Truck blind spot sensing alarm system

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Abstract

As autonomous driving technology advances rapidly, accidents caused by blind spots in large trucks have become increasingly common. To reduce such incidents, a blind spot detection and alarm system for large trucks has been developed, utilizing ultrasonic radar/millimeter-wave radar combined with AI intelligent cameras. This system can detect targets entering the blind spots in real time. When a vehicle enters the left or right blind spot, the ultrasonic radar/millimeter-wave radar immediately detects it and alerts the driver via warning lights, enhancing safety. Meanwhile, the AI intelligent camera captures the road environment, automatically detecting moving objects in the front and rear blind spots, and issues warning messages through text and voice prompts to remind drivers to avoid them, effectively reducing the risk of traffic accidents caused by blind spots.

Keywords

Ultrasonic radar, millimeter wave radar, large trucks, blind spots, induction.

1. Introduction

Currently, autonomous driving technology is advancing rapidly, yet large trucks remain the primary culprits behind major traffic accidents, often seen as "road killers." Most accidents involving large trucks are related to "blind spots." It is necessary to develop a device that can detect targets entering these blind spots and also signal drivers to minimize traffic accidents as much as possible.

The blind spot detection and alarm system for large trucks employs a combination of ultrasonic radar/millimeter-wave radar technology and AI smart cameras to detect targets entering the blind spots of the field of view. When a vehicle enters the left or right blind spot, the ultrasonic radar/millimeter-wave radar can immediately detect it and alert the driver via warning lights, enhancing safety assurance. The AI smart camera captures the road and its surroundings in real time, automatically detecting any vehicles or other moving objects within the drivers blind spot on both sides. If such an object appears within this range, it issues a warning message and alerts the driver to avoid them through text and voice prompts.

2. Research contents

Currently, heavy truck blind spot detection and alarm systems use one or more cameras installed in the vehicles rearview mirror. When a camera detects target information, it alerts the driver through audio or visual signals. Another method involves installing pairs of ultrasonic radars on both the front and rear wheels of the vehicle. If the radar detects an object nearby, the cabin will issue audio-visual alarms to alert the driver to avoid obstacles. There is also a method that projects lights from the vehicle to warn pedestrians or other vehicles, which is more suitable for nighttime driving environments using flashing lights or red light patterns. However, these methods rely solely on single cameras or radars to detect obstacles within a small range around the vehicle, often leading to false alarms when there are obstacles that do not pose a collision risk with the heavy truck. This results in low accuracy and requires

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continuous operation for extended periods, significantly increasing the energy consumption of the system.

The blind spot sensing alarm system device introduced in this paper adopts conditional control switch, obtains external information through Angle alarm and distance alarm, uses the fast calculation ability of microprocessor controller to predict the vehicle driving trajectory and make collision judgment, and finally carries out sound and light alarm to remind drivers, pedestrians or other vehicles to pay attention to each others avoidance.

The system integrates advanced equipment such as an AI control panel, high-definition LCD screens, and dual voice alarms, aiming to enhance stability and reduce risks. The millimeter-wave radar sends real-time detection information, which is received and analyzed by the AI control panel. A single button on the output port of the control panel sends a processing command, which is clearly displayed on the high-definition LCD screen. At the same time, the buzzer alarm and external dual voice alarms provide real-time warnings to truck drivers and surrounding personnel.

2.1. Alarm type selection

In the selection of truck blind spot alarm types, millimeter-wave radar alarms are an excellent choice. Millimeter-wave radars offer stable detection performance, long operating distance, and good environmental adaptability. Compared to ultrasonic radars, millimeter-wave radars also feature smaller size, lighter weight, and higher spatial resolution. Compared to optical alarms, millimeter-wave radars have strong penetration capabilities through fog, smoke, and dust, providing all-weather and all-time protection. In truck blind spot monitoring systems, millimeter-wave radar alarms can accurately detect and identify objects at both low and high speeds, offering comprehensive safety protection. Technical parameters of millimeter-wave radars are listed in Table 1.

