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DETECTING LASER SPOT IN SHOOTING SIMULATOR USING AN EMBEDDED CAMERA

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Abstract- This paper presents the application of an embedded camera system for detecting laser spot in the shooting simulator. The proposed shooting simulator uses a specific target box, where the circular pattern target is mounted. The embedded camera is installed inside the box to capture the circular pattern target and laser spot image. To localize the circular pattern automatically, two colored solid circles are painted on the target. This technique allows the simple and fast color tracking to track the colored objects for localizing the circular pattern. The CMUCam4 is employed as the embedded camera. It is able to localize the target and detect the laser spot in real-time at 30 fps. From the experimental results, the errors in calculating shooting score and detecting laser spot are 3.82% and 0.68% respectively. Further the proposed system provides the more accurate scoring system in real number compared to the conventional integer number.

Index terms: Shooting simulator, laser spot, embedded camera, color tracking, CMUCam4.

I. INTRODUCTION

Recently, a shooting simulator is commonly used for shooting practices. Compared to the traditional shooting range, the shooting simulator reduces the costs for providing complex infrastructures and system installation. Further by emplyoing the computer technology, the shooting simulator improves the performance of shooting skill effectively [1]. They proposed a simulated shooting training as the optional solution of the high cost real shooting range. Using the simulated one, the analysis of the shooting activity could be handled efficiently. Usually the shooting simulator consists of six components [2], i.e.: 1) Gun/articial gun; 2) Laser pointer; 3) Shooting target; 4) Camera; 5) Image card; and 6) Computer. In the system, the shooter aims a gun equipped with the laser pointer to the target. Then the laser spot on the target is captured by the camera and further processed by a computer for calculating the score.

The most important problem in the development of shooting simulator is detecting laser spot on the shooting target. Many researchers have proposed various image processing techniques to solve the problems [2, 3, 4, 5, 6]. In [2], a red laser spot was detected by red color segmentation based on RGB color space. Two thresholds were employed, the first threshold for indicating the degree of reddish and the second threshold for indicating the degree of brightness. In [3], they utilized the Wii remote camera for detecting the green laser spot. The infrared filter of Wii remote was replaced by the green color filter. In [4], they proposed a technique to detect the laser spot by combining several features such as the brightness, size, aspect ratio, and gradual change of intensity from the center of laser spot. A simple red color thresholding was in employed in [5]. The thresholding technique was applied in the red component of RGB color only. In addition, the size of laser spot should be greater than a certain threshold. In the work, the camera system is installed inside a non-transparent box. Thus the lighting environment could be controlled. Therefore the approach worked efficiently. In [6], the simple red color thresholding was combined with the color thresholding based on RGB chromaticity diagram to detect the red laser spot. The combination techniques provided an effective way for detecting the red laser spot under the different backgrounds.

Beside the shooting simulator, the image processing techniques have been employed to enhance the scoring system in the traditional shooting range [7, 8]. In [7], a computer vision technique was used to localize the target area, bullet hole segmentation, and scoring mechanism in the mobile shooting range. The back lighting illumination technique was employed to increase the accuracy of shooting calculation [8]. By introducing the back lighting, the bullet hole will be the lightest part in the target. Thus the bullet hole is located easily.

The above mentioned works used the camera systems which are connected to a computer using teh USB cable. In certain condition, those camera system arrangements become impractical. In the image vision fields, the alternative ways are by employing the FPGA [9] or embedded systems [10,11]. In [9], the image processing algorithms such as edge detection, color space conversion, and Hough transform were implemented in the FPGA hardware. The system provided a low cost and real time recognition system. In [10], a low cost automatic color sensor system based on an embedded 3-bit pseudo flash ADC was developed. It provided a simple color sensor system which could be implemented for sorting objects in the assembly lines. An embedded camera system based on 32-bit microcontroller was developed in [11]. It consists of a color camera, a frame buffer, and a 32-bit ARM7TDMI microcontroller. The embbeded vision system was equipped with motor servo ports. Thus it was suitable for robotics applications.

This paper describes the development of an embedded camera for detecting laser spot in the shooting simulator. To overcome the problem of varying lighting on the target, the embedded camera is installed inside a box of the shooting target. A simple color thresholding technique is adopted to detect the laser spot and the guided colored objects printed on the target for locating the circular pattern of the target. The proposed system provides the simple and portable shooting simulator, while provides the high accuracy of the shooting score calculation.

The organization of the paper is as follows. Section 2 presents the related works consist of the shooting simulator and laser spot detection techniques. Section 3 describes the configuration of proposed system. The laser spot and circular target detection techniques are described in Section 4. Section 5 discusses the experimental results. Finally, the conclusions are covered in Section 6.

II. RELATED WORKS

a. Shooting Simulator

A typical shooting simulator uses a camera system to capture the laser spot aimed by the shooter. The camera system is usually divided into two types : a) fixed camera systems [2, 3, 5] and b) moving camera or camera on the gun systems [4, 6]. In [2, 3], a camera is placed in front of the target and connected to the computer system. The camera captures the image of laser spot on the target, then a computer sytem detects the location of laser spot using the image processing techniques. The score is calculated based on the detected position of the laser spot on the target. A circular pattern target was used in [2], while a three-dimensional computer graphic was used as the target [3].

