A Low-Cost Design of Vehicle-mounted Door-opening Warning System for Active Safety

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As bicycles become increasingly popular for urban transportation, dooring accidents are becoming more and more common. Although the Safety Exit Assist System (SEA) to avoid dooring accidents is available on the market, it is typically only found in premium vehicles, not ordinary ones. The high cost limits its availability, furthermore it only alerts passengers inside the vehicle, providing no warning to cyclists approaching from behind. Thus, SEA shows limited effectiveness in preventing dooring accidents. The project discussed in this paper is an attempt to develop a more affordable and practical Vehicle-mounted Door-opening Warning System. This system can simultaneously alert passengers or drivers who are about to open the door as well as cyclists who are approaching the vehicle from behind. Thanks to its ”dual alert” feature, this system significantly reduces the chances of accidents caused by carelessly opening car doors. This system has been successfully tested in real-life situations. The success rate of both detecting the cyclists and triggering the buzzer reached 89% demonstrated the reliability of the performance and results. It is particularly suitable and useful for taxis that frequently stop to pick up and drop off passengers while it is also applicable to private cars. Furthermore, this system only requires low-cost hardware. People are able to both install and remove it easily without any special hardware or permanent changes to the vehicle.

Keywords: dooring accidents, dual alert , microwave radar, buzzer, laser light, waterproof.

Introduction

A dooring accident happens when a driver or passenger suddenly and carelessly opens a car door into the path of a cyclist resulting in a collision that can lead to serious injuries and even death[1]. In Canada, dooring has become one of the greatest route risks for cyclists. Specifically, this kind of accident accounts for 10% of all the accidents involving cyclists. In Vancouver, particularly, dooring accidents are also increasing due to the booming cycling population. A study conducted by the University of British Columbia also reveals that roads with parked cars pose the greatest risk for cyclists[2].

As an increasing number of people begin to use bicycles as environmentally friendly transportation, dooring accidents are dramatically increasing. Reports show that cities in North America list dooring accidents among their top three causes of bicycle - vehicle collisions. Within the five-year period between 2015 and 2020, there were 751 reported dooring incidents according to the statistics from Montreal police report[3].

The initial idea of this project came from an accident my grandmother experienced when she was riding her bike. Someone suddenly opened a car door in front of her causing her to crash and injure herself. My grandmother's accident inspired me to find a solution for this common problem.

To investigate the current solutions of dooring, I visited the dealers of Ford and Honda. In Ford and Honda, Safety Exit Assist System (SEA), aiming to improve the safety of passengers when opening car doors, has been implemented in certain premium vehicles. However, the SEA costs thousands of dollars and is only equipped in premium vehicle models, meaning that it is unavailable for ordinary cars which people drive in daily life. The high cost of the SEA is due to its need to alert the presence of all approaching objects at the same time, such as pedestrians, bicycles, motorcycles, cars, and others. Scientists designed it in an extremely precise and accurate way so that it can predict the speed of each of the approaching objects in a relatively long detective range. Therefore, the system is quite complex and expensive[4].

The SEA has been invented for many years, and not widely adopted in most vehicles due to its high cost. Moreover, although SEA can warn the passenger who are about to open the door and temporarily secure the doors, it cannot warn cyclists outside the door when they are about to pass the vehicle.

However, the effective spread and use of the Parking Assist System (PAS) sharply contrasts with the SEA. The PAS can help drivers reverse safely and are affordable, helping drivers to park precisely and safely, using guidance system technology with ultrasonic and other camera-based solutions. The PAS is effective and affordable, so it has become a common feature in most vehicles[5].

