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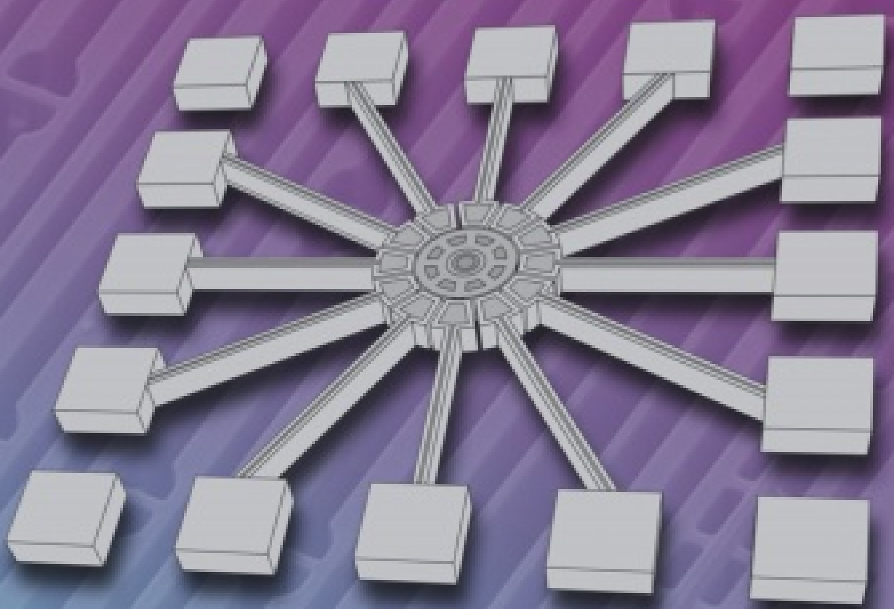

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Sensors & Transducers

Photodiode Array for Detecting Laser Pointer Applied in Shooting Simulator

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Abstract: This paper presents the application of photodiode array for detecting laser pointing in the shooting simulator. The photodiodes are arranged in circular pattern similar to the conventional shooting target. To minimize the cost, the scanning and multiplexing techniques are employed to access the photodiode array. A low-cost 8-bit microcontroller system is used to calculate the shooting position, display it to the seven-segment display, and send the data to a computer. To overcome the problem of varying lighting conditions, an adaptive voltage reference is introduced. Experimental results shows that the proposed system work properly to detect the laser shooting in indoor and outdoor environments with the effective shooting distance of 10 to 20 meter and the lighting intensity below than 5000 Lux. *Copyright © 2013 IFSA.*

Keywords: Photodiode array, Laser pointer, Shooting simulator, Shooting target, Scanning technique, Multiplexing technique.

1. Introduction

Shooting simulator is a common tool used in military training for shooting practices. In the simulator, a laser beam generated by laser pointer is employed to replace the bullet for shooting the target. A projector-camera system was developed in [1] to project the image on the target and detect the laser beam by the camera. They proposed two different approaches: a) single stationary camera; b) multiple moving camera or camera on weapon. The main problems of the system are to handle the geometric projection and the illumination changes. In [2], by adjusting the shutter, gain, exposure, and various setting of the camera, the laser beam is made brighter than the surrounding. There is another problem of the varying color for the different laser pointer sources as reported in [3]. They reported that the laser beam forms a set of rings on the target with the different colors. Therefore they proposed a method to use a specific color that always detect some of those rings for many types of the laser pointers.

In our previous work [4], instead of installing a camera in front of the target, a camera is placed behind the target inside the box. This arrangement minimized the problem of illumination changes, because the light condition could be controlled inside the box. However it requires some adjustments of the camera system, and proper preparation of the target screen.

A low cost solution without the need of complex projector-camera system was proposed in our earlier work [5]. The proposed system employed a photodiode array as the laser sensor. The photodiodes are arranged to form circular pattern on the shooting target. A microcontroller system is used to compute the shooting score and display it on the target box. This paper presents some improvements of the earlier work, mainly in two folds: a) Introducing an adaptive threshold to work with outdoor environment (sun light); b) Reducing the numbers of electronic circuits (comparator circuits) by employing the multiplexer system.

The rest of paper is organized as follows. Section 2 describes the details of proposed system. Section 3 presents the experimental results. Conclusions are covered in section 4.

