with two servo motors according to the position of the book automatically to avoid direct glare.

II. Architecture of the Intelligent Desk Lamp System

The proposed intelligent desk lamp system includes one servo motor for tilt control, one servo motor for pan control, a D5M CMOS camera, LEDs for lighting, and a DE0-Nano for image processing and system controlling. Fig. 1 shows the picture of the intelligent desk lamp.

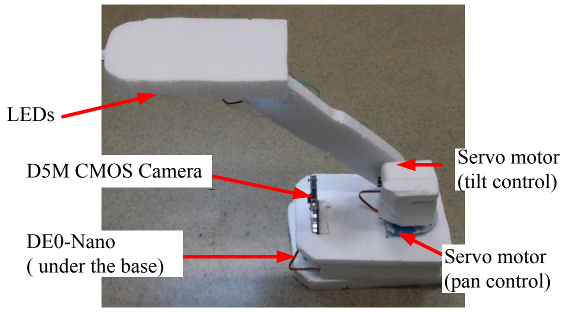


Fig. 1 The intelligent desk lamp.

Fig. 2 shows the architecture of the proposed intelligent desk lamp. A video signal input from CMOS camera is processed with a FPGA on the DE0-Nano. Two Servo motors are controlled according to the image processing result with a FPGA on the DE0-Nano.

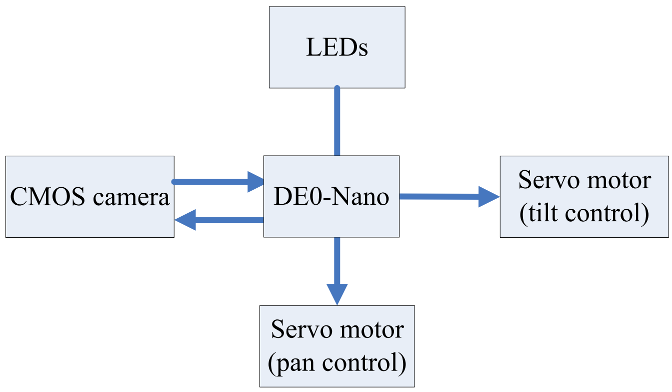


Fig. 2 The block diagram of the propose intelligent desk lamp.

Fig. 3 shows the flow chart of our proposed method. As shown in this figure, there are five major processes in the flow chart: vision signals captured from camera, real-time image processing, spot location calculation, pan/tilt decision and PWM signals control for Servo motors.

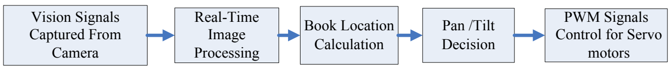


Fig. 3 The flow chart of our proposed method.

For vision signals captured from camera, the vision input was from the image sensor that outputs a RGB Bayer pattern [1]. For real-time image processing, the image raw data was then converted to its corresponding RGB values, and we used some image processing techniques tore move the noises of the image and locate the edge of a red spot. For spot location calculation, we extracted X and Y coordinates of spot corner. For pan/tilt decision, the system decided the pan/tile parameters of the desk lamp. For PWM signals control for Servo motors, two pulses of corresponding width were sent to two servo motors for pan/tilt control of the desk lamp .The details are organized as following.

A. Real-Time Image Processing

Today's CMOS sensors typically have a resolution of several mega pixels. Processing an image stream with e.g.5 mega pixels, a resolution of 12 bit and 15 frames per second has to be considered. Digital images are captured by camera with 800x480 resolutions that outputs a RGB Bayer pattern. Fig. 4 shows the flow chart of the real-time image processing.

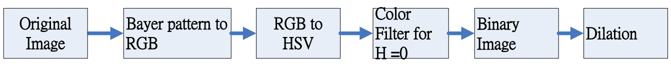


Fig. 4 The flow chart of the real-time image processing.

We transfer the original raw data to 30-bit RBG color image. However, HSV color space in terms of the Hue, Saturation, and Value describes color using more familiar comparisons such as color, vibrancy and brightness. The proposed system uses HSV color space to process color vision. The color filter for H =0 block lets only red color pass through. We transferred filter images to gray-level ones. We transformed the 256-graylevel image to bi-level image by Otsu's method. The Dilation block was used to give the expansion effect for the red region of the input image. Usual video cameras deliver images as serial data stream. Several image lines long shift register pipelines, are used for intermediate image data storage. The Dilation block uses 2D-FIR filter where pixel values of a whole image region (e.g. 3 by 3 pixels) are stored using line and pixel delay lines, comprising of shift registers [2]-[4]. The above-mentioned type of 2D Dilation filter is shown in Fig. 5. A 3×3 filter mask is used to process a 2-Dimensional (2D) traffic image. As the resolution of the CMOS camera will be set to 800x480 for our design, the tap of shift register is 800. The P_n means the registers to store the value of a pixel.