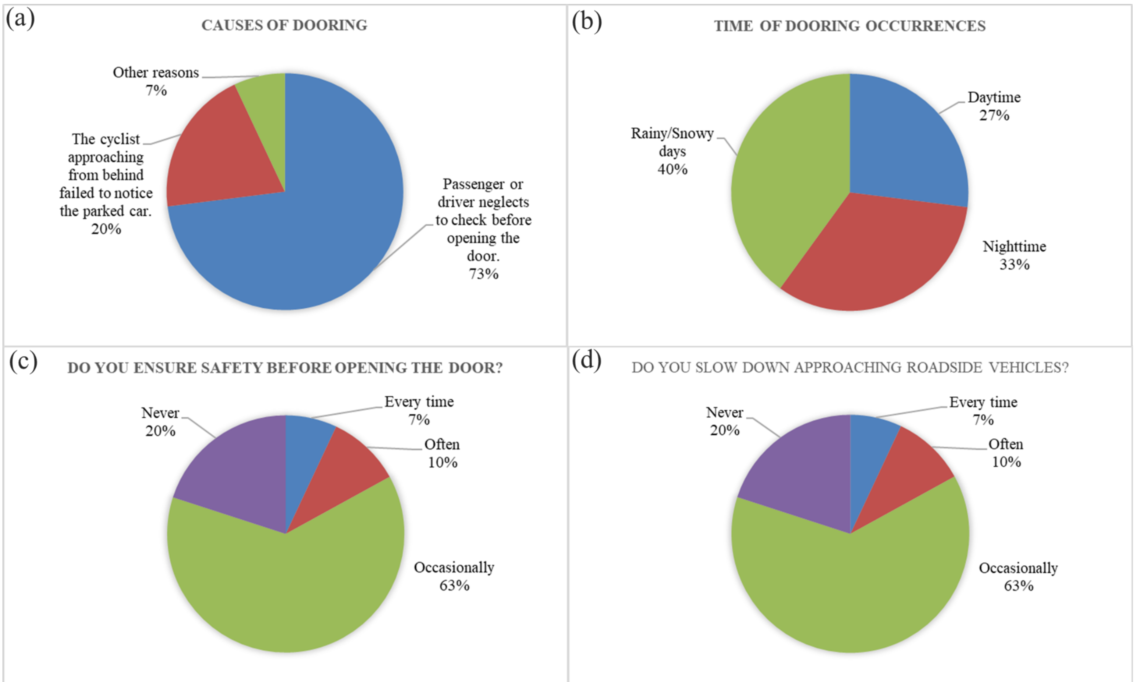

Fig. 1 Questionnaire Survey Results. (a) The statistical results regarding the causes of dooring. (b) The statistical results regarding the time of dooring occurrences. (c) The statistical results regarding whether you ensure safety before opening the car door. (d) The statistical results regarding whether individuals slow down when approaching roadside vehicles.

Survey: Root cause of dooring

In order to find the root causes of dooring, I conducted a survey with around 30 individuals, including my neighbors in the community and several taxi drivers. The survey results on the next page (Figure 1) illustrate the following conclusions: First, 73% of them believe that drivers should be responsible for dooring accidents while 20% blame cyclists for causing accidents as shown in Figure 1(a). Second, Figure 1(b) shows that people believe accidents are more prevalent in poor environmental conditions, especially during nighttime, as well as rainy and snowy weather. Third, Figure 1(c) demonstrates that most drivers or passengers do not have the habit of carefully checking whether there are people around their cars before getting off the vehicle; Finally, Figure 1(d) showcases that most cyclists do not pay much attention to approaching parked vehicles along the roads.

Therefore, it is necessary to design a technology to reduce the probability of traffic accidents caused by opening doors while parking.

System Design

In most cases, cyclists are the biggest victims of dooring accidents[6]. To address this main issue, my design will focus on detecting approaching cyclists, which can also help to simplify the design and reduce costs. My aim is to create an affordable warning system that alerts both the driver or passengers inside the vehicle and the cyclists approaching from outside. By meeting those needs, my design will become an ideal solution which can reduce dooring accidents.

According to market investigation[7], my innovation should include the following features to reduce dooring accidents: First, the system should detect cyclists approaching from behind at a sufficient safe distance, and at the same time, alert passengers or drivers who are about to exit the vehicle of the potential danger. Second, before the door is about to open, it should provide a clear warning signal to cyclists approaching from behind. The system then forms a "dual alert" feature. Moreover, this system should be able to adapt efficiently to various conditions, especially in situations with poor visibility such as rainy days or nighttime. Finally, my device should be easy to install without damaging the vehicle, and it should be affordable enough to spread widely across the country.

How to alert passengers or drivers inside?