2. System Configuration

The configuration of shooting simulator is illustrated in Fig. 1. The system consists of three main components, i.e. a shooting target, a laser pointer attached on the gun, and a personal computer. A Bluetooth communication is employed to communicate the shooting target with a personal computer. The shooting target is formed by photodiode array in the circular pattern, similar to the conventional shooting target. There are ten rings, where the outermost ring has the lowest score, while the innermost ring has the highest score. When a shooter aims the laser pointer to the target, a microcontroller system will find which photodiode is aimed, then calculates the score and display it to the scoring score (two digits seven segments display). At the same time, the microcontroller sends the score and precise position of targeted photodiode to the personal computer for further processes.

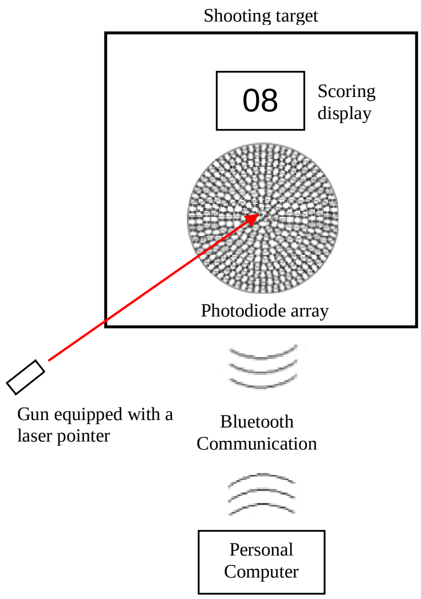

Fig. 1. Configuration of shooting simulator.

2.1. Photodiode Array

The important issue in designing the shooting target is determining the diameter of circular pattern formed by photodiode array. From a few experiments, it is obtained that the diameter of outermost ring is 10 cm as the most effective dimension. Using this arrangement, the diameter of each ring should be 1 cm. Since 3 mm photodiode is used, the distance between the photodiode along the ring's perimeter is made 5 mm. Therefore the number of photodiodes in each ring could be calculated as listed in Table 1. The total numbers of photodiodes are 360 pieces. By considering the PCB layout of the photodiode array and the number of electronic components, only the half of total photodiode is taken into consideration, in the sense that every two adjacent photodiodes are connected in parallel. Using this method, only 183 points (photodiodes) should be processed by the microcontroller system.

Table 1. The number of photodiodes in the shooting target.

Ring No.	Diameter (cm)	Number of photodiodes (calculation)	Number of photodiodes (implementation)
1.	1	6.28	5
2.	2	12.56	11
3.	3	18.84	18
4.	4	25.12	22
5.	5	31.4	30
6.	6	37.68	38
7.	7	43.96	48
8.	8	50.24	56
9.	9	56.52	62
10.	10	62.8	70

Fig. 2 shows the common circuit for detecting light using a photodiode. In the circuit, the photodiode is operated in reversed bias, thus when light falls into the photodiode, the current flows into the photodiode and drops the voltage across it. The values of R_2 and R_3 are used to determine the reference voltage of the comparator.

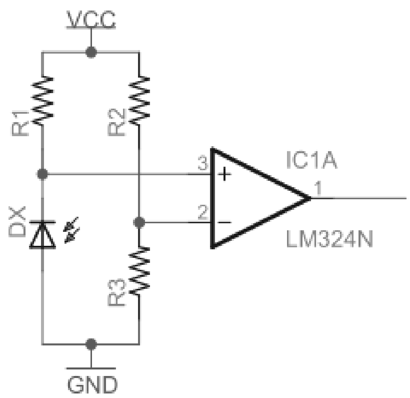

Fig. 2. Photodiode circuit with a comparator.

The brutal approach to detect 183 photodiodes is to use 183 comparators, one comparator for each photodiode. The effective method to reduce the number of comparators is by introducing a scanning technique as proposed in our previous work [5]. It divides the photodiode array into 23 rows and 8 columns as shown in Fig. 3. The rows are connected to the comparator circuits, while the columns are connected to the output ports of the microcontroller. To read the detected laser on the photodiodes, the microcontroller scans the columns and reads the comparator outputs to determine the detected photodiode. This method requires 23 comparator circuits, 23 input ports of microcontroller, and 8 output ports of microcontroller.

