Developing of Low Cost Vision-Based Shooting Range Simulator

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Summary
In this paper, we propose a vision system to detect laser spot from the laser pointer used in the shooting range simulator. The developed shooting simulator utilizes a low cost wireless camera to capture the laser spot on the target. Different from the existing laser pointer-camera systems, our system places the camera inside a target box where the circular pattern target attached in front of it. The algorithm locates the position of circular pattern automatically by employing the image processing techniques. The simple thresholding method is adopted to detect the laser spot. From the experiments conducted, our system could detect the position of the laser spot accurately.

Key words:
Shooting range simulator, laser pointer, image processing, wireless camera.

1. Introduction

Shooting range is an important tool for shooting practice, especially in military. In the conventional shooting range, shooter shoots the firearm into a target made from plastic or paper. This equipment requires high cost for installation and maintenance. Safety rules should be considered carefully to avoid accident and injury caused by the weapon. Further, the toxic waste from the weapon needs the special treatment and disposal [1].

Recently, the shooting range simulators are developed to overcome the drawbacks mentioned before. The simulator ranges from the simple projector camera systems to the complex ones. There are mainly three kinds of sensors used in the simulator [2]: a) Video camera (digital CCD matrix); b) Laser beam deviation matrix; c) Sound sensor. The CCD sensors are the most popular one, where the shooter shoots the gun equipped with the laser and CCD sensor is used to capture or detect the shooting point. The simple shooting simulator uses low resolution CCD matrix (480 x 620 pixels) with the high accuracy can be achieved till some centimeter to 100 meter distance.

A typical shooting range simulator consists of a projector, a screen, one or two cameras, and a computer system [1]. The computer generates a target pattern such as soldier, tanks or circles, and projected onto the screen by a projector. Shooter then shoots the target using a laser pointer. The laser spot on the screen is captured by one or two cameras, and further analyzed by the computer system.

There are many researches related to the laser pointer detection using the camera systems [3]-[7]. They proposed difference techniques for detecting laser spot. In [3], a square-shape 6x6 pixels is used as the reference pattern of the laser point. The reference pattern is moved over the image to detect the laser spot. Matching process is done by calculating the correlation coefficient between the histograms of the pattern and the image. Finally, the subpixel-precise estimation is found by calculating an intensity-weighted average of the coordinates of the pixels covering the best match of the laser point pattern.

In [4], a two level detection technique is employed to detect the laser spot. At first, laser point is detected if the brightest red spot is greater than a threshold. If there is not laser spot detected by the first method, then a convolution filter is used to find the spot. The difficult problem using the technique is when the laser hits the white area of the display, due the fact that laser tends to saturate the camera producing a white spot rathen than a red one.

A simple thresholding technique is used to identify the brightest pixels in the image as the detected laser spot [5]. Then the position of laser spot is defined by calculating the centroid of the cluster of the brightest pixels. The technique allows the low computation cost. They noted that the usage of the very shiny object as a target causes the problems, as they reflect laser in arbitary different directions.

In [6], the existence of laser point in the image is found by comparing the maximum luminance value of the current frame and the initial one. The initial maximum luminance value is the normal RGB average value at the first frame where the laser is detected on the starting program.

In the laser interaction systems decribed above, detecting the laser point is the main challenging task, due to the varying lighting conditions. It is possible to ensure that the laser point is the brightest than surrounding area by adjusting the camera’s parameters [7]. However it could not ensure that the laser spot could be detected by a fixed threshold. The problems of a fixed threshold could be classified into two cases [7]: variation of spatial intensity and variation of temporal intensity. To overcome those problems, they used the threshold image as reference. The threshold image is created before starting the system by generating the spatial and temporal data over the series of images.

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All camera systems in [1]-[7] are installed in front of the screen or target to capture the laser spot emitted by the laser pointer. In our proposed shooting range simulator system, the camera is placed behind the shooting target in a closed box. Therefore the problems of lighting variation could me minimized. Our aim here is to develop a low cost shooting range simulator by utilizing a vision system to detect the laser spot. To minimize the cost and provide the flexibility of the simulator, the cheap wireless camera is used at the target. The image is then transmitted wirelessly to the computer system which handles the image processing task. Our task is to develop a robust algorithm to detect the position of the laser spot on the target under low quality of the image.
The rest of paper is organized as follows. Section 2 presents our proposed shooting range simulator. It describes the configuration of the system and the devoloped algorithm to detect the laser spot. In section 3, the experimental results are described. Section 4 covers the conclusion.