My design solves this problem by equipping a microswitch on the interior handle of the right rear door and a microwave radar on the right rear bumper. When the passenger opens the door, the microswitch will be turned on. If a cyclist enters the detection range of the radar, the buzzer inside the vehicle will emit both audible and visual alarm, alerting the passenger not to open the door. Similarly, if we want to alert the driver, just install the microswitch on the interior handle of the driver side door and change the position of the radar to the left rear side.

How to alert cyclists approaching vehicles from outside?

If the cyclists behind know that the door is about to be opened, they will slow down. I plan to install a laser light on the outside of the right rear door. Before the passenger gets off, they will pull the interior handle, activating the microswitch which will trigger the laser light. The laser light then projects a bright red beam on the ground, forming an unmissable warning to cyclists. The laser light can be installed on either side of the vehicle.The design flowchart is shown in Figure 2.

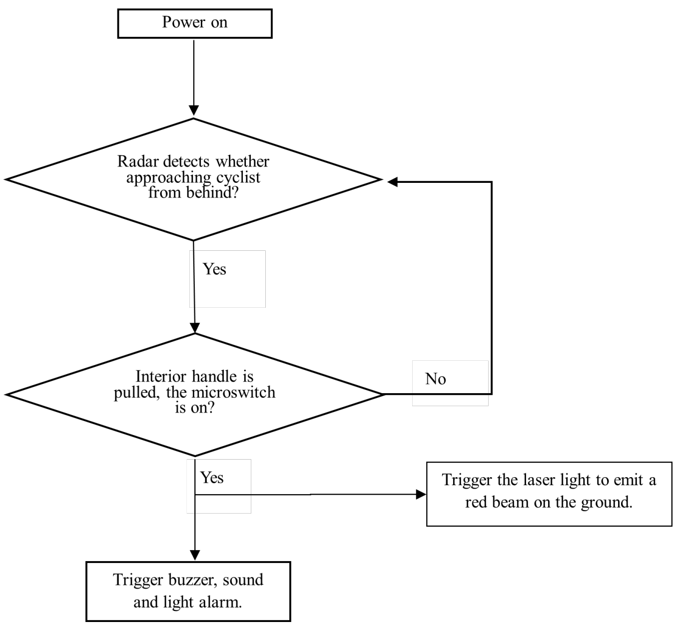

Fig. 2 Flowchart of Vehicle-mounted Door-opening Warning System

Implementation Procedure

This section presents the implementation process of design, including hardware selection, components installation, blind spot elimination and final circuit plan.

Comparison of four different radars

The key to this design is to select a reliable and accurate sensor that can detect cyclists rapidly approaching from the side of the car[8]. For movable objects detection, there are four common types of radar/sensor equipment in the market: laser radar, millimeter-wave radar, ultrasonic radar, and microwave radar. Considering factors such as effectiveness, cost, and reliability, I finally chose to use the microwave radar for my design. A comparison of the advantages and disadvantages of the four radar equipment types is shown in Table 1[9]. Specifically, the microwave radar equipment generates a Doppler effect when detecting moving objects, triggering an alarm. Microwave radar equipment demonstrates a relatively higher penetration power and is less affected by the environment outdoors[10].

Mathematical relation of Doppler shift for microwave radar

Doppler shift refers to the change in frequency of a radar signal as a result of the relative motion between the radar and a moving object. For microwave radar, this shift occurs when the frequency of the reflected signal differs from the frequency of the transmitted signal due to the movement of the object. Microwave radar measures the distance to an object by emitting short pulses of microwaves and measuring the time it takes for the pulses to return after reflecting off the object. This is known as the time delay method.

The distance is calculated using the formula:

$$d = \frac{c \times t}{2} \quad (1)$$

Where:

- d is the distance to the object in meters.
- c is the speed of light in meters per second.
- t is the round-trip time of the signal in seconds.

Selection and Installation of Microwave Radar

The next issue is to select the detection distance of the microwave radar, which must ensure the accuracy of the radar detection and reduce the probability of false alarms. I purchased four microwave radar equipment (type WB-001-12V) with detection distances of 3m, 5m, 7m, and 10m. The wavelength of the microwave radar is 12.5mm. The size of the radar unit is 6cm (length) × 4cm (width) × 2.5cm (height). I intentionally chose a waterproof type so that it will be utilized in poor weather conditions. The waterproof type of radar has the ability of the radar unit to resist water ingress and operate effectively in various wet conditions.