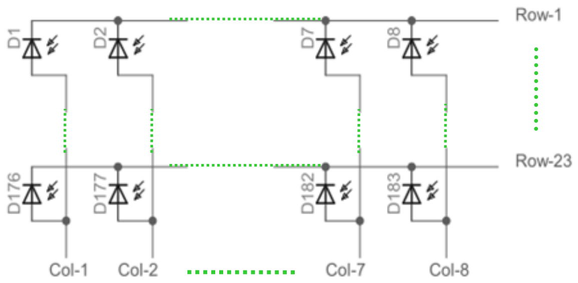

Fig. 3. Photodiode array 23 rows × 8 columns.

This paper improves the previous work by reducing the number of comparator circuits and introducing an adaptive voltage reference of the comparator circuit as discussed in the next section.

2.2. Interfacing Module

A multiplexing technique is employed to reduce the number of comparator circuits as shown in Fig. 4. Using this technique, only one comparator is required to read 23 rows. It is implemented using two 16-channel analog multiplexer ICs (CD4067). To select the channel, six I/O ports of microcontroller are used: two ports for selecting the multiplexer device (multiplexer-1 or multiplexer-2), and four ports for selecting the channel (channel-1 to channel-16).

As shown in Fig. 4, row-1 to row-16 are connected to channel-1 to channel-16 of multiplexer-1, while row-17 to row-23 are connected to channel-1 to channel-7 of multiplexer-2. The control inputs A, B, C, D are used to select each channel of the multiplexer. The control input Inhibit is used to disable or enable the multiplexer.

The comparator circuit shown in Fig. 2 uses a fixed reference voltage determined by the values of R_2 and R_3. The circuit has a drawback as described in the following. When the shooting simulator is used in outdoor place, the sunlight irradiates the photodiode and may cause the current flowing into photodiode, similar to the laser beam behave. In the case, the comparator is always ON even though there is no laser beam is aimed to the photodiode.

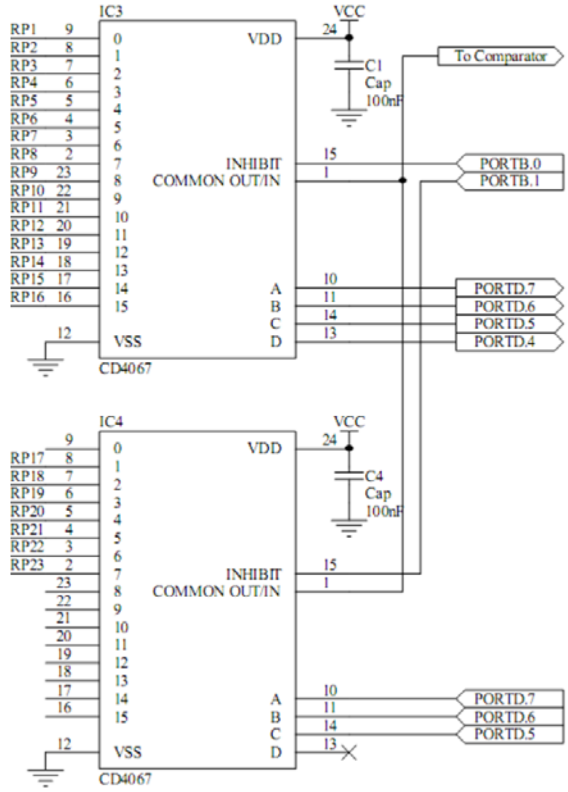

Fig. 4. Multiplexer circuit.

To overcome the drawback, the adaptive voltage reference is proposed as shown in Fig. 5. In the circuit, a reference photodiode is put in series with a resistor and connected to the inverting input of op-amp. In the shooting target, the reference photodiode is placed near to the photodiode array. Thus, when the simulator is placed outdoor, the sunlight irradiates the photodiode array and the reference photodiode simultaneously. Since the resistor's values connected to the two photodiode are different, then in the normal condition (no laser beam), the voltage on the non-inverting input is higher than one on the inverting input, and the output of comparator will be in the high state. The resistor's value on the reference photodiode is slightly higher than the one on the photodiode array. This value is chosen so that when the laser beam falls into the photodiode array, the voltage on the non-inverting input is lower than the one on the inverting input, and the output of comparator is in the low state.