Since the target and camera system are installed separately, the proper camera installation and callibration are required in [2,3]. To overcome the drawbacks, a specific target box with camera inside was proposed in our previous work [5]. In the system, a wireless camera is placed behind the target inside a box. By this arrangement, a complex camera calibration does not required. Further since the camera is placed inside a box, the lighting environment could be controlled. Thus it reduces the problem of varying illumnination.

In the moving camera system, the camera is mounted on the gun. The system provides an easy installation of the target, however it needs a specific camera arrangement to be mounted on the gun. The complex image processing tasks are required for detecting both the target dan laser spot.

b. Laser Spot Detection Techniques

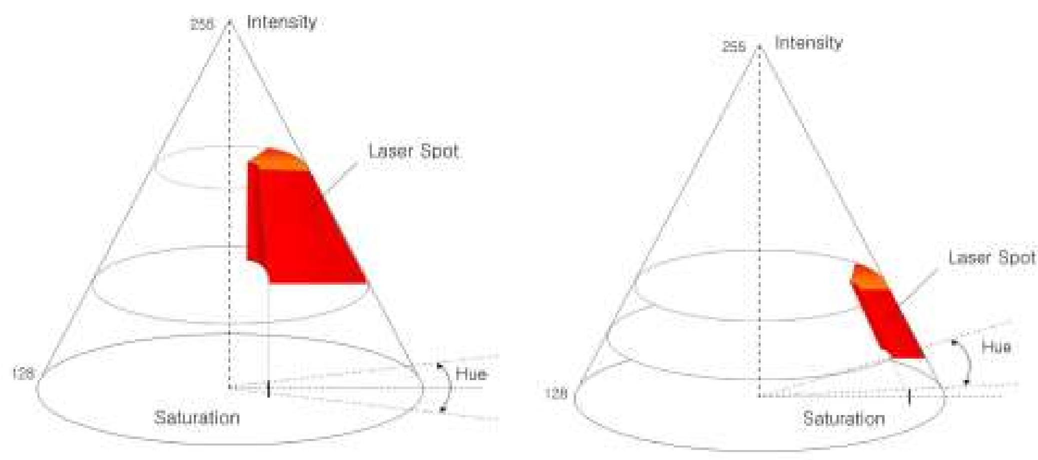
Recently many researchers develop the interaction devices using a laser pointer which is commonly used as the standard pointing tool in the presentation. The red laser pointer with the wavelength of 650nm is the one which is commonly used. To detect the presence of the laser spot, several image processing techniques have been proposed, from the simple ones to the complex ones [12, 13, 14]. In [12], the laser spot is detected by searching the brightest position on the area of interest that satisfy the following equation

$$\left| I_{(u,v)} - \frac{1}{N}\sum I_{(x,y)} \right| > threshold \qquad (1)$$

where the first and second terms represent the brightness values (in HSI color space) of the detected position and the average brightness of the pixels within area of interest respectively. In [13], three components of HSI color space are calculated in the detection phase. The pixels (*x,y*) are defined as the laser spot if they satisfy the following equation

$$f(x,y) \in \{(H,S,I) \mid \theta_1 < H < \theta_2, \alpha < S, \beta < I\} \qquad (2)$$

where $\theta_{\cdot}, \theta_{-}, \alpha, \beta$ are thresholds as shown in figure 1. Figure 1(a) shows the range of laser spot in HSI color space when no laser filter is used. When the red laser filter (630nm – 650nm) is used, the range of laser spot is shown in figure 1(b).



(a) (b)

Figure 1. The range of laser spot in HSI color space with (a) no bandpass filter (b) bandpass filter [13].

Figure 2 shows the laser spot detection algorithm proposed by [14]. This technique converts the RGB image into grayscale image, then finds the maximum pixel value on the image as the lower threshold. The best lower threshold is obtained as 1.1 x maximum pixel value, while the upper threshold is set to 255. If the pixel value falls between the lower and upper thresholds, then it is assigned as the laser spot. The RGB color segmentation is adopted to extract the laser spot [2]. The color segmentation is expressed as

$$S(R,G,B)=\begin{cases}1\ if\,(R-G>T_1)\,AND((R-G>T_1)\,OR\,(R>T_2)) \\ 0 \qquad else\end{cases} \tag{3}$$

where T_1 represents the degreee of reddish, and T_2 represents the degree of brightness. The threshold T_2 is added to handle the situation when the laser spot is very bright.