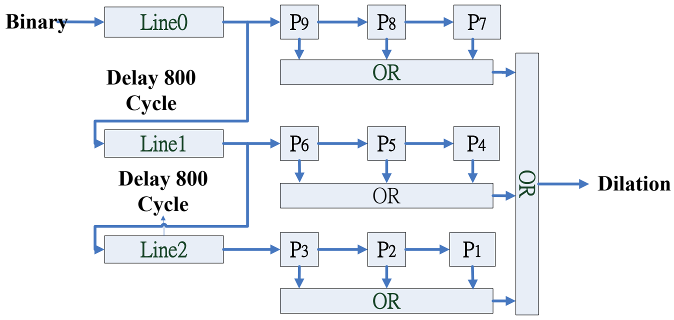


Fig. 5 The 2D Dilation filter.

The corresponding structuring element comprises a 3 x 3 pixel array. The nine corresponding pixel values are OR concatenated, i.e. the result is a logical "1" if any of the accessed pixels of the original image is equal to "1" [6].

B. Spot Location Calculation

In order to trace the red spot on the object, we trace the location of the red spot by the coordinates of left up corner of the red spot as shown in Fig.6. Assume the video cameras deliver images as serial data stream, i.e. line by line from left up corner of a frame. We developed a 2D 20x24 storage structure to count the pixels which the binary valve is 1. When the count value in the 20x24 storage structure is larger than a threshold value, for example, 350, the coordinates of the right down corner of the 20x24 structure were assigned to variant data_x and data_y. The variant data_x and data_ y can be reassigned only at next frame. If the location of the red spot at frame1 is different from frame2, the data_x and data_y will be different. We can trace the data_x and data_y as the red spot move.

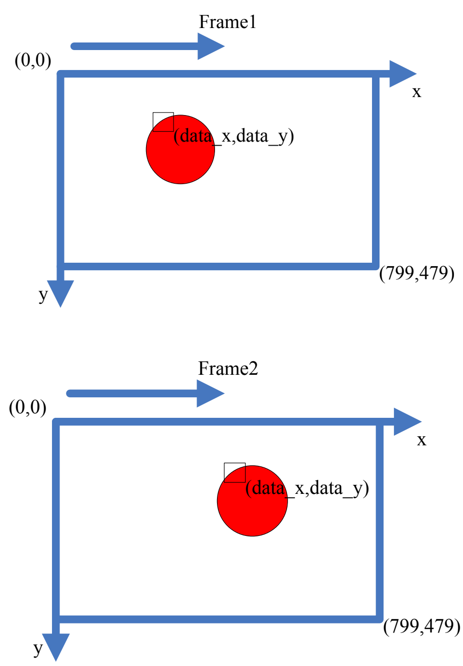


Fig. 6 The location identified for the red spot.

The above-mentioned type of 2D 20x24 storage structure is shown in Fig. 7. We developed the 20x24 storage structure by using the shift registers. To achieve this, a scan-line buffer and a window buffer are used. A scan-line buffer is a buffer which is able to contain several numbers of scan-lines in the input image, and a window buffer is a set of shift registers which can contain the pixels in the window. As the resolution of the CMOS camera will be set to 800x480 for our design, the tap of shift register is 800. The Pn_m means a register to store the value of a pixel. The identification flow for the red spot is shown in Fig 8.

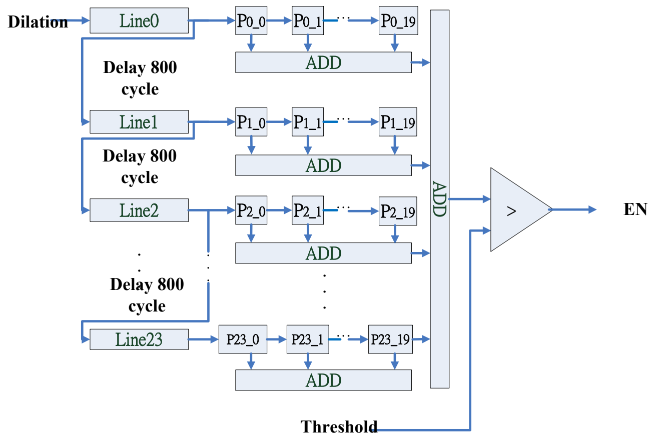


Fig. 7 The 2D 20x24 storage structure.