Table 1. Technical parameters of millimeter wave radar

Name	Technical parameters
Operating Voltage	24V
Operating Temperature	-40~85℃
Detection Range	60m
Dustproof and Waterproof Rating	IP67
Operating Frequency	24GIlz
Detection Angle (Horizontal)	110°
Detection Angle (Vertical)	20°
Angle Measurement Accuracy	2rms°
Response Time	100ms
Relative Speed Range	-180~180km/h
Relative Speed Accuracy	±0.2km/h
Relative Speed Resolution	0.4m/s

2.2. Alarm layout and optimization

The switch detection module of this device primarily monitors the on/off status of the right turn signal for heavy-duty trucks. The steering angle detection module uses a vehicle steering

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angle alarm, which is installed on the steering shaft to obtain information about the vehicles steering angle, providing data for algorithm calculations. To improve the accuracy of relative position detection, two 24kHz millimeter-wave radar alarms are mounted on both sides of the vehicle body, continuously detecting the relative position between the vehicle and obstacles. The control module employs an STC89C52RC microcontroller to process the data transmitted from the steering angle alarm and the millimeter-wave radar alarm accordingly. To achieve simultaneous alarms inside and outside the vehicle, enhancing the intuitiveness of the alerts, the in-vehicle alarm uses red, yellow, and green LED lights or an LCD screen, while the out-of-vehicle alarm uses a red, yellow, and green audio-visual alarm.

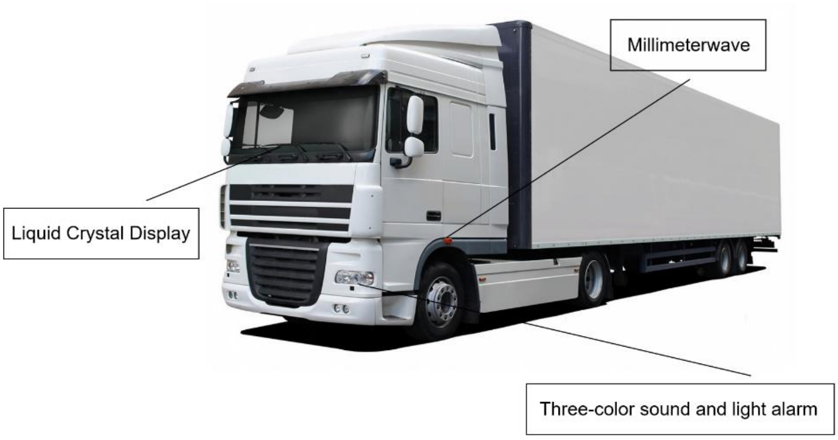


Figure 1. Installation of truck alarm

2.3. Data processing algorithm

2.3.1. 1 Sub-section Headings

The laser ranging radar and ultrasonic ranging alarm are used to identify the path and obstacles in front of the robot. In the laser ranging radar, at least two radars are needed as alarms to ensure the accuracy of the identification results

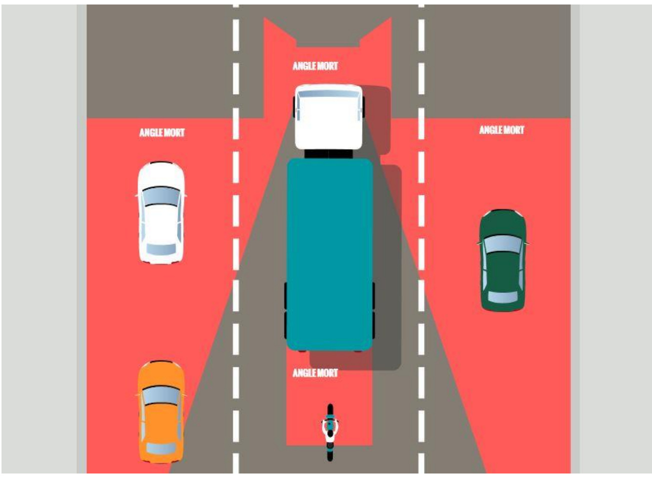


Figure 2. Truck alarm detection range

The ranging direction of lidar is basically the same as the driving direction. However, if there is only one radar device, its identification range in front of the driving direction has certain limitations, which can easily cause obstacles identification loopholes. The multi-scale model of grid map established by lidar is expressed as:

