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Research on Vehicle Rear-End Collision Prevention Systems

Wen-Kung Tseng*, I-ChenTsai**
**Professor, Graduate Institute of Vehicle Engineering, National Changhua University of Education, Taiwan R.O.C.*
*** Postgraduate Student, Graduate Institute of Vehicle Engineering, National Changhua University of Education, Taiwan R.O.C.*
Corresponding Author:andy007@cc.ncue.edu.tw

Abstract: *This paper presents a system that uses relative distance to calculate speed in order to assess rear-end collision risks, with the goal of deploying the vehicle's external airbags before a collision occurs to mitigate injury from the impact. The study utilizes LiDAR (Light Detection and Ranging) as the primary tool for measuring speed and distance. By analyzing the collected LiDAR data, the system determines whether activation of the airbag system is necessary. This system employs real-time sensing technology, enabling the vehicle to react in advance when a rear-end collision is imminent, thereby enhancing the vehicle's safety and effectively reducing the risk of injury in rear-end accidents.During the experiment, the LiDAR sensor is installed at the rear of the vehicle, responsible for continuously measuring the distance between the rear vehicle and the test vehicle. These distance data are transmitted to a single-chip system, which processes and converts the data using specific algorithms to calculate the average speed per second. Based on the calculated speed data, the system further assesses whether there is a risk of a rear-end collision. If the approaching vehicle's closing speed exceeds a preset safety threshold, the system automatically identifies the risk of a rear-end collision and deploys the external airbags in advance to protect the vehicle's occupants. This process relies on accurate distance measurement and real-time data processing, aiming to improve the vehicle's response speed to sudden accidents and minimize the injury risks associated with rear-end collisions.*

Keywords: *Relative distance; rear-end collision; LiDAR; real-time sensing technology; a single-chip system.*

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I. INTRODUCTION

Regarding whether airbags can truly reduce the impact force from large objects such as vehicles, many people have expressed skepticism. In 1994, Clark, C. C. and Young, W. A. proposed a method where the airbags, placed at the front of the vehicle, inflate instantly before a collision to create a buffer zone that reduces the impact force[1]. The study indicated that airbags could reduce the impact force, but if the airbag deflation is delayed, it could cause the vehicle to rebound. The experiment tested whether the rebound acceleration would double the chest load on passengers wearing seatbelts. The results showed that the load was noticeable but did not lead to discomfort or injury.A year later, in 1995, Clark, C. C. and Young, W. A. conducted real-world crash tests in two parts[2]. The first test involved a frontal collision at 48.5 km/h, using a low-pressure airbag inside a high-pressure airbag box located on the outer side.The results showed that the airbag bumper absorbed 19% of the collision energy. The second test was a side collision at 48.5 km/h, using only the high-pressure airbag. After the collision, the airbag deformed and entered the side of the vehicle, but provided limited protection.

In the field of automotive industry, LiDAR has been used for many years, typically for sensing the surrounding environment, with limited use for speed and distance measurement. In 2021, Vasile, Ionuţ, et al. proposed using LiDAR to measure speed and distance on moving vehicles[3]. In their study, the LiDAR was placed at the rear of a train model to detect data such as distance and speed relative to a rear model train, with the target under test also equipped with a speed sensor. The results can be divided into two parts:

- DistanceMeasurement
  The error is less than 5%, and it works under low reflectivity and low ambient light conditions.
- SpeedMeasurement
  The relative speed is calculated based on the change in distance, with the data showing a difference of approximately 5% from the actual speed.

In 2020, Vu Van Quang et al. proposed a method of detecting vehicle speed using passive infrared sensors[4]. The study involved installing two sensors along a simulated road and using the shape of signals from the target vehicle to determine its speed. The results showed that within a speed range of 20 km/h to 60 km/h, the error was less than 5 km/h. Potential sources of interference included heat sources and misalignment between the two sensor light axes.There have been numerous studies on the dangers of rear-end collisions. In 2022, Caitlin H. McCleery et al. published a paper using data from the Insurance Institute for Highway Safety (IIHS) to examine the relationship between vehicle and occupant accelerations, as well as the relative acceleration between the cervical and lumbar spine during rear-end collisions[5]. The results indicated that the head and pelvis accelerations of the occupants were significantly higher than the sled acceleration. The analysis also showed significant differences in pelvic acceleration between sedans and SUVs.

There has also been research on low-speed rear-end collisions. In 2000, Feng Luan et al. analyzed the kinematics of the neck during low-speed rear-end collisions[6]. Using an X-ray system capturing 250 frames per second, they tracked the motion of each cervical vertebra and calculated relative displacement and time trajectories to qualitatively analyze neck kinematics during different stages of the collision. Figure 1 illustrates the neck movement at each stage. The following is a description of the neck kinematics in three stages:

- Stage 1 (First 100 ms after impact): The neck undergoes flexion deformation.The forward curve disappears, and it starts to straighten. There is minimal rotation within the first 50 ms, and after 50 ms, the upper and lower cervical vertebrae experience bending torque, with shear force transmitted upward, straightening the neck. The axial force changes from compression to tension.
- Stage 2 (Next 30 ms): The neck assumes an S-shape, with the lower part extending and the upper part following suit, causing the previously straight neck to curve forward again. The lower part is subjected to anextension torque, and the upper part to a flexion torque, while all levels experience shear force and tension along the axial direction.
- Stage 3 (Final Stage): Both ends of the neck are subjected to extension torque, putting the entire neck in an extended state. Shear force and tension continue to act on the neck. After 180 ms, the head reaches maximum extension and begins to rebound, with the extension torque on the upper neck decreasing.