The radars were placed at the rear of the vehicle respectively, powered on, and the radar was connected to a buzzer. Each radar equipment was tested exactly 40 times, and the experimental results are summarized in Table 2. The result shows that the false alarm rate would significantly increase as the detection distance

Table 1 Comparison of Four Different Radars Performance

Radar Type	PROS	CONS
Laser Radar	High measurement accuracy, long-range capability, relatively high resolution, unaffected by ground clutter.	Performance degradation in strong light exposure and extreme weather conditions; higher cost.
Millimeter-Wave Radar	Strong penetration through fog, smoke, and dust, all-weather capability (except heavy rain), less affected by environmental changes.	Lower penetration capability through dense foliage compared to microwaves; higher component costs and relatively high processing precision requirements.
Ultrasonic Radar	Strong anti-interference capability, minimal detection distance reaching 0.1-0.3 meters, low cost.	The major drawback of ultrasonic radar is its narrow detection angle, requiring several installations at different angles for a single vehicle.
Microwave Radar	Excellent directionality, large detection angle, strong penetration through fog, smoke, and dust, less affected by environmental changes, low cost.	Lower accuracy compared to laser radar, shorter detection range than millimeter-wave radar.

increases. However, there may be a huge difference between the experimental environment and the actual use environment on the busy roads. In other words, the actual environment may contain significantly more interference than the experimental environment such as radiation, leaves, and passersby, so the false alarm rate may be even higher. Therefore, it is not a suitable idea to increase the detection distance to ensure safety.

Table 2 Comparison of False Alarm Rates for Microwave Radar with Different Detection Ranges

Radar Detection Range	Number of Experiments (times)	False Alarms (times)	False Alarms Rate (%)
3 metres	40	2	5.0%
5 metres	40	3	7.5%
7 metres	40	7	17.5%
10 metres	40	13	32.5%

According to research, the general reaction time of the human body is 180 ms∼200 ms[11], and the speed of a cyclist is approximately 5 m/s∼8 m/s. Considering the unpredictable factors that may affect the reaction distance, I increased the reaction distance by 3 times (safety factor) which should meet the safety requirements. The reaction distances for cyclist will be the following calculation:

$$S = vt = 8\,\mathrm{ms}^{-1}\,(\text{max. speed of cyclist})$$

$$\times 0.2\,\mathrm{s}\,(\text{max. human response time}) \times 3\,(\text{safety factor}) \approx 5\,\mathrm{m}$$

Based on the above calculations, a radar with a detection distance of 3m cannot meet the safety distance requirements. Considering factors such as reliability, false alarm rate, and reaction distance, I concluded that selecting a radar with 5m detection distance can meet both safety distance requirements and false alarm rate within a reasonable range.

I installed the radar at the position below the right rear bumper of the vehicle, shown in Figure 3. To avoid damage to the vehicle, the radar is installed actually inside the bumper, which cannot be seen directly. The power and signal lines run from the trunk into the interior of the vehicle.

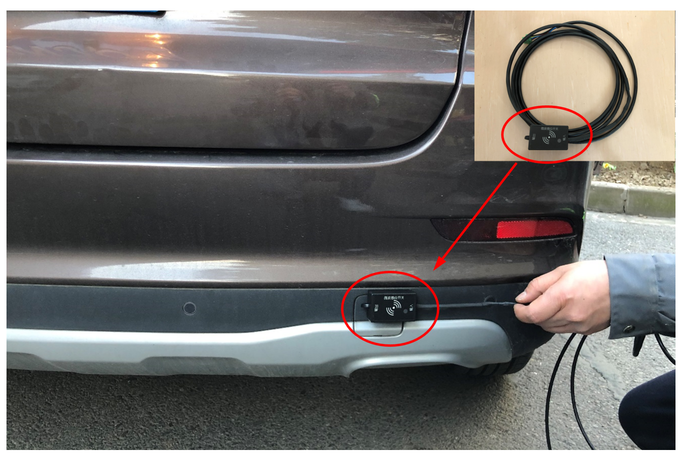

Fig. 3 Microwave Radar installed on the right rear bumper.