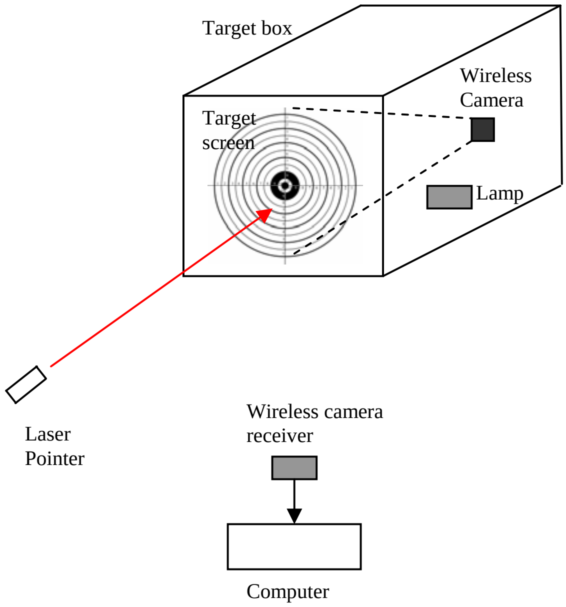

Fig. 1 System configuration.

2. Proposed System

2.1 System Configuration

Figure 1 illustrates the configuration of our system. There are six components: 1) Laser pointer; 2) Target screen; 3) Wireless camera system; 4) Lamp; 5) Target box; 6) Computer. Laser pointer is installed in the gun or weapon for shooting the target. Target screen is made from a thin paper with circular pattern drawn on it, and placed in front of target box. Wireless camera system is used to capture the laser spot on the target screen. It consists of a CMOS camera transmitter and receiver. Lamp is the lighting source inside the target box. Target box is a non transparent closed box, except the front side where there is a hole to attach the target screen. By this arrangement, laser spot on the target screen could be captured by the camera inside the box, while the lighting is controllable. The image is then sent to the computer for further processing.
We employ two steps to detect laser spot: target localization and laser spot detection. Target localization is used to localize the circular pattern on the target screen. In this system, position of the target screen and the camera is fixed. However, in order to provide an easy alignment during installation of the target box, the algorithm should be able to detect the position of circular pattern on the target screen automatically. In the laser spot detection step, the position of the laser spot is searched within image. More specifically, the position of the laser spot in the circular pattern.

2.2 Target Localization

Our proposed shoot range simulator uses a circular pattern as the target as shown in Fig. 2. The target consists of ten concentric circles numbered from 1 to 10, from the outermost ring to the innermost ring. The numbers also represent the shooting score.
In the target localization step, we search the position of the circular pattern in the image automatically. This information is needed for calculating the shooting score of the laser spot with rescpect to the ring numbers. To calculate the shooting score, we should know the coordinates of each circle in the image. Once the laser spot is detected and its coordinate in the image is known, the score could be determined easily.
The circular pattern usually has the same width of the circles. Unfortunately, since the low quality camera is used, those circles are often blurred. Thus it is difficult to detect all circles properly. Moreover, detecting all circles requires a high computation cost. To overcome the problems, we modify the circular pattern by thickening the outermost circle as shown in Fig. 2. Here we assume that the distance from each circle to another is the same, therefore instead of finding all ten circles, we only find the outermost circle, then the coordinates of the inner circles are mapped appropriately.

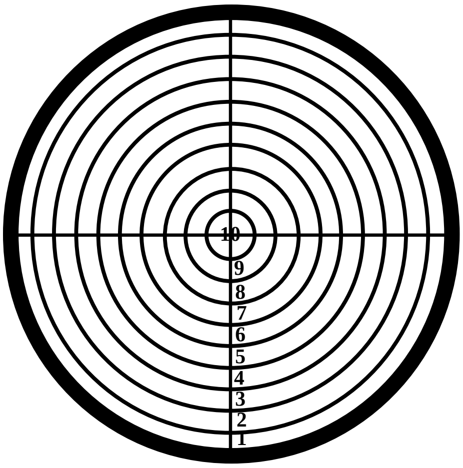

Fig. 2 Target pattern.