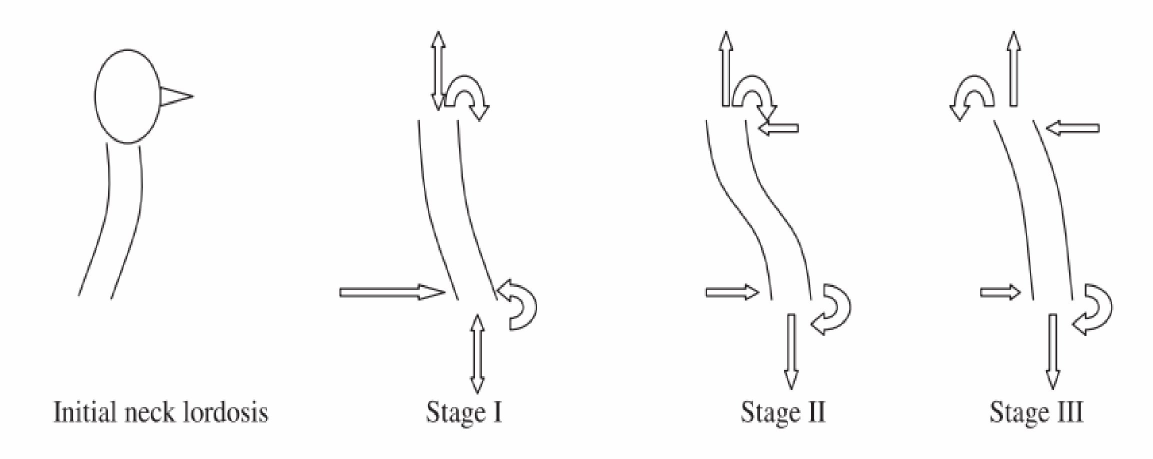


Fig. 1.Neck movements at different stages

The question of at what speed a rear-end collision may cause harm to the driver and passengers is an important one to consider. A study by W. H. Castro et al. in 1997 explored whether rear-end collisions at low speeds could result in cervical spine strain, particularly focusing on rear-end collisions at speeds between 10 to 15 km/h[7]. The study involved 19 volunteers who participated in 17 vehicle rear-end collisions (with speed changes ranging from 8.7 to 14.2 km/h) and 3 bumper car accidents (with speed changes ranging from 8.3 to 10.6 km/h). The results showed that only one volunteer experienced a 10-degree reduction in leftward neck rotation within 10 weeks. Based on these findings, the study concluded that the stresses generated in a rear-end collision are not harmful within the speed range of 10 to 15 km/h.

II. VEHICLE REAL-END COLLISION PREVENTION SYSTEMS

The rear-end collision prevention systems available on the market today are mainly equipped in high-end and mid-to-high-end vehicle models [8]. These active rear safety systems are typically used in conjunction with other driver assistance technologies to provide comprehensive safety functions. For example, these systems often work together with rear collision warning, rearview cameras, automatic emergency braking, and collision alerts. When automakers deploy active rear safety systems, they typically use a range of sensors, including radar, cameras, and ultrasonic sensors, to continuously monitor the situation behind the vehicle as shown in Figure 2. These sensors assess the distance and relative speed of objects behind the vehicle to detect potential rear-end collision risks. Once the system identifies a risk of collision, it warns the driver through visual or auditory alerts, allowing the driver to react in advance. In some cases, the system may even bring the vehicle to a complete stop after the impact. This active braking operation helps to mitigate the severity of rear-end accidents, thereby reducing the risk of injury or damage. By integrating these advanced safety systems, automakers aim to enhance overall vehicle safety and provide an additional layer of protection for drivers, especially in situations where the driver might not be able to react in time. However, these systems are limited in that they can only alert the driver and cannot provide protective measures, such as reducing collision-related injuries, in the event of an impending impact.