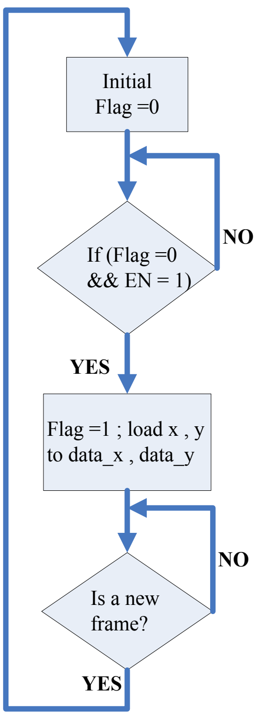
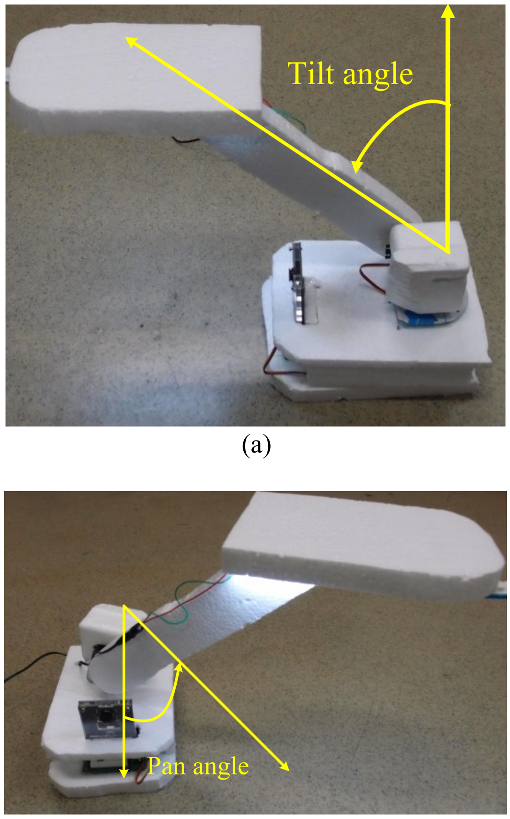


Fig. 8 The identification flow for the red spot.

C. Pan/tilt Decision

As the coordinates of red spot is determinate, the pan/tilt angle of desk lamp is determinate according the data_x and data_y, respectively. The pan and tilt are defined in Fig. 9. Table 1 and Table 2 list the corresponding pan/tilt angle for data_x and data_y, respectively.



(a)

(b)

Fig. 9 The pan and tilt definition of desk lamp.

TABLE I
THE RANGE OF PAN ANGLE

Data_x	Pan angle (degrees)
0~208	60
209~544	30
545~799	0

TABLE III
THE RANGE OF TILT ANGLE

Data_y	Tilt angle (degrees)
0~159	0
160-319	15
320~479	30

D. PWM Signals Control for Servo Motors

The pan/tilt angle of the desk lamp is controlled by two Servo motor. The Servo motor angle rotation is controlled by adjusting PWM ratio. The PWM signal can be genegrated by the hareware in FPGA. The PWM control circuit block diagram is shown in Fig. 10. We can adjust the parameter A to vary the pulse width of PWM signals [5]. For example, if the pulse width is equal to 1.8 ms and for pulse width is equal 20 ms as shown in Fig. 11, the desk lamp controlled by the desk lamp will tilt 0 degrees. The parameter A in Fig. 10 will be set to 180 for the 0 degrees tilt of the desk lamp.

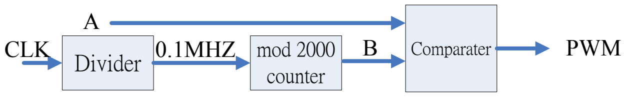


Fig. 10 The PWM control circuit block diagram.

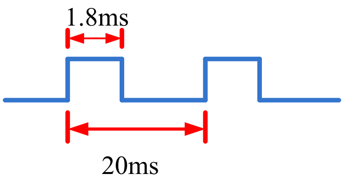


Fig. 11 The pulse width is equal to 1.8 ms.

The pan and tilt angle versus parameter A in Fig .10 is shown in Table 3 and Table 4, respectively. The corresponding pulse width of PWM signal is also shown in Table 3 and Table 4.