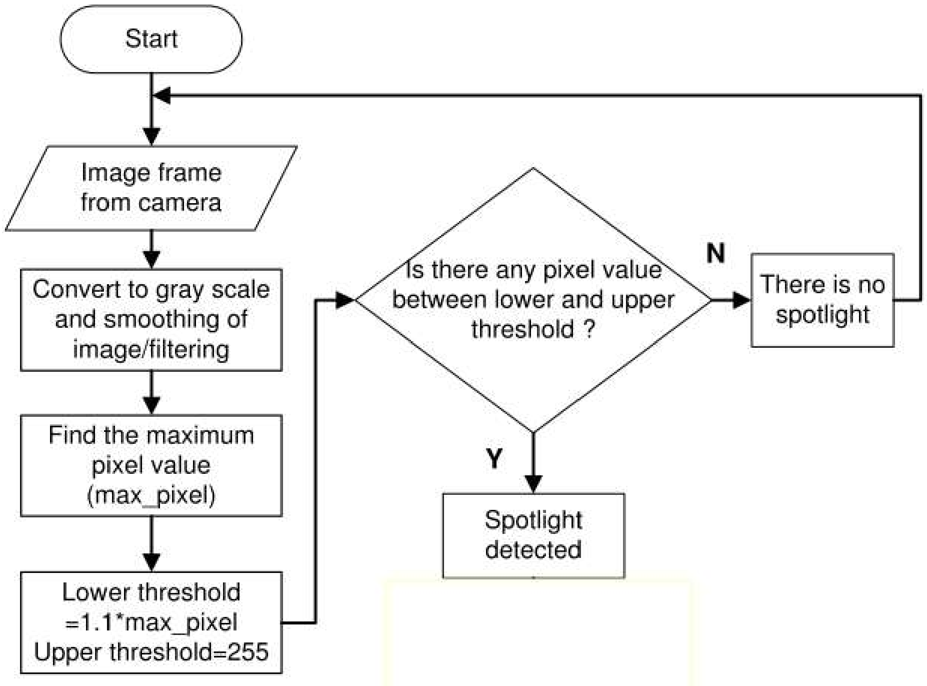


Figure 2. The laser spot detection algorithm proposed by [14].

In our previous work [5], the camera is placed in the controlled lighting environment. Thus the simple thresholding technique expressed below is adopted.

IF $R > TR_1$ THEN assign pixels as the laser spot (4)

where TR_1 is the threshold. The simple thresholding expressed in Eq. (4) also extracts all the brighter objects in the image. Therofore the new color thresholding is proposed in [6], which is expressed as

IF ($R > TR_1$) AND ($g - r < TR_2$) THEN assign pixels as the laser spot (5)

where TR_2 is the threshold, g and r are the chromaticity coordinates in the normalized RGB chromaticity diagram which are expressed as

$$g = \frac{G}{R+G+B} \tag{6}$$

$$r = \frac{R}{R+G+B} \tag{7}$$

The second term in Eq. (5) represents the reddish objects in the normalized RGB chromacity diagram which are easier to be extracted compared to the ones in the RGB color space [15].

III. SYSTEM CONFIGURATION

The proposed shooting simulator uses a specific target box as developed in our previous work [5], where a wireless camera is placed inside the box to capture the image. The drawbacks of the system are: a) a computer should be run continuously to receive the image sent by the wireless camera; b) the quality of image degrades when the radio interference exists. In this work, an embedded camera is employed to overcome the problems. The system configuration of proposed shooting simulator is shown in figure 3.

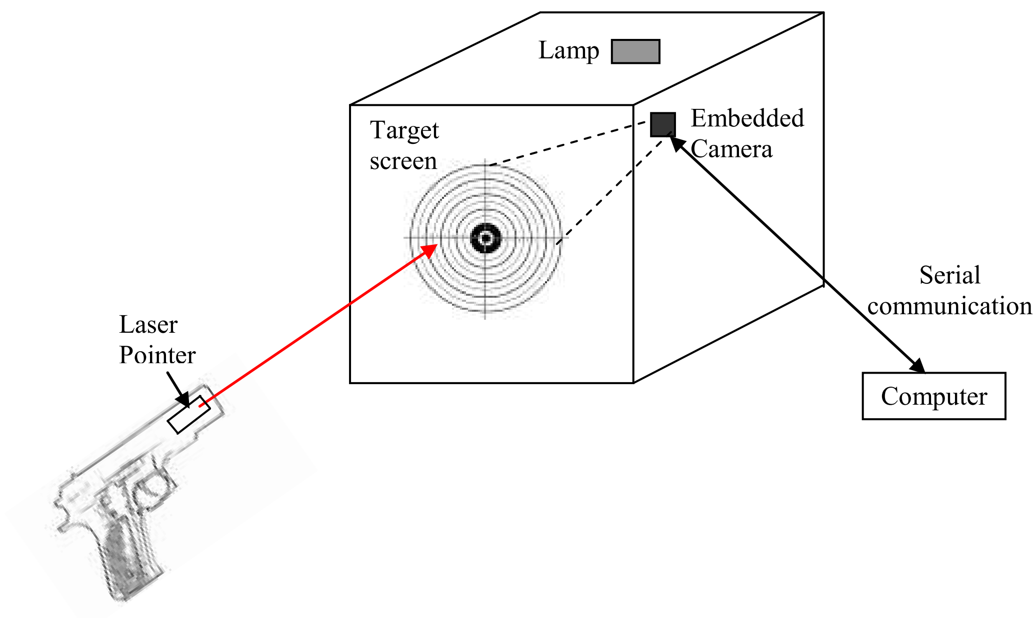


Figure 3. The system configuration of shooting simulator.

The shooting simulator consists of five main components: 1) Laser pointer mounted on the gun; 2) Target screen; 3) Embedded camera; 4) Lamp; 5) Computer. Target screen, embedded camera and lamp are located on a non transparent box made from acrylic plastic. The dimension of target box is 30cm x 30cm x 25cm. Target screen is made from a piece of paper and attached on a hole in fornt of the box. The diameter of circular pattern drawn on the target is 10cm and printed on both side of the paper. The circular pattern is discussed in more detail on the next section. Since the box is closed on all sides, a lamp (fluorescent lamp) is placed inside the box as lighting source.