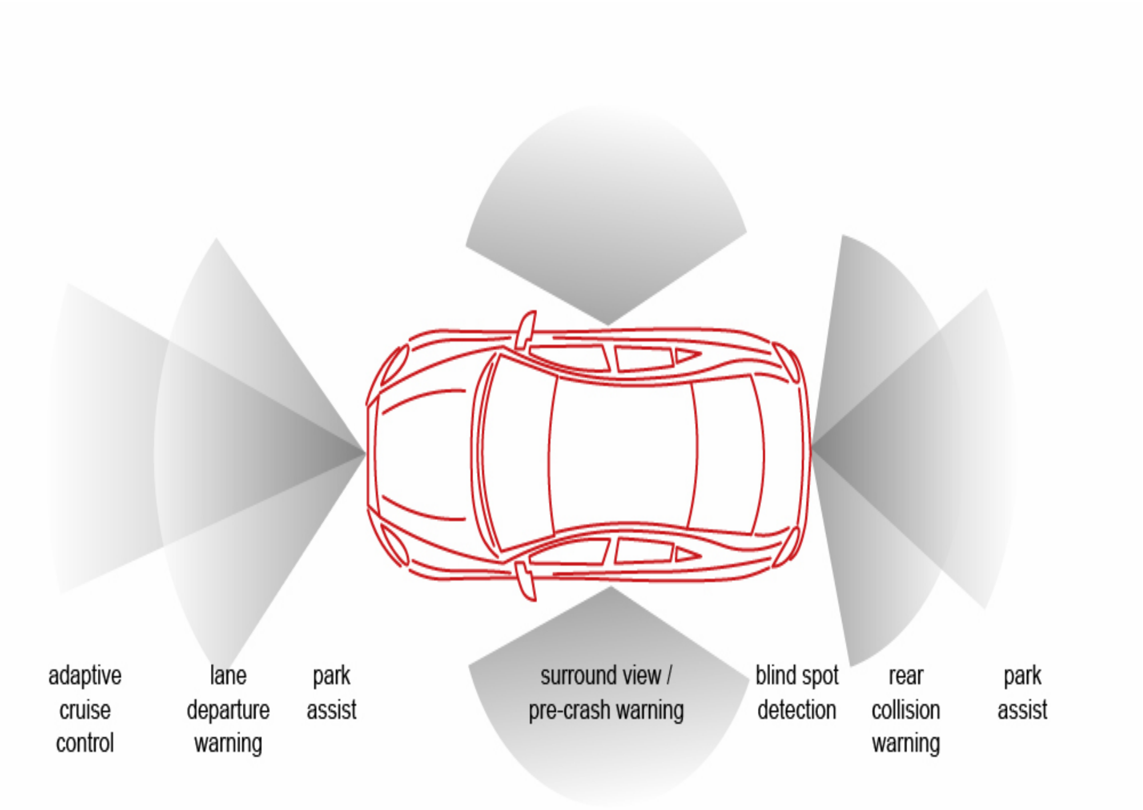


Fig. 2.Vehicle Driver Assistance Systems[8]

The accuracy of measurements is crucial for both speed and distance measurement. In reference [9], methods for measuring distance using optics were discussed, which could be broadly categorized into active and passive measurements. Active measurements include time-of-flight (ToF) and interferometric methods, while passive measurements typically determine the position of the target object using geometry. Different methods are applicable in different situations.Laser rangefinders are also an excellent method for distance measurement, sometimes even providing higher accuracy than LiDAR. The authors of reference [10] improved measurement precision by using the start and stop signals of a digital counter in conjunction with a second-degree polynomial least squares approximation of pulse samples. This approach allows the measurement results to be very close to the actual distance, with an uncertainty of only 1 cm. However, the downside is that the rangefinder needs to be self-built, and it is uncertain whether it can measure moving objects.Low-cost LiDAR is most suitable for the experiments in this study. The LiDAR and measurement methods used in reference [8] are similar to those in this paper. However, in that study, an electric model train was used, and according to the description, its maximum speed was about 2.16 km/h, which is significantly lower than the speeds encountered in real-world measurements.

III. EXPERIMENT AND RESULTS

Figure 3 shows the entire experimental system, which can be broadly divided into two parts. The first part is the collision detection system, where the LiDAR distance sensor serves as the input, sending signals to the Arduino development board. The output from the development board is connected to a relay, which controls whether the 12V power supply activates the solenoid valve. The second part is the airbag simulation system, which uses a CO_2 cylinder to provide high-pressure air. The solenoid valve controls the flow of the gas, and a check valve is installed in front of the solenoid valve to prevent gas from flowing back into the airbag after a collision. Finally, there is a pressure gauge and a balloon that simulates the airbag. The pressure gauge can detect the airbag's pressure, allowing for monitoring of the balloon's condition.

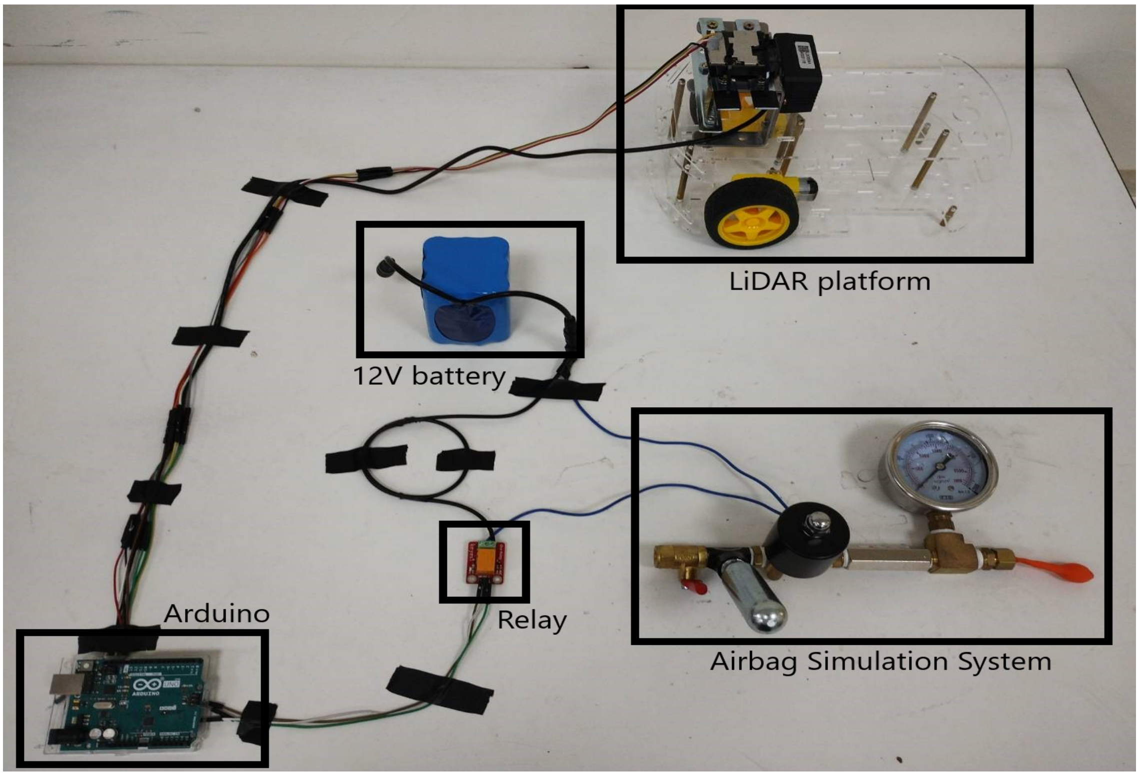


Fig. 3.The experimental system

In this study, we used a remote-controlled car to simulate the rear-impact vehicle, and mounted the LiDAR on a fixed platform constructed from plastic materials and angle iron. This platform remains stationary during the testing process and was equipped with height-adjustable mechanisms at both the front and rear to ensure that the LiDAR stayed as level as possible during the test, thereby improving the accuracy and consistency of the measurements. The stable installation of the LiDAR helps reduce variables during the test, ensuring that the data collected was more reliable and accurate.The test covered four main scenarios, as follows:

1. The performance of the LiDAR system in measuring speed and lateral distance when the rear-impact vehicle's speed is less than 15 km/h.
2. The performance of the LiDAR system in measuring speed and lateral distance when the speed exceeds 15 km/h but does not reach the set distance, as well as whether the airbags are deployed.
3. The measurement accuracy, speed, and lateral distance performance of the LiDAR system when the speed exceeds 15 km/h and the set distance is reached, along with whether the airbags are deployed.
4. The ability of the LiDAR to accurately measure the vehicle's speed under high-speed conditions, particularly its stability and accuracy in high-speed motion scenarios.

Each test scenario will be repeated five times to verify the stability and accuracy of the LiDAR system under different conditions, minimizing the influence of random factors on the results. The LiDAR test data will be output to the Arduino IDE's serial monitor, providing real-time measurement results. Additionally, a speed gun will be used to measure the speed of the remote-controlled car, and this speed will be considered the actual speed of the car. Finally, the most representative results from all the test data, along with the speed gun data, will be selected and plotted as a line graph for further data analysis and observation, allowing a more intuitive presentation of the LiDAR system's performance and measurement results in different scenarios.Figure 4 shows the fixed platform for the LiDAR.

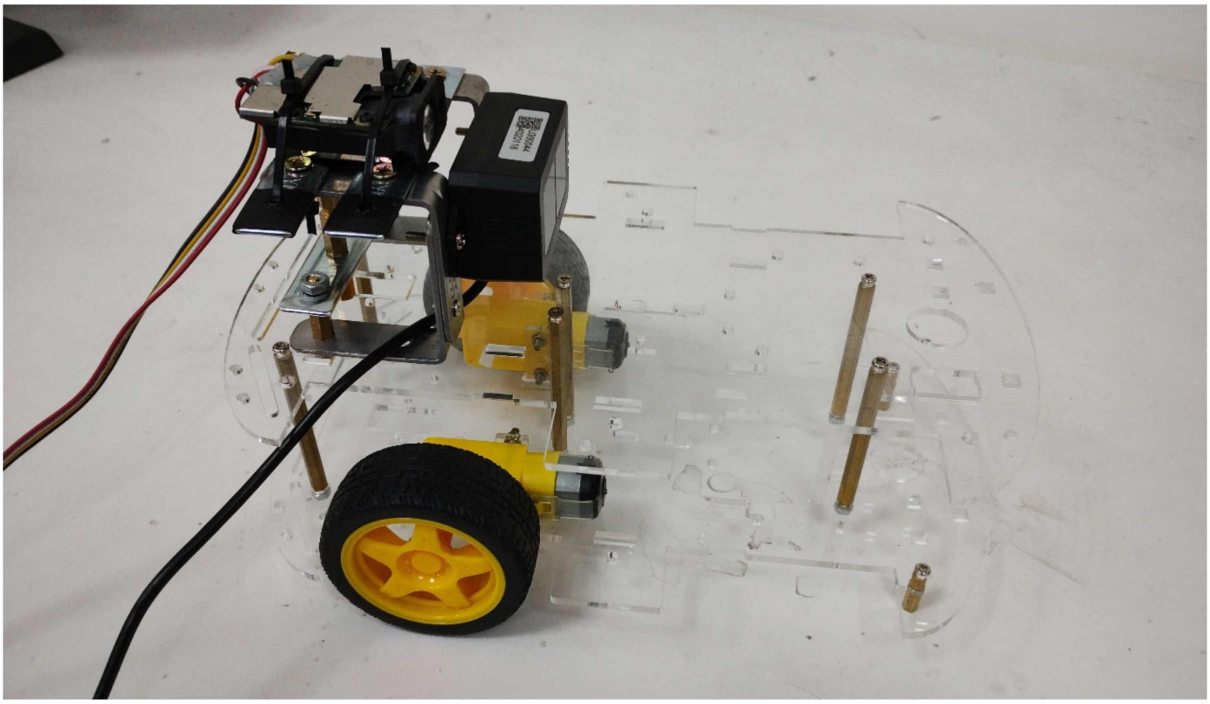


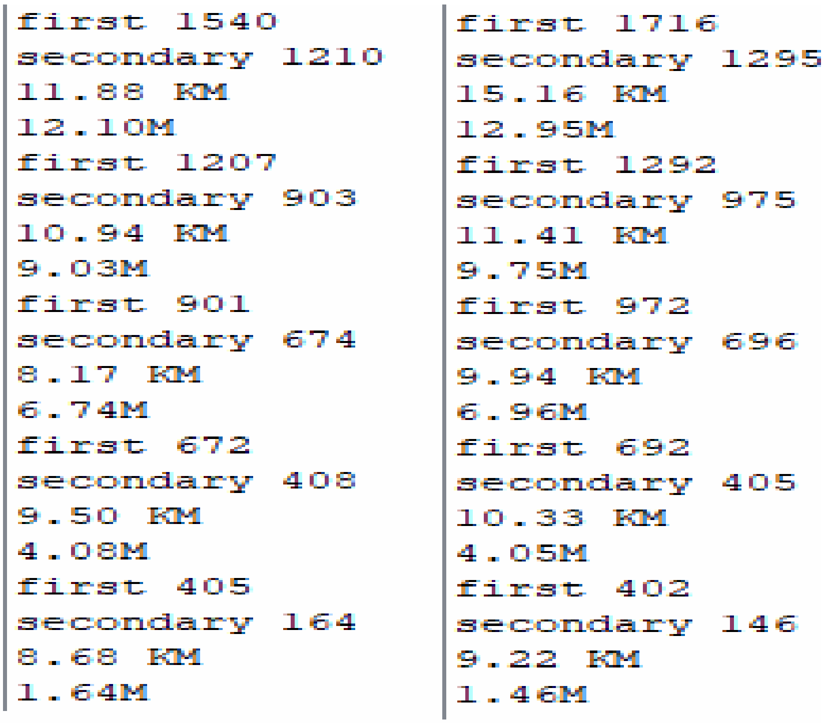
Fig. 4. Fixed platform for the LiDAR

In order to activate the airbags before a collision occurs, the activation distance is dynamically adjusted based on the vehicle's speed. Specifically, the higher the speed, the longer the pre-warning distance for the airbags, as higher speeds increase both the vehicle's reaction time and the time required for the collision to occur. Therefore, the airbags need to be deployed earlier to provide more effective protection. To ensure the scientific accuracy of this process, this study adopts the safety distance calculation method provided by the Ministry of Transportation, which has been widely applied in vehicle collision warning systems and can reasonably adjust the pre-warning distance based on different driving speeds.The specific calculation method involves dividing the measured vehicle speed by two, then converting the result into meters. This allows for a more precise determination of the safe distance a vehicle