TABLE IIIII
THE CORRESPONDING PULSE WIDTH OF PWM SIGNAL FOR PAN ANGLE

pan angle (degrees)	A	Pulse width
0	120	1.2ms
30	150	1.5ms
60	180	1.8ms

TABLE IVV
THE CORRESPONDING PULSE WIDTH OF PWM SIGNAL FOR TILT ANGLE

tilt angle (degrees)	A	Pulse width
0	180	1.8ms
15	165	1.65ms
30	150	1.5ms

III. IMPLEMENTATION

For the main processing stage, ADE0-Nano Development and Education Board was chosen. DE0-Nano is tiny and suitable for portable applications. The core of the board is the Altera Cyclone® IV EP4CE22F17C6N FPGA. Two 40-pin Headers (GPIOs) provides 72 I/O pins. For the video systems, we were using 5-megapixel CMOS Camera (connected on GPIO_1) and the 32MB SDRAM. One 26-pin header (GPIO_2 of JP3) was used to connect servo motors. We also used a 4.3" LTM connected on GPIO_0 for image display and debug. The usage of DE0-Nano board in this work is shown in Fig .12.

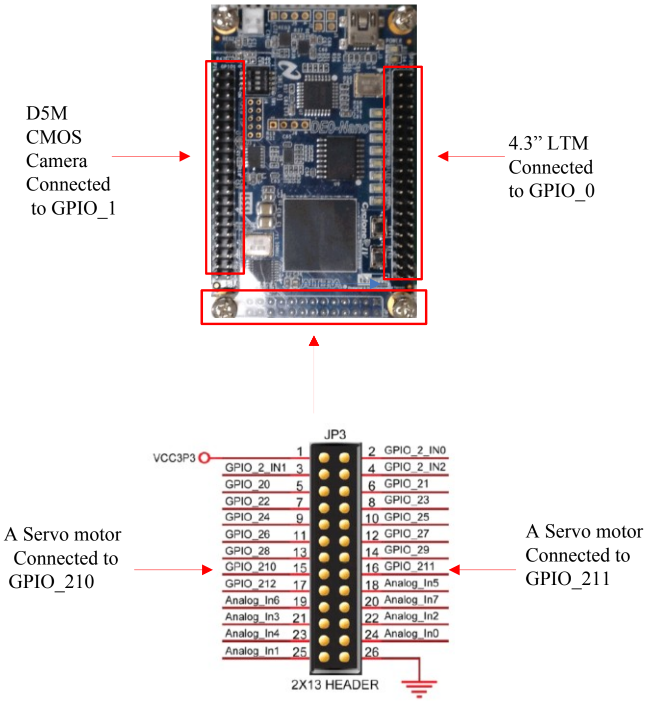


Fig. 12 The usage of the DE0-Nano board.

We established an Intelligent Desk Lamp that includes the TRDB_D5M (D5M) board with one CMOS Camera, an Altera DE0-Nano board, two servo motors and LEDs as shown in Fig. 13.

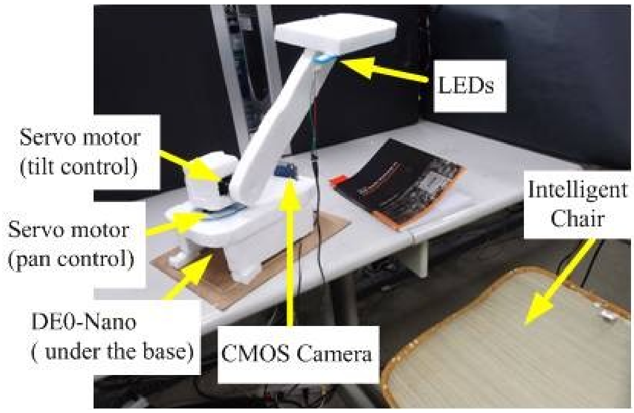


Fig. 13 Intelligent desk lamp system.

System architecture was shown by Fig. 14. The Verilog HDL is used to design the proposed architecture.