$$H^{k}_{pre}(x,y)=\max H_{msp}(x_i,y_i)$$

X and y are the coordinate values on the x-axis and y-axis, respectively; Hmsp(xi, yi) represents the probability mapping value of the grid where the coordinates are located, with xi and yi being the returned coordinate values. Ultrasonic ranging technology can more accurately detect obstacles in front of the vehicle, thus consuming more energy compared to LiDAR. By using these two intelligent positioning alarms, real-time trajectory mapping and positioning results can be obtained, while also analyzing the covariance matrix of residual terms to identify and recognize obstacles ahead of the robot.

2.3.2. Obstacle location

Combining the LiDAR alarm and ultrasonic positioning alarm, we can obtain the coordinate of the symmetric signal node between the robot and the obstacle, represented as (-k, 0, 0) and (k, 0, 0), respectively. At this point, the coordinate of the center point is (0, 0, 0). Through the signal source, we can determine the relative geometric relationship between the robots current position and the coordinates of the obstacle:

$$\begin{cases} (k-y_i)^2 + X_c^2 = X_d^2 \\ (k+y_i)^2 + X_c^2 = X_a^2 \\ y_i^2 + X_c^2 = X_b^2 \end{cases}$$

In the formula: (xi, yi, zi) represents the center coordinates of the obstacle point obtained from the alarm; Xa and Xb represent the coordinates of the two signal processing centers to the front and rear of the obstacle point, respectively; Xc andXd represent the coordinates of the left and right sides of the obstacle point from the signal processing center. Through this geometric relationship, the position coordinates of the obstacle point are linearized, resulting in the observation equation for the position vector:

$$\boldsymbol{F}_k(t) = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & -\sin\alpha & -\cos\alpha & 0 & 0 \\ 0 & 0 & \cos\alpha & \sin\alpha & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

In the formula: Fk(t) represents an uncertain covariance observation matrix, which can serve as the observation equation for position; α is the angular deviation between the obstacle point and the robot, i.e., the angle deviation from the robots front direction to 0°. The distance between the robot and the obstacle point is then:

$$X_{ij} = \frac{f_c(t_p - t_k)}{2}$$

In the formula: Xij represents the straight-line distance between the robot and the obstacle point; Fig.1 Radar range radar 1 travel direction robot v radar 2 artificial intelligence and robot 49 Automation&Instrumentation 2023,38 (1) represents the speed of the transmitted signal; tp and tk are the precise times for lidar ranging and ultrasonic ranging, respectively. Based on the above angles and distances, the positioning coordinates of the road obstacle relative to the robots current position can be obtained.

2.3.3. Intelligence Fusion

Through the weighted average method, the information obtained by different intelligent positioning alarms can be assigned weights, and more accurate measurement coordinates can be obtained. Let the state equation and observation equation in the whole measurement system be:

$$\begin{cases} D(t)=\dfrac{\alpha_t D(t-1)+\delta_t K(t)}{Z(t)} \\ P(t)=\dfrac{\eta_t D(t)}{v(t)} \end{cases}$$