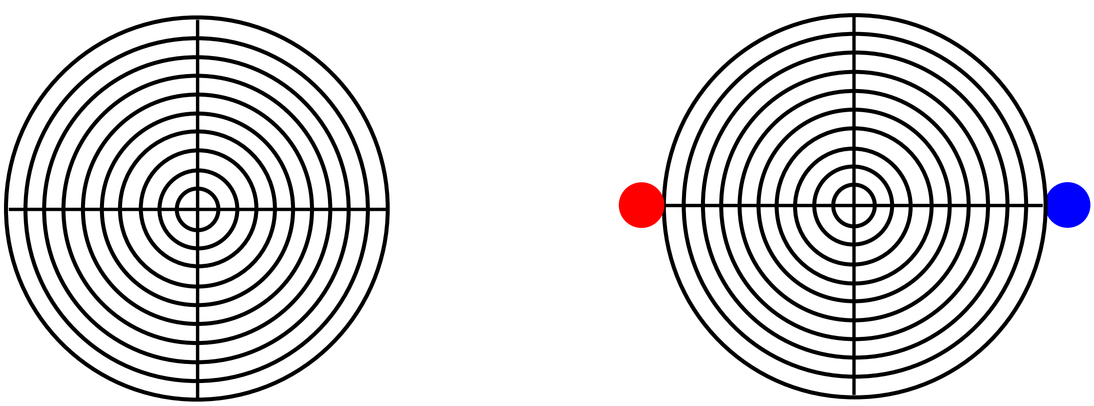
In this system, a CMUCam4 [16] is employed as the embedded camera. The CMUCam4 uses a OmniVision 9665 CMOS camera module and a Parallax P8X32A (Propeller Chip) microprocessor. The module provides a serial port to communicate with other microcontroller or computer. A computer is used to control and monitor the CMUCam4 module for further processing.

IV. DETECTION ALGORITHM

a. Detection of Circular Pattern Target

a.i Design of Circular Pattern Target

The circular pattern target is shown in figure 4, where figure 4(a) is the outside pattern, while figure 4(b) is the inside pattern. As shown in the figure, the inside pattern is exactly the same as the outside one with additional two small circles on the left and right part. The reason of introducing two circles is described in the following.



(a) (b)

Figure 4. Circular pattern target : (a) outside pattern; (b) inside pattern.

The target is composed of ten concentric circles with the same distance between each circle. The location of each circle should be known for calculating the shooting score. Eventhough the position of target and camera is fixed, however it might change during installation. Therefore the circular pattern should be detected automatically by the camera system. The common method for detecting the circle using image processing technique is by applying an edge detection followed by the circle detection. Unfortunately, since the low resolution camera is used in the embedded camera system, the edge detection will not work well due to the blurred image. Further the circle detection technique requires a high computation cost, which is hard to be handled by the embedded system. To overcome the above problem, the circular target is located using the center coordinate and the diameter of outermost circle. Then the position of each circle could be calculated easily, due the fact that the distance of each circle is the same.

Instead of using the edge detection technique, a simple color tracking is employed to locate the circular pattern. Thanks to CMUCam4 that is able to track the color objects in realtime at 30 fps. The main information obtained from the color tracking is the center of tracked object called as the centroid, which is used to determine the location of circular target. To perform the color tracking, a solid colored object should be painted on the target. An easy way is by drawing a solid color on the innermost circle (center part). However from a few experiments, by coloring the center of the target, the laser spot could not go through this colored circle. Thus it could not be captured by the camera. The other method is to draw a colored ring outside of the outermost circle. Using this method, the color of large colored ring should be uniformly. Unfortunately, this condition could not be satisified using the existing embedded camera.

The proposed method is by drawing two small solid circles on the left and right of the target as shown in figure 4(b). The reasons of using this method are listed belows:

- The small solid circle is selected to provide the color uniformity of the tracked object. It is used to ensure the stability of color tracking.
- Two solid circles are located on the left and right to provide the information for calculating the center coordinate and the diameter of outermost circular target. After the center coordinates of the left anf right circles are obtained, then the center coordinate and the diameter of outermost circular target could be calculated easily.
- From the second reason, it requires that two solid circles should be tracked separetely. Thus they should be painted in the different colors.
- The red and blue colors are used to make the color tracking easier, in the sense that it considers only one component of RGB color space (the red component for red circle and the blue component for blue circle). The solid red and blue circles are drawn using the picture editing software, where the values of RGB color are R=255, G=0, B=0 for the red solid circle and R=0, G=0, B=255 for the blue solid circle.