Figure 3 shows flowchart for detecting the outermost circle. It first converts the color image to the grayscale image. The resulted grayscale image is then filtered using the median filter. The median filter replaces the intensity of the pixel with the median value of its neighborhood. In the circular target image, the circles are in the black color with the white background (see Fig. 2). If we apply the median filter, then black circle would be replaced by the background color or the black color depending on the area of the neighborhood pixels. If the chosen neighborhood area is large, then the median value of the neighborhood belongs to the background color, thus the black circle is replaced by the color of the background. However, if the black circle is thicker than the previous one, then the median value of the neigborhood might belong to the black circle. Thus it preserves the thick black circle. Since our aim is to detect the outermost circle, then we should draw the outermost circle thicker than the inner circles as shown in Fig. 2. In the research we use 8 x 8 neighborhood pixels for blurring or eliminating the inner circles, while preserving the outermost circle.

After applying the median filter, the edge of the outermost circle is sharper than the edge of the inner circles. Therefore by employing the Sobel edge detector, we could extract the edge of the outermost circle only. Finally the circle detection is used to detect the circle.

To extract the circle from the edge pixels, we employ the ellipse fitting method as used in [8],[9]. An ellispe is the general representation of a circle. The ellipse can be expressed as

$$a_1 x^2 + a_2 xy + a_3 y^2 + a_4 x + a_5 y + f = 0 \quad (1)$$

The least square estimator estimates the coeficients of $A = \left[a_1\, a_2\, a_3\, a_4\, a_5\right]^T$ from the given data points (in this case is the edge pixels) by minimizing the squares sum of an error between the data points and the ellipse

$$e = \sum_{i=1}^{N} \left(a_1 x_i^2 + a_2 x_i y_i + a_3 y_i^2 + a_4 x_i + a_5 y_i + f\right)^2 \quad (2)$$

The values of estimated coefficients A are then converted to the ellipse parameters: orientation, center coordinate, semi-major axis, and semi minor axis.

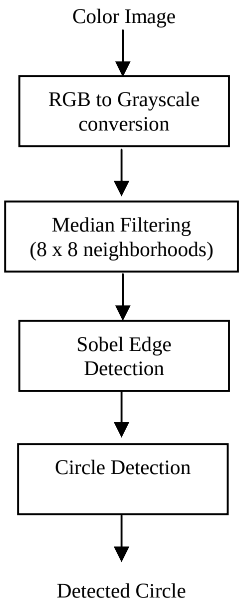

Fig. 3 Flowchart to detect the outermost circle.

2.3 Laser Spot Detection

In our system as illustrated in Fig. 1, the camera is installed inside a non-transparent box. We use the white super bright LEDs as the lighting source. Here, the lighting condition is controllable. Therefore, we might adopt a fixed threshold method for detecting the laser spot. To detect the laser spot, a simple thresholding is employed as follows. Let R_i is the value of red component of a pixel-i. Then the pixel-i is assigned as the laser spot if $R_i > 240$. In addition to this rule, the area of detected spot should be greater than 20.

After the laser spot is detected, the centroid of the detected cluster is computed. Then the shooting score S, i.e. the ring's number where the laser spot hits the target is calculated by

$$S = 11 - ceil\left(\left(10\sqrt{\left(cx_2 - cx_1\right)^2 + \left(cy_2 - cy_1\right)^2}\right) / r\right) \quad (3)$$

where,

cx_1 is the x-coordinate of the center of the circular target;

cy_1 is the *y*-coordinate of the center of the circular target;
cx_2 is the *x*-coordinate of the center of laser spot;
cy_2 is the *y*-coordinate of the center of laser spot;
r is the radius of the outermost circle;
ceil(A) rounds to the nearest integer greater than or equal to *A*.

3. Experimental Results

In the experiment, we implement our algorithm using MATLAB. The camera systems consist of a CMOS wireless camera Anboqi 203: camera resolution is 320 x 240 pixels; lens's diameter is 2mm; the wireless frequency is 1.2 GHz, and a USB DVR to convert video signal of the camera receiver to USB port of the computer. The target screen is made from paper with the circular pattern is printed on the both side. The diameter of the outermost circle of the target pattern is 10 cm.

Figure 4 shows the color image of the target pattern captured by the wireless camera. The resulted image after applying median filter is shown in Fig. 5. From the figure, it is clear the filter preserves the black color of the outermost circle, while the inner circles are smoothed to the white color (background). The edge image and the detected circle are shown in Fig. 6 dan Fig. 7, respectively. It is noted that the ellipse fitting method fits the data points (edge pixels) to the best ellipse. Thus the detected circle in Fig. 7 is the average of two circles shown in Fig.6.