In the formula: D(t) and D(t-1) represent the systems state at the current moment and the previous moment, respectively, with t being the current time of the system; K(t) denotes the control coefficient of the systems state; Z(t) represents the noise coefficient during the systems operation; αt and δt are parameters for observing the system gain and linear recursive parameters, respectively; P(t) is the observation value of the system at time t; v(t) indicates the operating speed of the system at time t. Based on this equation, the variance of the weights can be obtained:

$$E_p=\frac{P(t)}{k_i^2\sum_{i=1}^{n}\frac{1}{k_i^2}}+D(t)$$

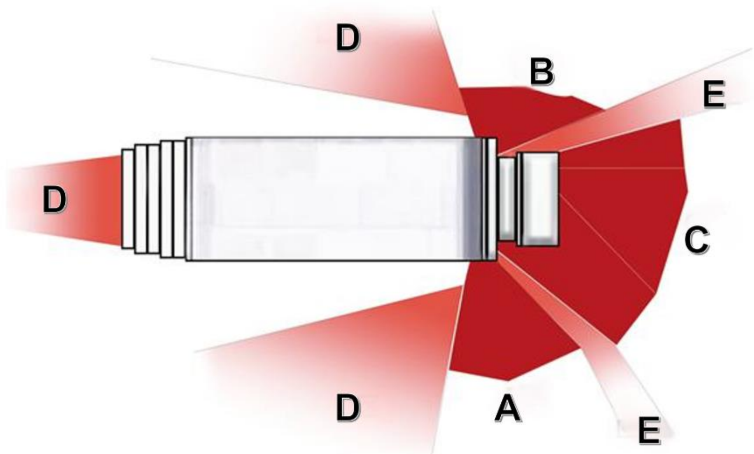


Figure 3. Blind spot diagram of truck operation

2.4. Technological innovation points

2.4.1. Millimeter wave radar and ultrasonic radar joint technology is adopted

The principle of ultrasonic radar operation is to emit ultrasonic waves outward through an ultrasonic transmitter and measure the distance based on the time difference between the emission and reception by a receiver. Ultrasonic waves have strong penetration capabilities, low cost, but a limited monitoring range. Millimeter-wave radar operates at high frequencies, offering high detection accuracy, high spatial resolution, and long detection distances. This system analyzes the blind spots and usage conditions of heavy trucks, employing a layout and control strategy that integrates millimeter-wave radar and ultrasonic radar. This approach reduces costs while maintaining a detection range for blind spots, effectively alerting drivers to dangers on the right side of the vehicle.

The ultrasonic radar controller and the millimeter-wave radar controller both use the trucks 24V power system. The controllers are connected via CAN lines, with the ultrasonic radar controller communicating with the entire vehicle through the CAN network. The controller receives and processes obstacle information transmitted by the radar in real time. It acquires data on vehicle speed, gear signals, wiper signals, headlight signals, right turn signal, and steering wheel angle through the CAN network to determine the current driving status and environmental conditions such as rainy or evening weather. Further internal algorithms effectively identify obstacles and output warning signals from indicator lights or buzzers. The driver can turn the blind spot monitoring system on and off using a control switch.

A, B and C zones: semi-blind zone, the danger range is determined by the size of the vehicle.

Zone D: The total blind zone is outside the drivers direct line of sight and the three rearview mirrors

Zone E: Total blind area, which is blocked by the A-pillar on both sides of the windshield.

As shown in the figure, the blind spot at the front of the truck is not significant, and there are front and rear wide-angle mirrors to observe the semi-blind spots ABC. The right side and rear of large trucks have larger blind spots, making them the most dangerous areas for pedestrians. The left side has relatively smaller blind spots, but it also has two smaller blind spots, such as the DE area. Additionally, due to differences in the shape of windows, mirrors, and A-pillars across different models, some large trucks may even have larger blind spots.

The ultrasonic radar controller should be installed in the driving room and fixed reliably with screws. According to the actual arrangement of the actual vehicle, the wiring should be arranged reasonably, taking into account the connection direction of the wire harness, paying attention to avoid interference, and waterproof, moisture-proof and dust-proof treatment should be done.

The buzzer is installed in the cab by means of pasting, and the buzzer is placed near the drivers seat to ensure sufficient volume.

The warning light is installed on the right A column or instrument panel of the cab. The indicator light has backlight and can be adjusted to two levels of brightness during day and night. It is controlled by the vehicles headlights signal.