a.ii Color Tracking

A simple color tracking [16] is employed to track the solid circles on the circular target. The algorithm processes frame by frame of the video image. Each image frame is tracked independently. In each frame, the algorithm examines the pixel that satisfies the desired tracked color. The range of tracked color is defined by the lower and upper values of red, green and blue components of the RGB color space. Once the pixel satisfies the user-defined range, it is marked as the tracked pixel. The process is repeated sequentially from the top left of the image to the bottom right of the image. During the process, the sum of vertical and horizontal coordinates of tracked pixels are calculated. The total number of tracked pixels is also counted. At the end of the process, the centroid of the tracked object is calculated using the following equations:

$$cx = \frac{\sum_{i=1}^{n} tx_i}{n} \quad (8)$$

$$cy = \frac{\sum_{i=1}^{n} ty_i}{n} \quad (9)$$

where cx and cy are the x-coordinate and y-coordinate of the centroid respectively, tx_i and ty_i are the x-coordinate and y-coordinate of tracked pixel-i respectively, n is the total number of tracked pixels.

a.iii Localization of Circular Pattern Target

As mentioned previously, the circular pattern target is located by the center coordinate (CMx,CMy) and the diameter of outermost circle (D_out) as shown in figure 5. The algorithm starts with tracking the red color to find the centroid of red solid circle. The x-coordinate and y-coordinate are found as CRx and CRy respectively. Then it tracks the blue color to find the centroid of blue solid circle. The x-coordinate and y-coordinate are found as CBx and CBy respectively. Finally the location of circular target which is determined by three parameters (CMx,CMy, D_out) is found using the following equations:

$$CMx = \frac{CRx + CBx}{2} \quad (10)$$

$$CMy = \frac{CRy + CBy}{2} \quad (11)$$

$$D\_out = \frac{10 \times (CBx - CRx)}{22} \quad (12)$$

It is noted here that the diameter of red and blue solid circles is the same as the diameter of innermost circle of the target. Thus the diameter of outermost circle of the target (*D_out*) could be expressed by Eq. (12).

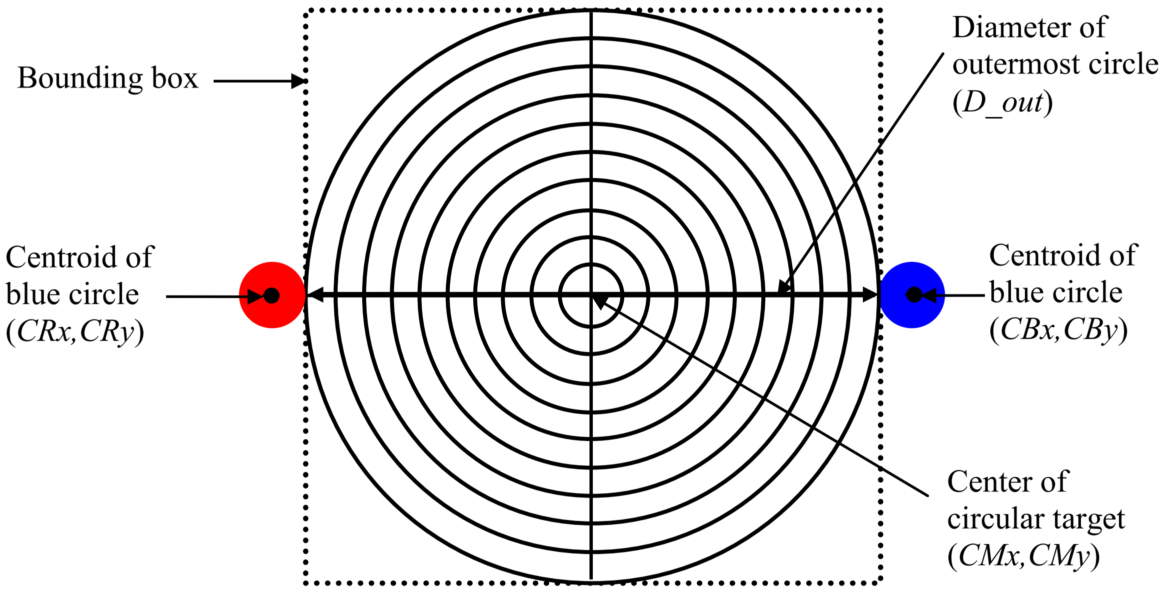


Figure 5. Localization of circular pattern target.

b. Detection of Laser Spot

To detect the laser spot, a simple color tracking similar to [5] is adopted. It works by tracking the pixels that satisfy the condition expressed by Eq. (4). The algorithm detects the red laser spot effectively when the lighting environment is controllable [5]. Due to its simplicity, the algorithm could be implemented easily on the CMUCam4 embedded camera system. This tracking method is the same as the one for detecting the red and blue solid circles, except the range of tracked color. According to Eq. (4), only the range of red component should be defined to track the laser spot.

c. Calculation of Shooting Score

In the conventional shooting range, score is computed based on the position of the laser spot on the circular target, namely the score is 10 when the laser spot falls inside the innermost circle and the score is 1 when the laser spot falls between the outermost circle and the 9^{th} circle. The score is an integer number, thus the score for laser shooting on the center of innermost circle is the same as the one near the outer of innermost circle. In our proposed system, since the coordinate of laser spot could be calculated accurately, the score could be the real number. It increases the accuracy of shooting score.

Let us *CLx* and *CLy* are the *x*-coordinate and *y*-coordinate of the centroid of laser spot, then the shooting score (*S_score*) is calculated using the following equation:

$$S\_score = 10 - \left(\frac{10 \times \sqrt{(CMx - CLx)^2 + (CMy - CLy)^2}}{D\_out} \right) \tag{13}$$

where *CMx, CMy, D_out* are obtained using Eqs. (10) – (12).