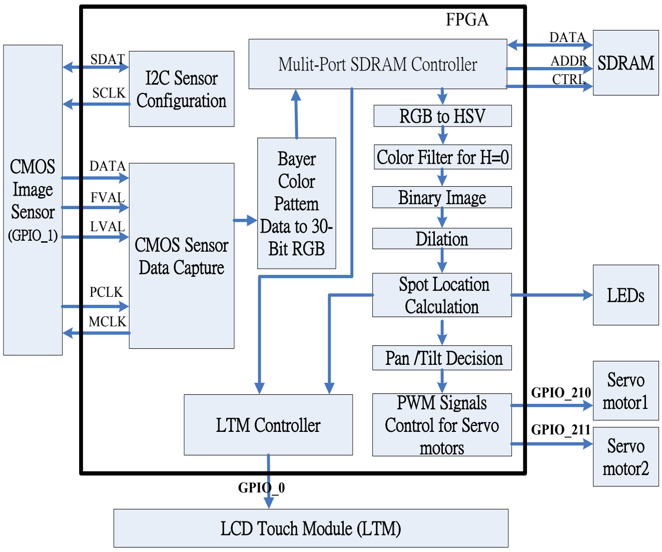


Fig. 14 System architecture.

The I2C sensor configuration module configures image sensor device according to I2C protocol. As resolution of the LCD screen is set to 800x400 for display the image of the CMOS camera. The resolution of CMOS sensor can be set to 800x480 with I2C sensor configuration module. The CMOS Sensor Data Capture module is used to capture signals from image sensor. The Bayer Color Pattern Data to 30-Bit RGB module render the image raw data into RGB format. The SDRAM is used as Frame buffer. The LTM Controller module is used to read data from SDRAM. The RGB to HSV module is used to transfer RGB color space to HSV. The Color filter for H=0 module is a red color pass filter. The Binary Image module sets the pixel value to 0 or 1023 according to the threshold value. The Dilation module can expand the red spot. As the video signal is read in sequentially as a line, and up to down line by line, the Spot Location Calculation module locate the first cluster through a proposed 20x24 window. When the number of the light pixel in the 20x24 window is larger than 350, the coordinates of first cluster in a frame satisfied is set to identified location of the red pot of the object. The pan/tilt Decision module sets the pan/tilt angle of the desk lamp according to the location of the red spot. The PWM Signals Control for Servo Motors module generates the corresponding PWM signals to servo motors on the intelligent desk lamp to control the pan/tilt angle of the desk lamp.

We also developed an intelligent chair system to control the power of the intelligent desk lamp for energy saving [6]. With a pressure sensor in the chair, we used a DE0-Nano to deal with the signal from the circuit of the pressure sensor. When there are some one sit on the chair, the "on" code is transmitted to another DE0-Nano board with relay control by Bluetooth devices. And the power of the intelligent desk lamp is on. As the person left from the chair, the "off" code is transmitted, and the power of the intelligent desk lamp is off. The system of the intelligent chair system is shown in Fig. 15.

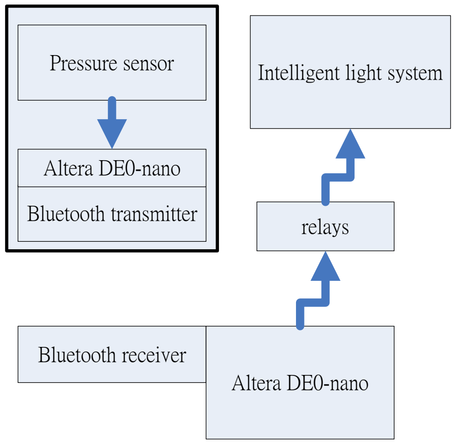


Fig. 15 The system of the intelligent chair system.

The block diagram of intelligent chair system is shown in Fig. 16.

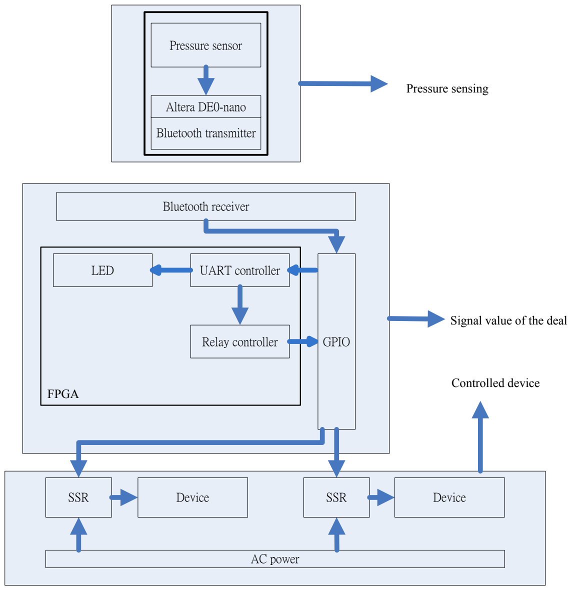


Fig. 16 The block diagram of the intelligent chair system.