Ultrasonic radar is installed on the vehicles bumper and fender via snap-fit, with an upward tilt angle of 0° and a relative ground height control between 0.7-1m. The millimeter-wave radar is mounted at the rear right position behind the right wheel arch, secured to the vehicle body with a mounting bracket. There is no obstruction in the rear direction, ensuring that the radar has a horizontal angle of 45°±1° and an upward tilt angle of 0°, with a relative ground height control of 1.2-1.8m.

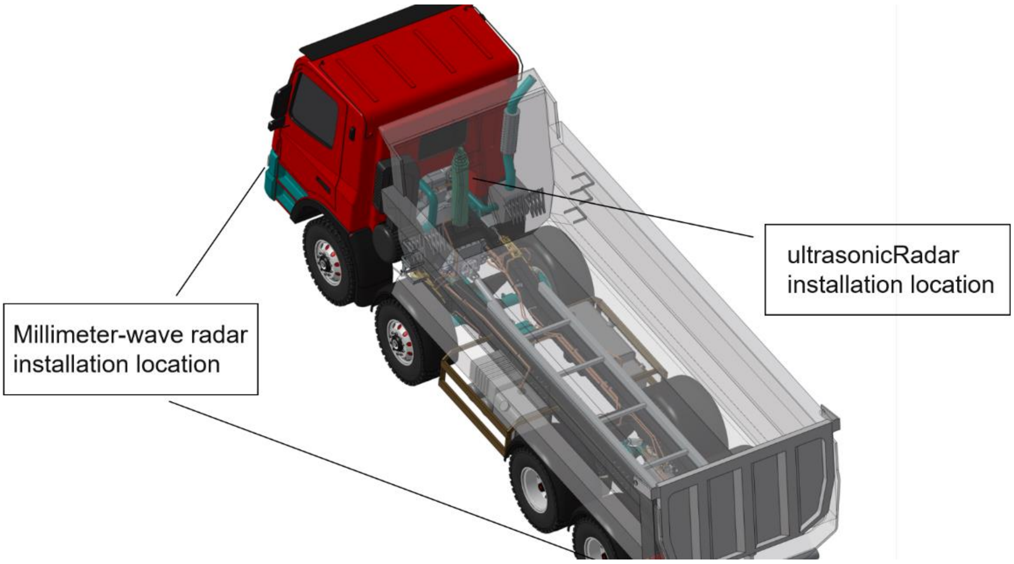


Figure 4. Truck radar installation diagram

2.4.2. Use temperature sensing control device

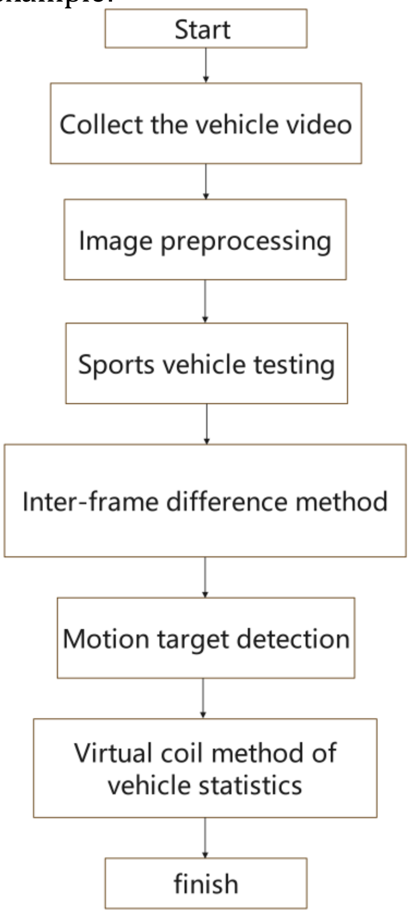
In addition, the temperature sensing control system is added, and the device shell is made of insulating material to avoid the influence of the external environment, so as to avoid the error caused by the unstable instrument temperature due to weather and outdoor temperature.