V. EXPERIMENTAL RESULTS

a. Experimental Setup

The main objective of the experiment is to test the performance of embedded camera system in detecting laser spot and calculating the score. Since CMUCam4 is employed as the embedded camera system, its features and specifications are described in the following. The CMUCam4 uses an OmniVision 9665 CMOS camera as the camera sensor. The camera resolution is 640x480 pixels, RGB565 color image. RGB565 means that a pixel is represented by 5-bit red component, 6-bit green component and 5-bit blue component. The CMUCam4 is able to track the color image with the resolution of 160x120 pixels at 30 fps.

In the experiment, the camera module is connected to a computer via a serial communication, where the baudrate is 115200 bps. The application software is developed on the computer to receive and display the target image. This image is only sent once at the beginning and used for callibrating the system. However the laser spot tracking, i.e. the position of laser spot is updated continuously at 30 fps. The tracked laser spot is displayed on the target image captured previously.

The parameters for the tracking process are listed on Table 1. Two different experiments are carried out to test the performance of shooting simulator. The first experiment is by changing the camera position inside the box and examining the detected circular pattern target. This experiment is used to verify the algorithm for localizing the circular target. Since only the red and blue circles tracking are required, there is no laser shooting in the first experiment. In the second experiment, the camera is in a fixed position, while the distance of the shooter/laser pointer and the target is changed. The objective of the second experiment is to verify the algorithm in calculating the shooting score. For both experiments, the detected target and calculated score are compared to the manual inspection.

The manual inspection is carried out as follows. The target image is captured by the CMUCam4 and sent to the computer which stores the image into a bitmap file. Then the center coordinate, the diameter of outermost circle of circular target and the center coordinate of laser spot are found manually by utilizing the picture editor software (MS Paint).

Table 1: Color tracking parameters

Object Tracking	RED		GREEN		BLUE	
	Min.	Max.	Min.	Max.	Min.	Max
Red solid circle tracking	100	255	0	80	0	80
Blue solid circle tracking	0	50	0	68	100	255
Laser spot tracking	250	255	0	255	0	255

b. Experimental Results

In the first experiment, five different camera positions are tested by moving the camera slightly to the left, right, front and behind. The experimental results are listed on Table 2. In the experiment, the coordinates are represented with respective to the image resolution of 640x480 pixels. Since the tracking process of CMUCam4 uses the resolution of 160x120 pixels, a scaling operation is performed to fit the results into the image of 640x480 pixels.

Table 2: Results of the different camera positions

Camera position	Proposed system			Manual inspection			Error (%)		
	CMx	*CMy*	*D_out*	*CMx*	*CMy*	*D_out*	*CMx*	*CMy*	*D_out*
Position-1	328	264	356	331	264	353	0.91	0.00	0.85
Position-2	340	260	382	341	262	381	0.29	0.76	0.26
Position-3	288	264	342	292	262	337	1.37	0.76	1.48
Position-4	304	260	370	308	260	369	1.30	0.00	0.27
Position-5	348	260	392	355	258	396	1.97	0.78	1.01
						Average	1.17	0.46	0.77

From the table, it is shown that there are small errors (about 1%) on the calculation of *CMx, CMy* and *D_out*. From the observation, it is obtained that the errors are caused by fluctuation of the tracking result. The centroid coordinate of tracked color usually fluctuates around 1 to 2 pixels. The fluctuation is caused by the quality of CMOS camera and the low image resolution (160x120 pixels) used in the tracking.

Figure 6 shows some detected target images under the different camera positions. The detected center and bounding box of the circular target are shown in the figure. The images are 640x480 color images captured by the CMUCam4. The black color in the background is the color of the target box, while the white background is the paper where the circular target is printed on. As shown in the figure, due to some errors discussed previously, the bounding boxes do not exactly enclose the outermost circle of target and the centers of circular target do not match perfectly.