Selection and Installation of Other Hardware

Microswitch

Due to the need for installation inside the door handle, the microswitch must be very small, approximately the same size as a one-dollar coin. I chose the model B076L2F9ZG microswitch with a mini size, shown in Figure 4(a).

Laser light

The laser light is only the size of a fingernail. The bandwidth of laser is 1nm. Although it has an output power of only 0.1 watt, it can create a noticeable red strip on the ground. Install the laser light on the right rear fender of the vehicle using double-sided tape and run the power line into the interior of the vehicle through the gap in the rear seat, shown in Figure 4(b). Waterproofing is also required. Noted that based on safety consideration, this type of laser light is widely used as an advertising tool in front of stores to attract customers, providing minimal irritation to the eyes. On top of that, in my design, the laser light was installed on the right rear fender of the vehicle (0.6m height) downward, making it impossible for people to directly look at it.

Buzzer

The buzzer needs to be installed inside the car, so it needs to be small in size, but it must have a high "output" to emit a loud sound and a noticeable flashing light to alert passengers who are about to exit the vehicle. Mount the buzzer junction box with double-sided tape in front of the right rear passenger. This position does not obstruct the front passenger and is within view of the rear passengers, shown in Figure 4(c).

Power supply

The socket plug connector can be inserted into the car's 12v socket to provide power to the radar, buzzer and laser light. Considering that the car power supply is 12V, all the electronic components I bought are 12V. The power for this design is provided by the rear passenger's power socket. Most vehicles are equipped with power sockets in the rear. If there isn't one in the rear, you can run a wire from the front power socket, shown in Figure 4(d).

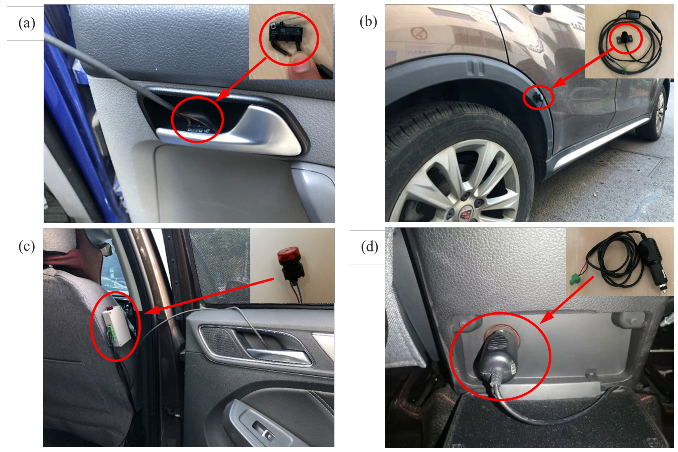

Fig. 4 Hardware installation (a) Microswitch inside the door handle. (b) Laser light on the right rear fender. (c) Buzzer beside B pillar inside. (d) Socket plug connector.

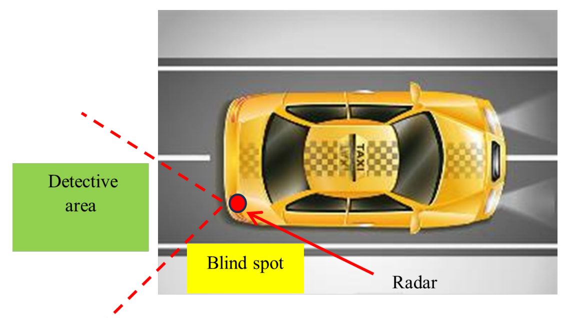

Fig. 5 Blind Spot Diagram

Blind Spot Elimination

When a passenger inside the car pulls the door handle, if someone happens to move into the yellow area (Figure 5) at this time, the radar mounted on the rear of the car cannot trigger the buzzer, which creates a blind spot in the yellow area.