The temperature sensing control system can monitor the temperature around the truck and adjust the operating parameters of the radar sensor based on temperature changes. For example, in high-temperature environments, the detection range of the radar sensor may be affected to some extent. At this time, the temperature sensing control system can automatically adjust the transmission power and reception sensitivity of the radar to ensure stable performance even in high-temperature conditions.

Adding aerogel and glass fiber, such insulating materials, to the alarm system can effectively block external heat interference. These two materials have a weak blocking effect on radar, allowing signals to pass through safely with minimal impact on blind spot detection in real situations. Additionally, adding an external constant temperature control device can manage extreme temperatures.

2.4.3. AI intelligent image algorithm is adopted

Take the obstacle vehicle as an example:



The detection of moving vehicles is a critical step in achieving vehicle statistics. To accurately extract background frames from the background images of videos, a Gaussian Mixture Model (Gaussian Mixture Model, GMM) has been introduced this time. Typically, this model consists of N Gaussian functions, where the probability P(Xt) that a pixel (x, y) at any time t takes value I(x, y) is expressed as:

$$P(X_t)=\sum_{i=1}^{N}\omega_{i,t}\eta_t(X_t,\mu_{i,t},\mathrm{cov}(i,t))$$

$$\eta_t(X_t,\mu_{i,t},\operatorname{cov}(i,t))=\frac{1}{(2\pi)^{\frac{d}{2}}\left|\operatorname{cov}(i,t)\right|^{\frac{1}{2}}}e^{-\frac{1}{2}m(\operatorname{cov}(i,t))^{-1}}$$

$$m=(X_t-\mu_{i,t})^{\mathrm{T}}(X_t-\mu_{i,t})$$

In the formula, μi, t is the mean; cov(i, t) is the covariance matrix, and d is its dimension. After each frame of the video is input into the model, the parameters are updated as follows:

$$\begin{cases}\mu_{i,t}=(1-\beta)\mu_{i,t-1}+\beta X_t\\ \sigma_{i,t}^2=(1-\beta)\sigma_{i,t-1}^2+\beta m\\ \omega_{i,t}=(1-\alpha)\omega_{i,t-1}+\beta X_t\end{cases}$$

In the formula, σ2 i, t is the standard deviation; α and β are the corresponding learning rates. After parameter update, the pixel of the frame image is matched with the Gaussian function, and the matching condition is as follows:

$$\left|X_t-\mu_{i,t-1}\right|<2.5\sigma_{i,t-1}$$

If the matching conditions are not met, only the weights between the Gaussian functions are updated in this iteration:

$$\omega_{i,t}=(1-\alpha)\omega_{i,t-1}$$

After the background extraction is completed, the motion target and background can be divided. Let B be the distribution of the background, which is expressed as follows:

$$B=\arg\min_b\left(\sum_{i=1}^{b}\omega_{i,t+1}>P\right)$$

Among them, P is the discrimination threshold; b is the accumulation factor. After detecting the moving vehicle in the video frame, the virtual coil method (Virtual Coil Method) can be used to count the vehicle.

3. Research areas and future plans

3.1. Shortage of research

3.1.1. Technical requirement

Wider detection range: Although the current alarm has a certain detection capability, in some special cases, such as bad weather or complex road environment, its detection range may still be limited. Therefore, it is necessary to further improve the detection capability of the alarm to deal with more complex scenarios.

Higher recognition accuracy: Although existing alarms can identify objects in blind spots, their recognition accuracy may be affected in some cases, such as at night or in low-light environments. Therefore, it is necessary to continue optimizing the design and algorithm of the alarm to improve its recognition accuracy in different environments.

3.1.2. Performance conditions

Stronger anti-interference capability: In practical applications, the alarm may be affected by interference from other electronic equipment or signals, affecting its normal operation.