2.3. Algorithm for Detecting Shooting Target Position

The shooting target position on the circular target is arranged into two parts. The first part represents the number of ring, i.e. 1 for the innermost ring, and 10 for the outermost ring. The shooting score is calculated inversely, i.e. score of 10 for ring number of 1, and score of 1 for ring number of 10. The second part represents the position along the perimeter in each ring. This position does not contribute to the shooting score, but it is sent to the computer for displaying the more precise shooting target position as shown in Fig. 6. The numbering is according to the clockwise direction from the top to the right. For example, the number of 35 for ring number of 10 indicates that shooting target is on the bottom of outermost ring.

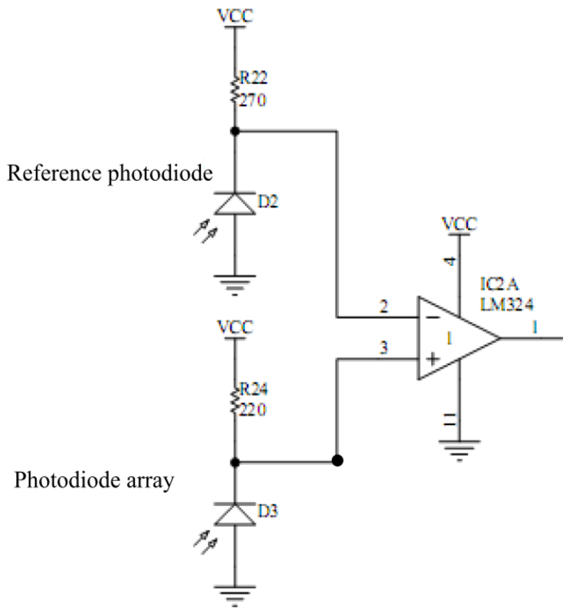

Fig. 5. Adaptive voltage reference.

Fig. 6. Target position on the computer.

Fig. 7 shows the flowchart for detecting the shooting target position which is implemented on the ATMega8535 microcontroller system. It starts by scanning the photodiode array. When the laser pointer is detected, the position of shooting target is determined using a look-up table. Then the shooting score is calculated from the ring number obtained previously. This score is displayed on the seven-segment display on the shooting target. Finally the score and precise position of shooting target is sent to the computer.

Since the scanning and multiplexing techniques are employed, it is important to ensure that the duration of laser pointer hits the photodiode is longer than the scanning time of photodiode. This requirement is provided by employing a monostable circuit on the gun. It will generate one-shot pulse with duration of 0.1 second.

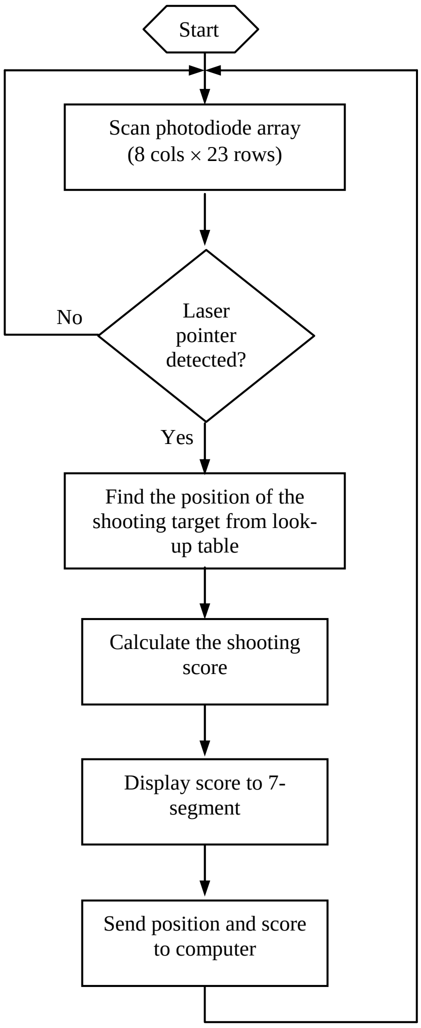

Fig. 7. Flowchart of detection algorithm.

4. Experimental Results

To test the reliability of proposed system, several experiments are conducted. The experiments comprise four aspects: a) Characteristic of laser beam; b) Characteristic of photodiode; c) Shooting detection; d) Shooting distance. The experiment on characteristic of laser beam is used to measure the diameter (size) and intensity of laser pointer from several shooting distance. The laser pointer used in the experiment is the Sharp Ace Laser Point which is commonly used as pointing device in the air gun.

Table 2 shows the measurement results of the laser beam intensity and size under varying distances. From the table, it is shown that the diameter of laser beam is larger when the shooting distance is far. Thus it will decrease the shooting accuracy.