should maintain at different speeds. For example, if the speed is 60 km/h, according to this method, the safe distance should be 30 meters. This calculation formula takes into account the time required for the driver to react and brake under normal traffic conditions, as well as the vehicle's braking capabilities. Such a distance setting helps minimize the risk of a collision and ensures that the airbags can be deployed quickly and effectively before a crash occurs, providing optimal safety protection.

Before starting the experiment, the LiDAR’s irradiation angle needs to be precisely adjusted to a horizontal position to ensure that the LiDAR can cover a sufficient measurement range during the testing process, thus improving the accuracy of the test. Next, the remote-controlled car will travel in a straight line at a similar speed five times, moving towards the direction of the LiDAR. During this process, if the car's path deviates, the corresponding data will be considered invalid, and the measurement must be repeated to ensure the reliability of the results. After completing the five measurements, the next test item will proceed.During the testing process, we found that at longer distances, the LiDAR's laser spot requires a larger object to effectively reflect the light waves and obtain stable data. Therefore, we decided to modify the appearance of the remote-controlled car by installing a large piece of cardboard at the front of the car to increase its surface area and thus enhance the chances of being detected by the LiDAR. However, considering that the cardboard itself has a low reflectivity, which could affect the measurement accuracy, we attached a layer of aluminum foil to the front of the cardboard to improve its reflectivity and further enhance the LiDAR's ability to detect reflected light.After these modifications, the tests were successfully conducted, and 20 data points were collected. For analysis and comparison purposes, we selected the most representative data and organized it into a line graph. This allows for a clear presentation of the LiDAR's measurement results and stability under different conditions, helping to better understand the performance of the LiDAR system in various experimental scenarios.Figure 5 shows the modified remote-controlled car, and Figure 6 shows the output results of the serial monitor for the speed below

15 km/h.Figure7 shows the output results of the serial monitor forthe speed above 15 km/h. When the speed exceeds 15 km/h the airbag deploysas shown in Figure 8.