Adding a timer relay is an effective approach [12]. I purchased a time-delay relay module with a time adjustable switch ranging from 0s to 10s, shown in Figure 6(a). I found that setting the time-delay to 5s could eliminate the blind spot by using the following calculation.

$$S_t = \frac{s}{v} = \frac{3 \text{ m (length of blind spot)}}{1.2 \text{ m/s}^{-1} \text{ (min. moving speed)}} \times 2 \text{ (safety factor)} \approx 5 \text{ s}$$

This means that if someone passes through the radar detection range within 5s before a passenger inside pulls the door handle, the buzzer inside will still sound the alarm, alerting the passengers. Then the blind spot is eliminated.

Circuit Setup

To avoid tangled wiring, I integrated the wirings and placed the circuit board in a junction box (size: 110x65x40mm) by a PCB circuit board. I even mounted the buzzer on the junction box, as shown in Figure 6(b). The radar, microswitch, and laser light are connected to the box via terminal blocks. There is only a

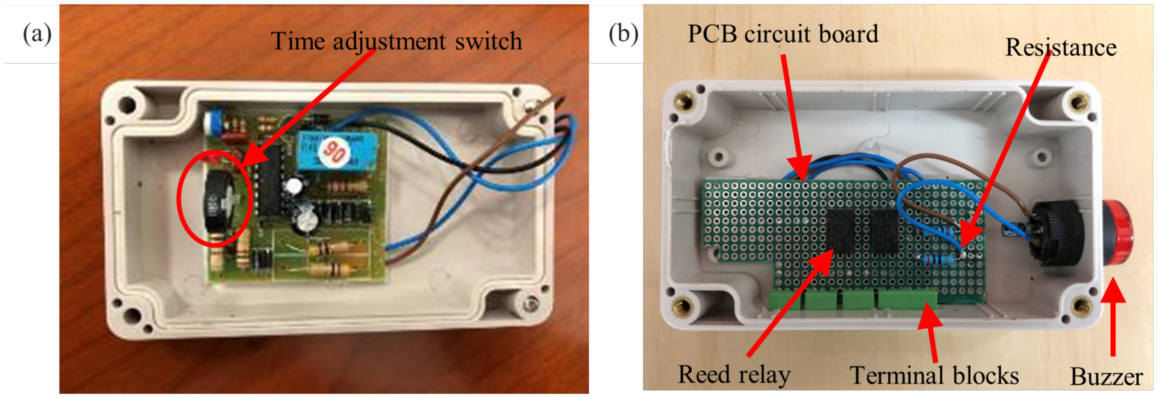

Fig. 6 Junction box. (a) Time-delay Relay Module with A Time Adjustable Switch. (b) PCB.

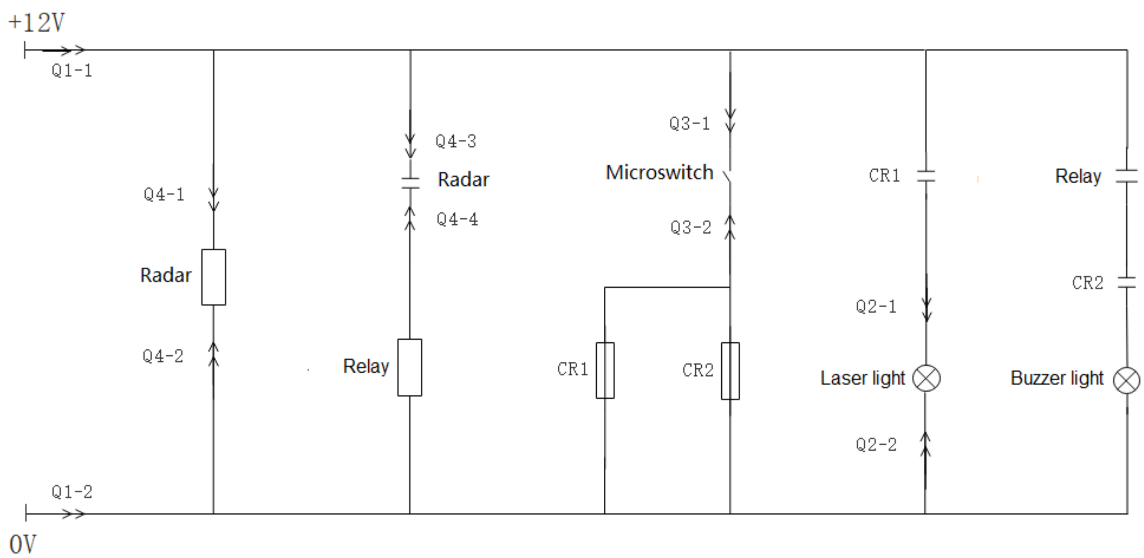

Fig. 7 Final Circuit Diagram

small box inside the vehicle finally, greatly improving the wiring appearance.