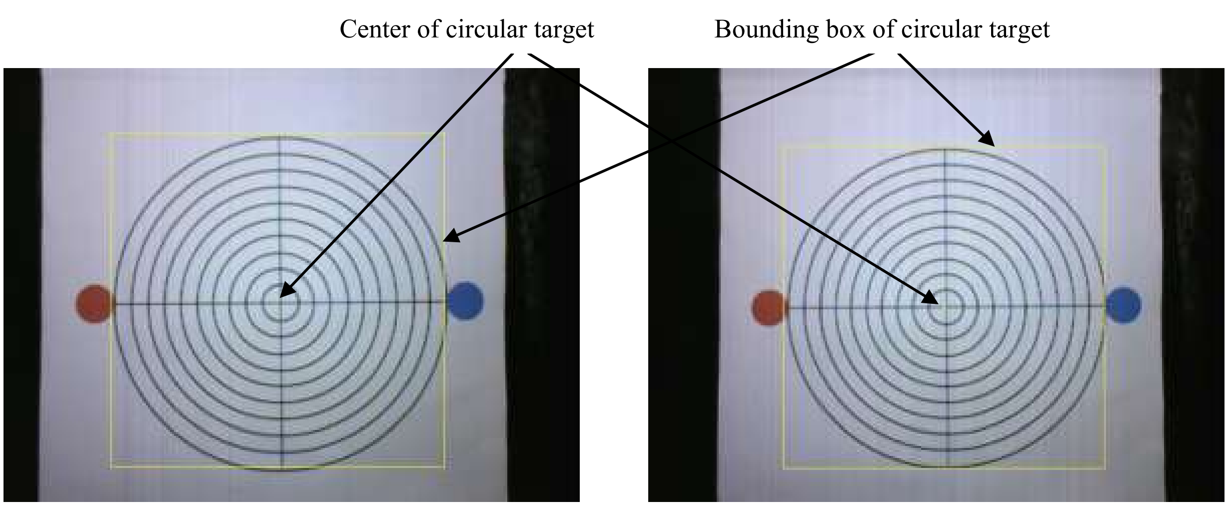


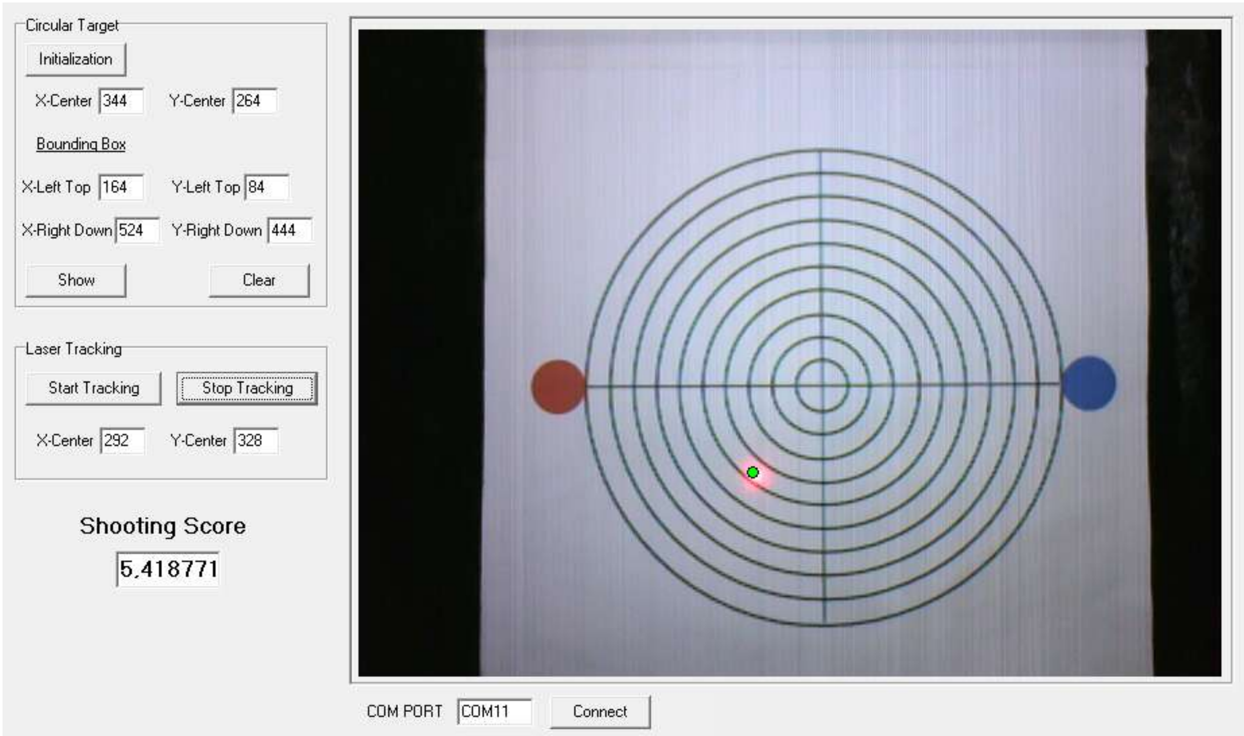
Figure 6. Detected target images under the different camera positions

In the second experiment, the shooting distances vary from 0.5 meter to 4.0 meter. The experimental results are listed on Table 3. In addition to the shooting score (*S_score*), the centroid of laser spot (*CLx, CLy*) is also measured. Compared to the manual inspection, the proposed system calculates score with the average error of 3.82%. While the average error of the laser spot detection is only 0.68%. Thus refer to Eq. (13), the error in localizing circular target contributes more error in the score calculation compared to the error in laser spot detection. It is caused by two reasons, i.e.: a) the diameter of laser spot is smaller than the red or blue solid circles, thus the color tracking is more stable due the smaller area of the object should be tracked; b) the color of laser spot is bright enough, thus it makes the tracking is more stable.