Fig.5. The modified remote-controlled car



```
first 1540
secondary 1210
11.88 KM
12.10M
first 1207
secondary 903
10.94 KM
9.03M
first 901
secondary 674
8.17 KM
6.74M
first 672
secondary 408
9.50 KM
4.08M
first 405
secondary 164
8.68 KM
1.64M
```

```
first 1716
secondary 1295
15.16 KM
12.95M
first 1292
secondary 975
11.41 KM
9.75M
first 972
secondary 696
9.94 KM
6.96M
first 692
secondary 405
10.33 KM
4.05M
first 402
secondary 146
9.22 KM
1.46M
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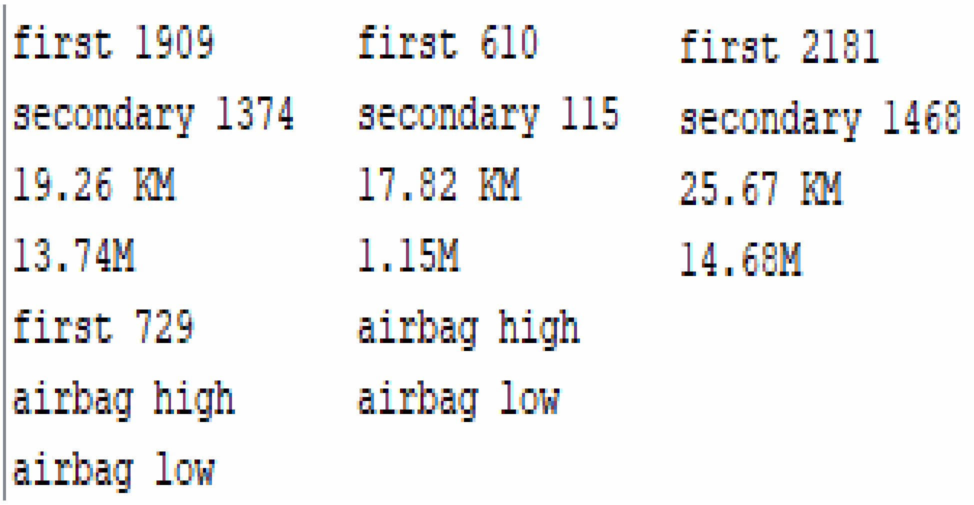
Fig.6. The output results of the serial monitor for the speed below 15 km/h



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first 1909       first 610        first 2181
secondary 1374   secondary 115    secondary 1468
19.26 KM         17.82 KM         25.67 KM
13.74M           1.15M            14.68M
first 729        airbag high
airbag high      airbag low
airbag low
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Fig.7. The output results of the serial monitor forthe speed above 15 km/h

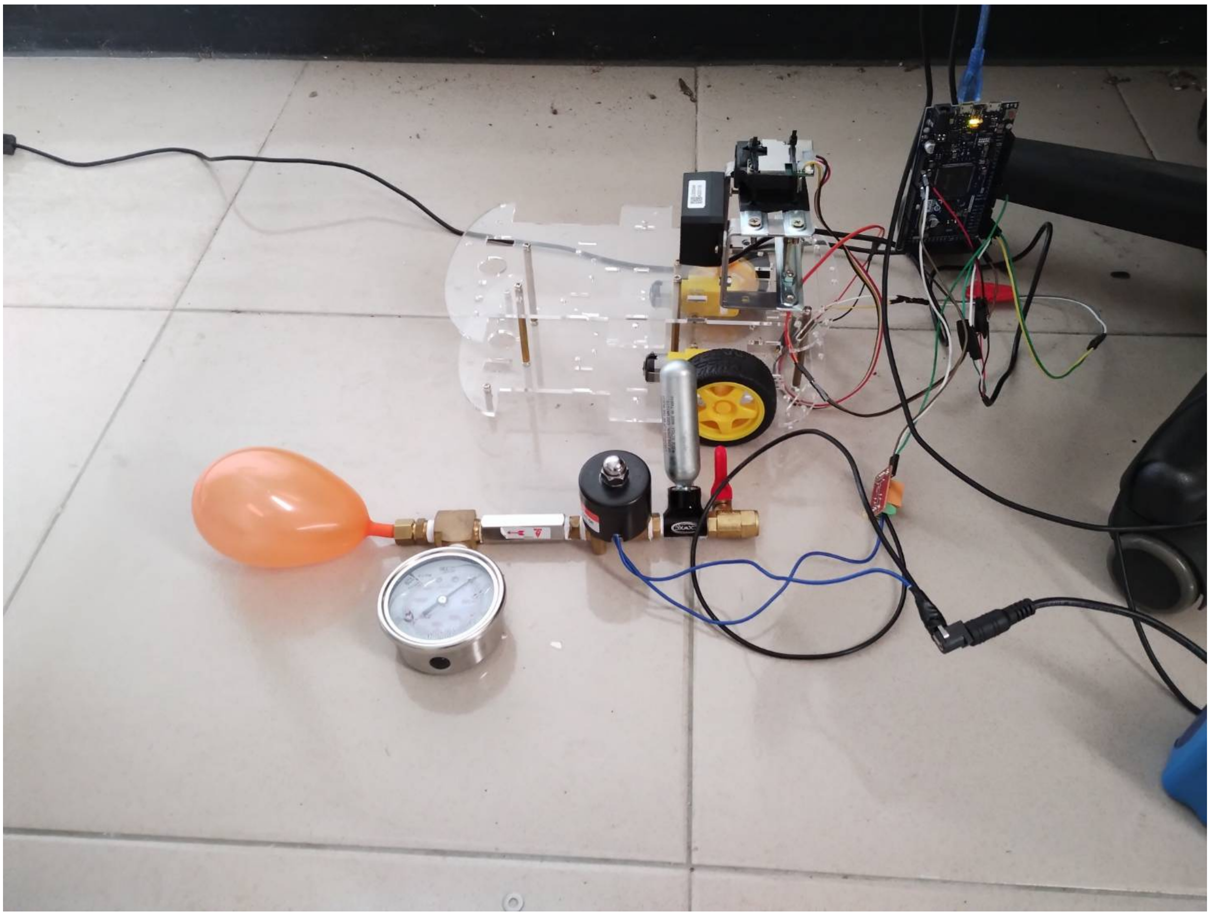

Fig.8. Airbag deployment when the speed exceeds 15 km/h

This system is capable of accurately measuring the distance and speed of the remote-controlled car. Through the high-precision measurements of the LiDAR system, the distance variation between the remote-controlled car and the measuring device can be obtained in real-time, while the vehicle's speed can be calculated using the LiDAR data, enabling precise tracking of the car's motion. When the measured distance is less than the set safety distance and the speed exceeds 15 km/h, the system can quickly trigger the airbag system's activation signal, ensuring that the airbags deploy in time before a collision occurs, thus providing optimal safety protection.After completing the experiment, we compared the speed data obtained from the LiDAR system with the data measured by a traditional speed gun to verify the accuracy and stability of the LiDAR in speed measurement. The following graph shows a line chart comparing the speed data from the LiDAR system with the speed gun measurements. This graph visually reflects the data comparison between the two methods. It can be seen that the measurement results from the LiDAR system are highly similar to those of the speed gun across different speed ranges, proving the reliability of the LiDAR system in practical applications. This line chart not only helps us analyze the differences between LiDAR data and traditional measurement methods more clearly, but also provides valuable insights for the optimization and improvement of related technologies in the future. Below are the line graphs for the four different test scenarios:

1. When the speed is below 15 km/h:

Since the speed is below the minimum speed threshold required to activate the airbag system, the airbag system will not deploy, regardless of how close the vehicle is to the measuring device. This is because the trigger conditions for airbag deployment depend not only on the distance but also on the vehicle's speed, in order to avoid unnecessary airbag deployment in low-speed or stationary conditions.In terms of speed measurement, the data obtained by the LiDAR system is very close to the results measured by the traditional speed gun, with a very small margin of error between the two as shown in Figure 9. According to the graph, the difference between the two methods does not exceed 1 km/h, indicating that the LiDAR system has a very high speed measurement accuracy within this range.

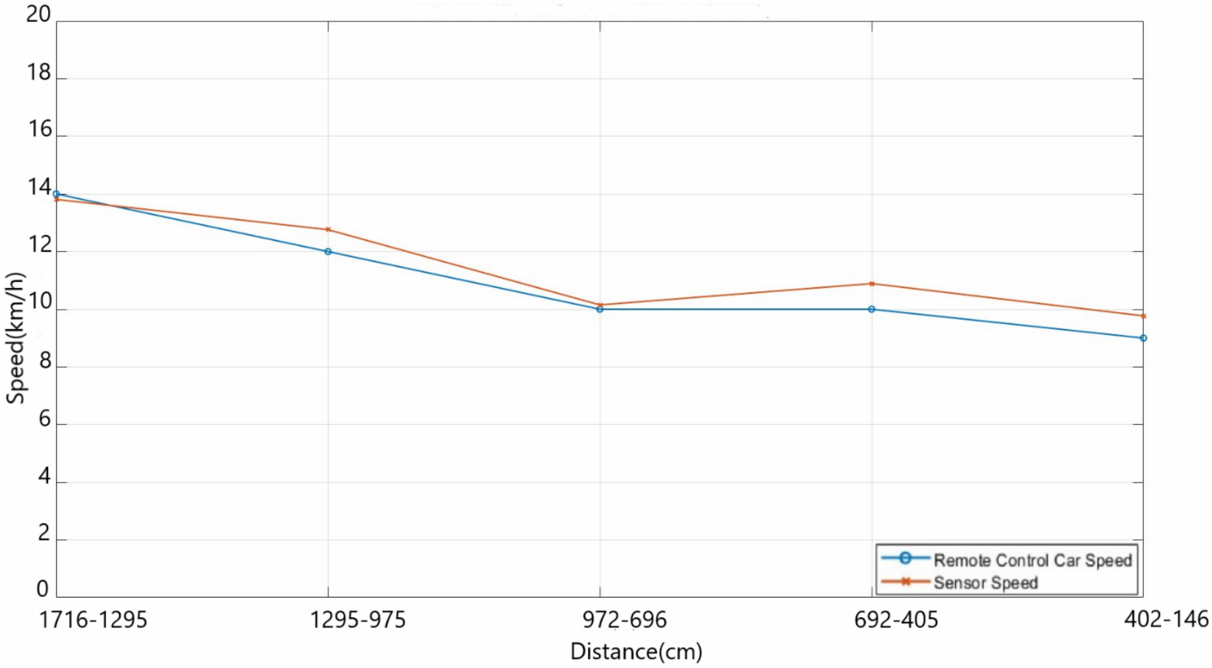

Fig.9.Speed difference for the speed between 8 to 14 km/h

2. Speed greater than 15 km/h but not reaching the safety distance

When the speed of the remote-controlled car exceeds 15 km/h, the airbag system will not activate if the condition of the vehicle being closer than the safety distance is not met. This is because the trigger condition for the airbag depends not only on the vehicle's speed but also on the distance between the vehicle and the measuring device. When the speed exceeds 15 km/h, the airbag will only be triggered if the vehicle is too close, i.e., if the distance is less than the set safety distance.As clearly shown in the Figure 10, since the remote-controlled car did not meet both trigger conditions during the test—i.e., the speed was greater than 15 km/h and the vehicle's distance was less than the safety distance—the airbag did not deploy. In this case, the LiDAR system continued to measure and detect the vehicle’s speed and distance, and its measurement results were highly similar to the data obtained by the speed gun.

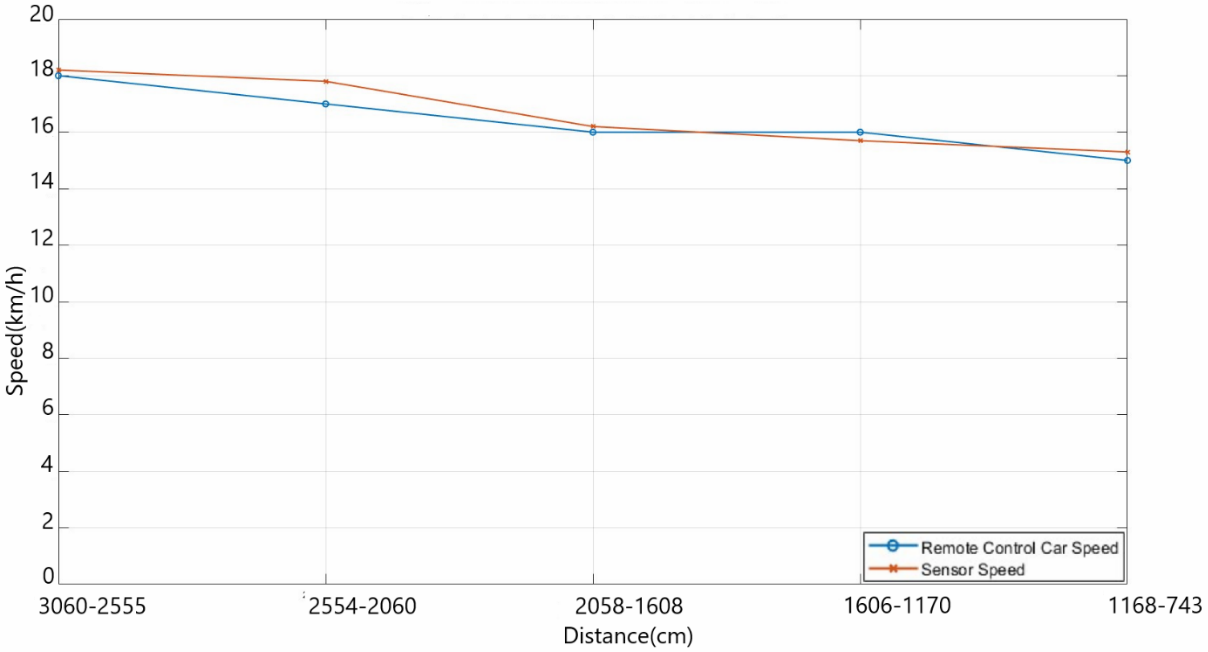

Fig.10.Speed difference for the speed greater than 15 km/h but not reaching the safety distance

3. Speed greater than 15 km/h and less than the safety distance