Results

Prototype

I installed the prototype on my own car. The prototype realized my original design intends to achieve "dual alert" successfully: When the passenger or driver pulls the interior door handle before getting off, the microswitch is on. If a cyclist enters the radar detection range of 5 meters behind the car at this time, the buzzer inside will sound and flash an alarm, reminding the passenger or driver not to push open the door, see Figure 8(a).

At the same time, the microswitch triggers the laser light, which emits a red beam outside the right rear door, creating a visible warning zone, alerting cyclists approaching from behind that the door is about to open. The warning zone on the ground is particularly noticeable in rainy or nighttime conditions, see Figure 8(b).

Experimental result

The prototype was tested 154 times over 5 consecutive days. Test results are shown in Table3. The success rate of triggering the laser light reached 99%, and the success rate of the radar identifying a cyclist approaching from behind and successfully triggering the buzzer reached 89%. The experimental results

Fig. 8 Prototype Test Show. (a) Buzzer alarm to alert passengers not to open the door. (b) The laser light emits a red beam which creates a distinct warning area on the ground.

Table 3 Experimental Results Record

Date	**Weather**	**Door open (times) Door open (times)**	**Laser light illuminating (times)**	**Buzzer alarm (times)**	**Successful identification (times)**	**False alarm (times)**
14/12/2023	Rainy	32	32	8	7	1
15/12/2023	Rainy	28	28	5	5	0
16/12/2023	Sunny	25	25	7	5	2
17/12/2023	Cloudy	33	32	10	9	1
18/12/2023	Cloudy	36	36	8	8	0
Total		154	153	38	34	4
Success rate			99%		89%	

also showed that the success rate is essentially the same on sunny and rainy days, demonstrating that weather conditions did not affect the application of this design. It was also important to consider the 11% false alarm rate. This was also a part of the overall assessment and limitation of the radar's performance.

During the 5 consecutive days of experiments, the driver reported that the alarm device provided a good reminder, especially when he sometimes forgot to check carefully for the approaching cyclists before opening the car door. Despite some false alarms, it added an extra layer of safety. The feedback from cyclists was that when seeing the bright light strip on the ground, they would instinctively slow down to approach the vehicle. The overall feedback were positive.

Table 4 Cost Breakdown List

Items	**Hardware**	**Price ($)**
1	Microwave radar	10
2	Microswitch	3
3	Laser light	8
4	Buzzer	4.5
5	Socket plug connector	5.5
6	Time-delay relay module	3.5
7	PCB, wiring terminals, etc.	6.5
8	Shipping cost	14
	Total	**55**

Prototype Cost

The prototype only cost around $55, details are shown in Table 4.

Conclusion

An effective Vehicle-mounted Door-opening Warning System has been explained through this paper. The data of the testing results proves that the prototype of this system meets my design requirements and performs reliably. The system mainly has three highlighted innovation points: First, the system provides a "dual alert": alerting the passenger or driver with sound and light alarms and informing cyclists approaching from behind of the potential danger with a bright red beam on the ground outside the vehicle. Second, it is easy for one to install without damaging the vehicle as the system utilizes the gap in the trunk to route the radar wire from the bumper and the laser light wire through the gap in the rear seat. Moreover, the system is affordable: it only costs around $55.

Clearly, the current success rates need improvement. Therefore, it is essential to find radars with enhanced anti-interference capabilities via research and experiment. Additionally, I plan to test my prototype more in real-world scenarios, such as installing it in taxis and regular cars. Taxis, with their frequent passenger pickups and drop-offs, face a higher risk of dooring incidents. Collecting a larger volume of actual data will help further optimize the design.

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