Figure 8 shows the image of the target when laser pointer hits it. The image in Fig. 9 is the image after thresholding process as described before. From Fig. 8 we can see that the laser spot is on ring-9, or the shooting score is 9. This score is the same as obtained by our algorithm. Moreover we carried out several experiments by shooting the laser pointer to the target ten times and observe the shooting scores computed by the software (our algorithm) and by inspecting manually. The results show that our algorithm compute all ten scores accurately, the same as the manual inspection.

Comparing to the existing systems where the projector and camera systems are used, our system has benefits as follows: a) The cost of the simulator is very low; b) Since the camera is placed inside a box, the lighting condition is controlled, thus the system is more robust; c) Installation is very easy, no need tight adjusments. However, the drawback of our system is the target pattern is fixed, and could not be changed easily.

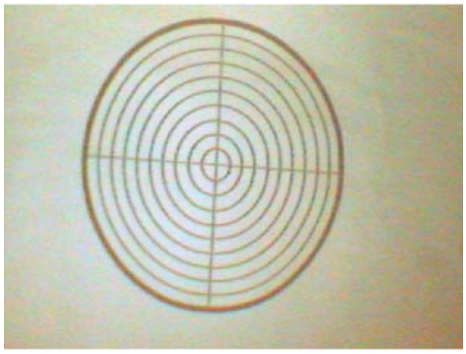

Fig. 4 Color image of the circular target pattern.

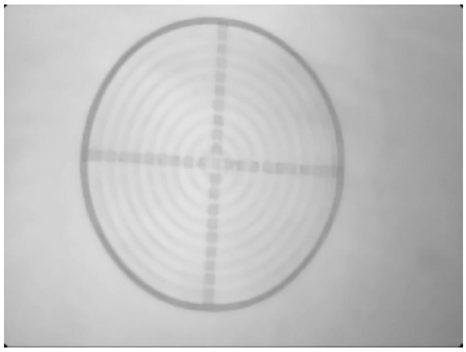

Fig. 5 Image after median filtering.

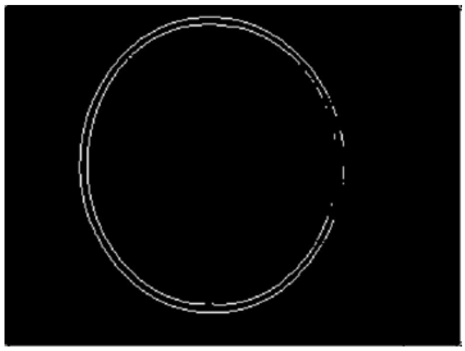

Fig. 6 Edge image.

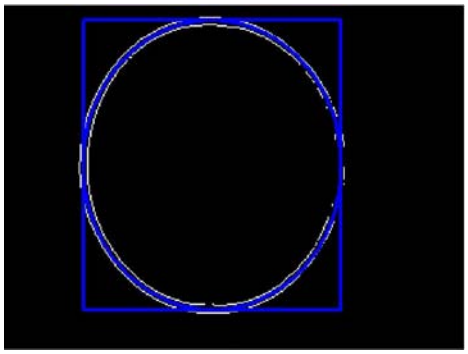

Fig. 7 Detected circle and the bounding box.

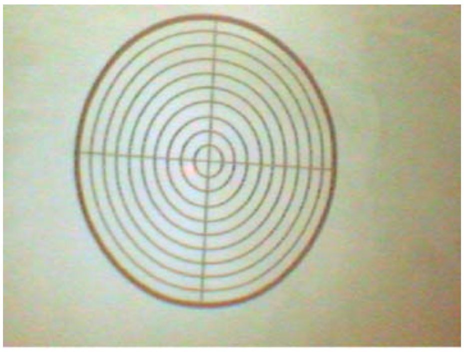

Fig. 8 Image of target pattern with laser spot hits it.

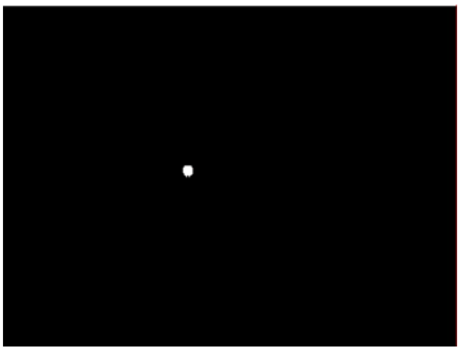

Fig. 9 Laser spot detected by the thresholding technique.

4. Conclusion

A low cost vision-based shooting range simulator was developed. It employed the simple effective image processing techniques for detecting and locating the laser spot on the target with a high accuracy.
In future, we will extend our system using an embedded camera and bluetooth communication system for communicating between the target and the computer system.

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