Table 2. Measurement results of the laser beam intensity and size under varying shooting distances.

Shooting distance (Meter)	Laser beam intensity (Lux)	Laser beam size (mm×mm)
5	423	0.6×0.4
10	347	1.4×0.5
15	278	2.0×0.7
20	184	2.5×1.0

The experiments on photodiode's characteristic are conducted by measuring the output voltages of the photodiode in the reverse bias under different lighting environments. In the measurement, the photodiode is connected in series with a 220 ohm resistor as shown in Fig. 5. Fig. 8 and Fig. 9 show the measurement results of the photodiode output voltage for indoor and outdoor environments respectively. From the figures, it is clear that for indoor environment, a fixed voltage reference could be used to differentiate the presence of the laser beam on the photodiode. However, for outdoor environment, the fixed reference may fail to differentiate them.

Table 3 shows the laser detection results for different lighting environments. The proposed system is able to detect laser shooting for both indoor and outdoor environment. However, when the lighting intensity is greater than 5000 Lux, the system fails to detect the laser shooting. From the observation, it is found that the detection failure is caused by the very strong intensity of the sunlight. In this case, the output voltage of reference photodiode is almost zero, thus when laser hits the photodiode array, the output voltage of photodiode array could not be lower than zero.

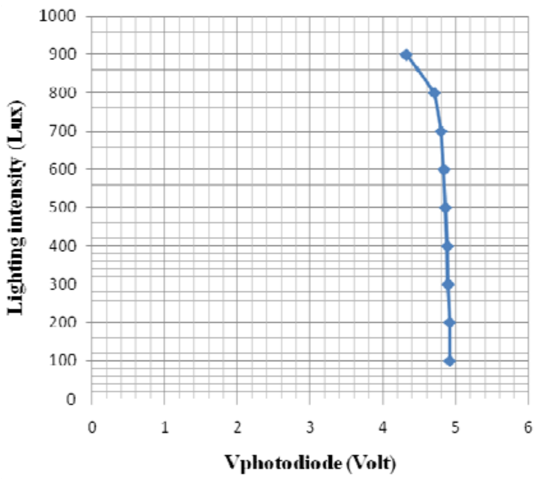

Fig. 8. Measurement results of the photodiode output voltage in indoor environment.

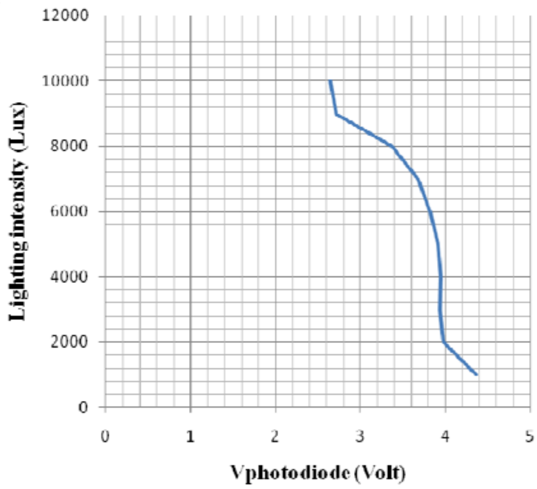

Fig. 9. Measurement results of the photodiode output voltage in outdoor environment.

Table 3. Laser detection results for different lighting environments.

Lighting intensity (Lux)	Laser detection	Remark
420	Success	Indoor
800	Success	Indoor
1000	Success	Outdoor
1500	Success	Outdoor
5000	Fail	Outdoor
10000	Fail	Outdoor

The experimental results of shooting detection for different shooting distances are shown in Table 4. The experiments are conducted in outdoor environment with the lighting (sunlight) intensity of 2400 Lux. The experimental results show that the system is able to detect the laser shooting until the distance of 25 meter.

Table 4. Laser detection results for different shooting distances.

Shooting distance (Meter)	Laser detection	Remark
5	Success	Tested in outdoor environments with the lighting intensity of 2400 Lux
10	Success	
15	Success	
20	Success	
25	Success	

5. Conclusions

A low-cost shooting simulator is developed. The laser pointer is attached on the gun for shooting the target. The main idea is to use the photodiode array for detecting the laser beam. The proposed system works well under variation of lighting conditions for both indoor and outdoor environments.

In future, the system is extended to the multi shooter. Further, the camera detection system will be developed for allowing the complex target scheme.

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