Therefore, it is necessary to enhance the anti-interference capability of the alarm to ensure that it can operate stably in various environments.

Lower energy consumption: Existing alarms may consume more energy when working continuously, which may have a certain impact on the endurance of large trucks. Therefore, it is necessary to study how to reduce the energy consumption of alarms to extend their service life and reduce maintenance costs.

3.1.3. Application conditions

More Robust Regulatory Support: While some regions have introduced policies to encourage the development of intelligent transportation and driving assistance technologies, there are still areas lacking clear regulatory support. This can lead to certain limitations in the promotion and application of blind spot detection alarm systems for large trucks. Therefore, it is necessary to further improve the relevant legal and policy environment to provide stronger support for the use of these alarms.

Wider market awareness: Although the market demand for truck blind spot sensing alarm system is growing, there are still some drivers and logistics companies who do not have enough knowledge about it. Therefore, more publicity and promotion activities are needed to improve the market awareness and acceptance of this technology.

3.2. Future plan

Strengthening technical breakthroughs and personnel training: In view of technical problems, we should strengthen cooperation with other universities, research institutions and enterprises to jointly overcome technical difficulties. At the same time, we should pay attention to the technical training and ability improvement of team members, and cultivate interdisciplinary and composite talents.

Optimize project management process: establish a sound project management mechanism, clarify project objectives and task allocation, strengthen progress control and risk management. Introduce professional project management tools and methods to improve the scientificity and efficiency of project management.

Refine Technical Details and User Experience: In the product development process, focus on handling technical details and optimizing user experience. Through repeated experiments and tests, continuously improve radar layout, algorithm optimization, and user interface design. At the same time, enhance communication with users and feedback mechanisms to promptly adjust product functions and designs.

Develop effective marketing strategies: Tailor effective marketing strategies based on market demand and user characteristics. Enhance cooperation and communication with potential clients such as truck brands and logistics companies to jointly explore business models and profit models. At the same time, leverage channels like trade fairs and forums to increase product awareness and influence.

Establishing industry-academia-research cooperation mechanisms: Strengthen collaboration with universities, research institutions, and enterprises to share technological resources, R&D equipment, and talent. Promote technological innovation and industrial upgrading through joint research and technology transfer. At the same time, focus on intellectual property protection and market expansion to ensure the sustainable development of projects.

4. Conclusion

This paper designs and develops a sensing alarm system for the frequent accidents. By integrating the technical advantages of ultrasonic radar, millimeter wave radar and AI intelligent camera, the system has successfully realized the real-time and accurate detection of obstacles in the blind area of trucks, and reminds the driver to avoid them through warning lights, text and voice, significantly improving the driving safety. In terms of technical research and application, this study adopts the combined technology of millimeter-wave radar and ultrasonic radar, which effectively overcomes the deficiency of detection range, accuracy and environmental adaptability of a single sensor. At the same time, combined with the AI intelligent image algorithm, the system can automatically identify and track pedestrians, vehicles and other obstacles in the blind area, further improving the accuracy and reliability of the early warning. The experimental results show that the system can work stably under different working conditions and effectively reduce the incidence of blind spot accidents. In addition, this study also deeply analyzes the causes and accident characteristics of the blind area of large trucks, which provides a strong basis for the design and optimization of the system. By optimizing the alarm layout, improving the data processing algorithm and enhancing the anti-interference ability of the system, the overall performance of the system is significantly improved. At the same time, this research also considers the marketing and application prospects of the system, and puts forward the strategies of cooperating with enterprises and reducing the research and development cost, which lays a solid foundation for the commercial application of the system.

In conclusion, the blind zone sensing alarm system of large trucks developed in this study has high practical value and marketing potential. The system can not only effectively reduce blind area accidents, ensure road traffic safety, but also promote the development of intelligent transportation system, and contribute to the construction of a safer, more efficient and green traffic environment. In the future, we will continue to optimize the system performance, strengthen the market promotion and application, and make greater contributions to the cause of road traffic safety.

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