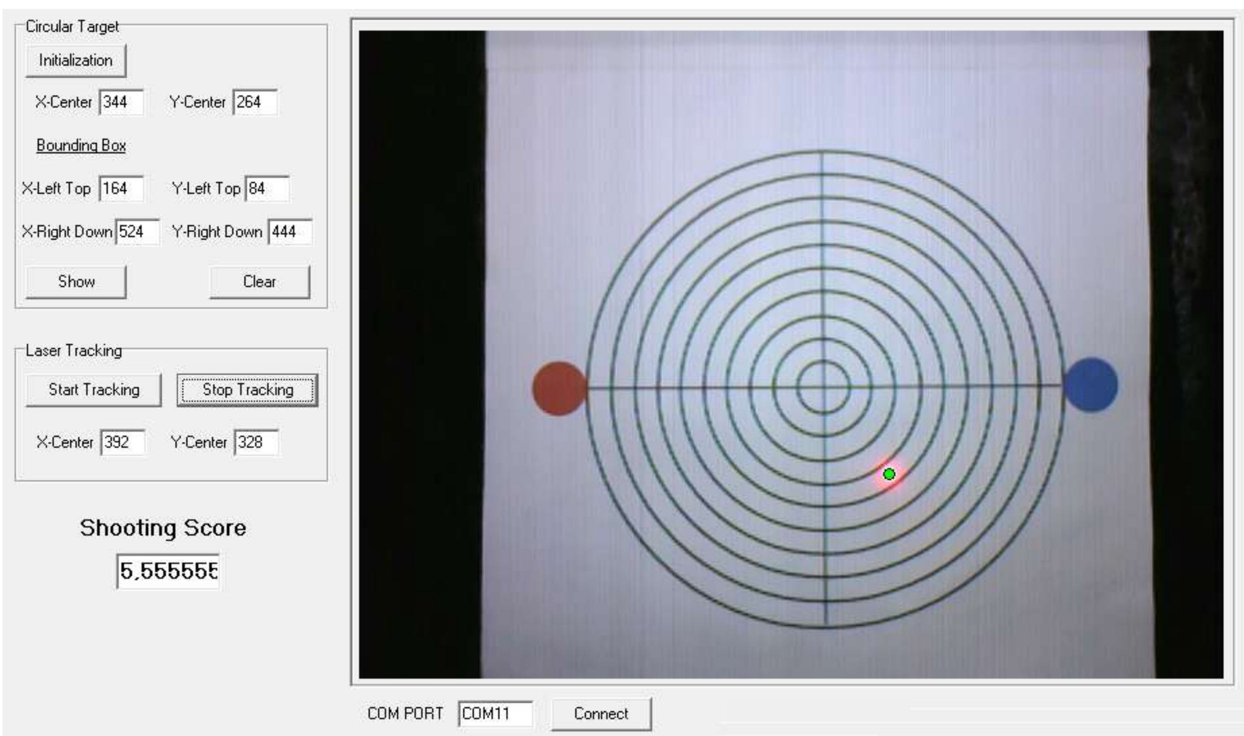
From Table 3, it is shown that the distance between shooter and target does not affect to the score calculation error. It means that the proposed system is able to detect laser spot effectively under varying shooting distance. In the experiment, the laser pointer is aimed to the target arbitrary when the shooting distance is changed. Therefore the score is always changed for every shooting distance. From the table, it is also shown that the score calculation error does not depend on the position of laser spot, whether near to the center or far from the center.

Table 3: Results of the different shooting distances

Distance between shooter and target	Proposed system			Manual inspection			Error (%)		
	S_score	*CLx*	*CLy*	*S_score*	*CLx*	*CLy*	*S_score*	*CLx*	*CLy*
0.5 meter	5.55	392	328	5.47	392	328	1.51	0.00	0.00
1.0 meter	7.73	384	272	7.40	389	273	4.46	1.29	0.37
1.5 meter	3.46	440	332	3.20	443	332	8.29	0.68	0.00
2.0 meter	2.94	460	212	2.71	463	215	8.54	0.65	1.40
2.5 meter	9.56	344	256	9.75	346	260	1.91	0.58	1.54
3.0 meter	8.67	320	264	8.87	324	264	2.22	1.23	0.00
3.5 meter	2.79	272	156	2.77	273	158	0.66	0.37	1.27
4.0 meter	5.42	292	328	5.26	294	331	2.97	0.68	0.91
						Average	3.82	0.68	0.68



(a)



(b)

Figure 7. User interface of developed shooting simulator: (a) Shooting score of 5.42; (b) Shooting score of 5.55.

Figure 7(a) and 7(b) show the user interface of developed shooting simulator. The coordinates of detected circular target and laser spot are indicated on the left side. The calculated shooting score is indicated on the bottom left side. The captured target image is displayed on the main screen. The red laser spot is displayed on the circular target. The green solid circle represents the detected laser spot. In both figures, the laser spots fall between 4^{th}-circle and 5^{th}-circle (circle is counted from the innermost one). In the conventional shooting range, the shooting scores of both figures are the same, i.e. score of 6 (score of 1 for the outermost circle and score of 10 for the innermost circle). Since the real number is adopted in the proposed system, the calculated score is 5.42 for Figure 7(a) and 5.55 for Figure 7(b). Compared to the conventional system, our proposed system provides more accurate scoring. Observing the positions of laser spots in both figures, the score of 5.42 and 5.55 represent the better scoring system than the score of 6 in the conventional scoring system.

VI. CONCLUSIONS

This paper proposes a shooting simulator using an embeded CMUCam4 for detecting circular target and laser spot. The simple color thresholding is adopted to track the colored object on the target and the laser spot. Instead of the integer number for scoring which is used in the conventional shooting range, the proposed system provide more accurate scoring using the real number. The user interface application is developed on a personal computer to easy interaction with the embedded system. In future, the application on the computer will be extended for analyzing the performance of shooting practices.

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