When the LiDAR output data simultaneously meets the conditions of the vehicle’s speed being greater than 15 km/h and the distance between the vehicle and the measuring device being less than the safety distance, the airbag system will immediately activate. In this case, the coil of the relay is energized, driving the solenoid valve to open, allowing the airbag to rapidly inflate and be ready to provide safety protection. At this point, the LiDAR will stop outputting measurement data, as the system has determined that there is a collision risk.As clearly shown in the Figure 11, once the distance between the vehicle and the measuring device reaches 685 cm, the LiDAR system’s output data immediately drops to zero. This data shows the behavior of the LiDAR system after the trigger conditions are met. Specifically, when the vehicle's distance from the measuring device is less than or equal to the safety distance, the LiDAR stops outputting data, indicating that the airbag system has been triggered and is in protective mode.

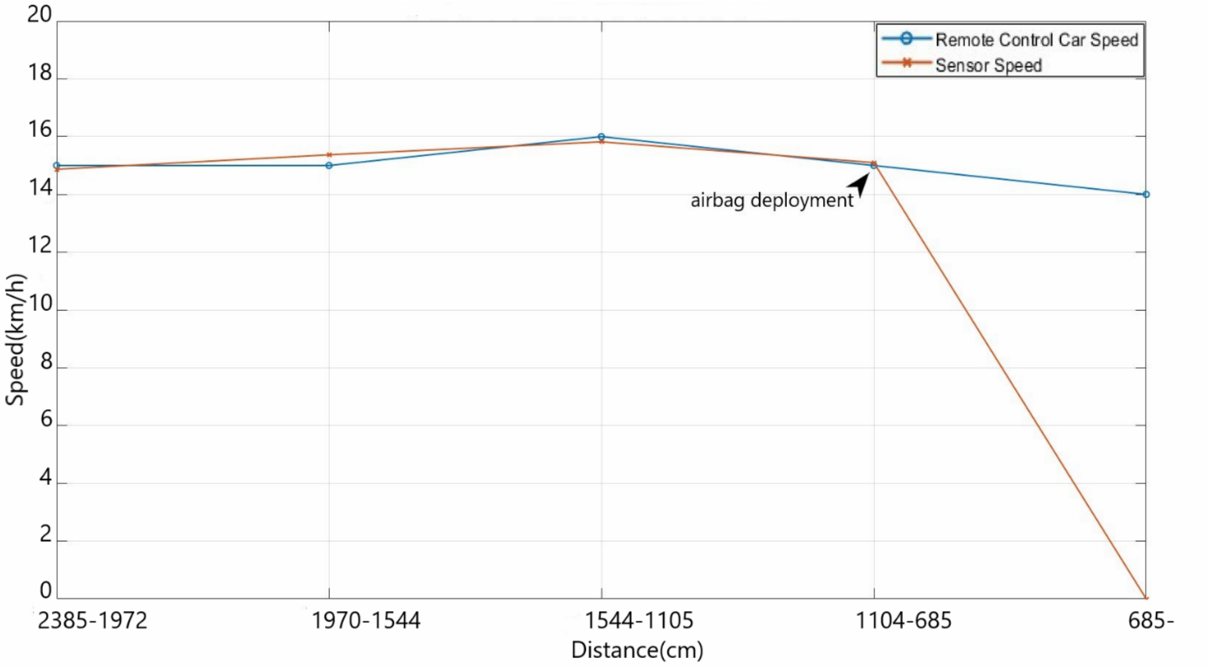

Fig.11.Speed difference for the speed greater than 15 km/h and less than the safety distance

IV. CONCLUSIONS

The goal of this experiment is to design and validate a system capable of detecting rear-end collision risks. The core of the system relies on advanced sensing technologies, such as LiDAR, to monitor the distance and speed changes of vehicles behind in real time, allowing the system to assess the potential collision risk. The key to this system is its ability to respond in the shortest time, activating the airbag system in advance to provide immediate protection and reduce the risk of injury to both passengers and the driver in the event of a collision.In order to minimize the potential injuries from rear-end collisions to passengers and the driver, the system needs to be optimized with appropriate airbag parameters, such as internal pressure, airbag thickness, deployment timing, and deflation timing. These parameters must be precisely adjusted to ensure effective protection for the occupants.In the future, the application of this rear-end collision risk detection system can be further expanded by adding additional features, such as vehicle recognition for neighboring lanes. This feature would enable the system to not only trigger safety devices like airbags when a collision is imminent but also monitor the surrounding environment in real time. This would provide more options for avoiding collisions, helping drivers react and prevent accidents in dangerous situations.

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