The chair with a pressure sensor transmits the dealt pressure data via Bluetooth Device controlled by DE0-Nano. The receiver is controlled by another DE0-Nano to control the SSR relay. When a person is sit on the chair, the relay will be on and the desk lamp will turn on. When a person leaves, the relay will be off and the desk lamp will turn off.

IV. Experiment and Results

Presented results are generated by implemented the proposed intelligent desk lamp system on an Cyclone® IV EP4CE22F17C6N device. Table 5 outlines the summary of the resources used of the project for the proposed intelligent desk lamp system.

TABLE V
DEVICE UTILIZATION SUMMARY

Total Logic Elementals (LEs)	3543 (16%)
Total Registers	1577
Total memory bits	72456 (12%)

The red spot of the object (for example, book) will be captured by the CMOS camera in the visible region as shown in Fig. 17. θ_1 is about 28 degrees. θ_2 is about 20 degrees.

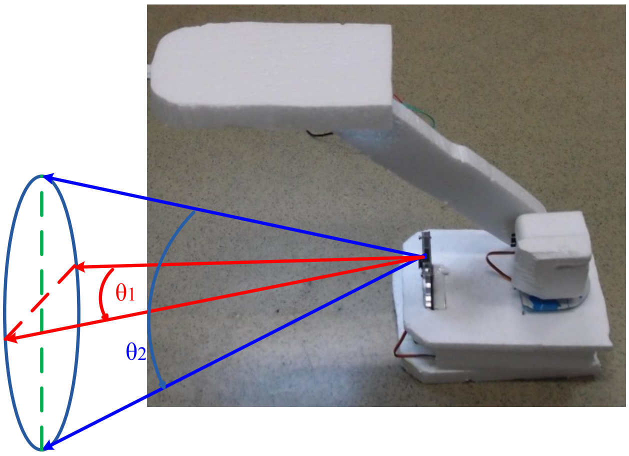


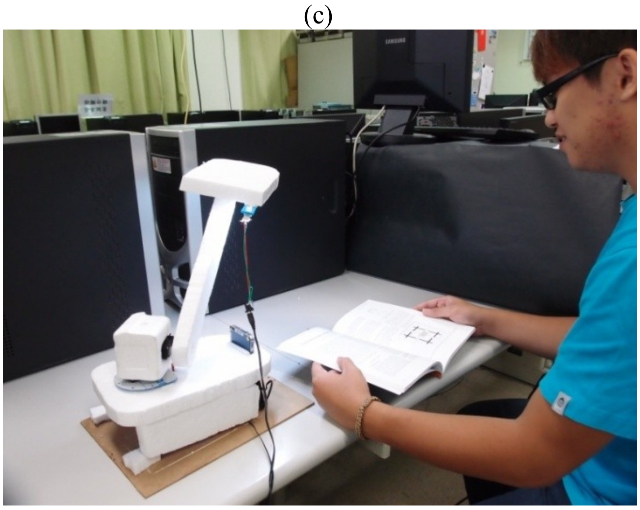
Fig. 17 The visible range of the intelligent desk lamp.

The experiment results of the intelligent desk lamp are shown in Fig.18. Fig.18 (a) shows the book with red spot in front of the intelligent desk lamp, the pan angle is 0 degrees and the tilt angle is 30 degrees. Fig. 18 (b) shows the book with red spot move forward about 10 cm, the tilt angle of the desk lamp is 30 degrees, but the pan angle is changed to 60 degrees. Fig. 18 (c) shows the book with red spot move up about 5 cm, the tilt angle of the desk lamp is changed to 15 degrees and the pan angle is 30 degrees. Fig. 18 (d) shows the book with red spot move down about 5 cm, the pan angle of the desk lamp is 30 degrees, but the tilt angle is changed to 30 degrees.

(a)

(b)

(c)



(d)

Fig. 18 The experiment results of the intelligent desk lamp.

V .CONCLUSIONS

This paper has presented a FPGA based intelligent desk lamp system with a CMOS camera, two servo motors, and LEDs. The processing modules are implemented by Verilog HDL hardware using FPGA Cyclone® IV EP4CE22F17C6N on Altera E0-Nano board. The proposed lamp can trace a moving book by automatic pan/tilt control. To save the power, the intelligent lamp can be controlled by other device, such as the intelligent chair system. When the user sits on the intelligent chair, the intelligent desk lamp turns on for eye caring. On the other hand, when the user leaves the intelligent chair, the intelligent desk lamp turns off for power saving. Thus, the user can read book with enough light for eye care and reasonable energy consumer for cost by this system.

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