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Highway Foreign Body Intrusion Detection System Based on Deep Learning

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Abstract: This paper introduces the expressway intrusion detection system based on deep learning to improve traffic safety. The system adopts deep learning, image recognition, and foreign body detection technology to monitor the road condition in real-time through lidar and binocular camera groups to detect and distance the foreign body on the road. The system visualizes the detection results on the onboard screen to assist the driver to avoid and improve the safety of highway driving. In addition, the system also includes emergency braking, blind spot monitoring, lane departure warning, and other functions. The system has wide application prospects and development potential and is expected to be widely used in the future, providing a strong guarantee for the safe operation of expressways in China.

Keywords: Deep learning; Assisted driving; Traffic safety

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1. Project overview

1.1. Research significance

Today, highways use many intelligent control systems, through the coordination of people, vehicles, and roads, and will support the automatic driving of cars in the future. However, the existing vehicle and road equipment systems are not enough to give warnings and assistance to drivers driving at high speed when sudden and irregular foreign objects invade the road. The foreign body intrusion detection of the expressway will realize the warning treatment of foreign bodies invading the road, which has high reliability, stability, and safety, and has great research significance and social significance.

1.2. Analysis of domestic and international research

In recent years, with the rapid development and application of deep learning in China, highway foreign object intrusion detection has become a hot research field. Domestic universities and research institutions have made some

achievements in this direction. In-depth research on binocular cameras and Generative Adversarial Networks (GAN) has been carried out, and a series of breakthroughs have been made. Currently, binocular stereo-vision technology can be used to measure the distance of the front scene and identify foreign objects through the GAN network (as shown in **Figure 1**). Additionally, progress has been made in the placement of lidar on the roof, which provides an effective solution for distance detection at night or in low-visibility weather.

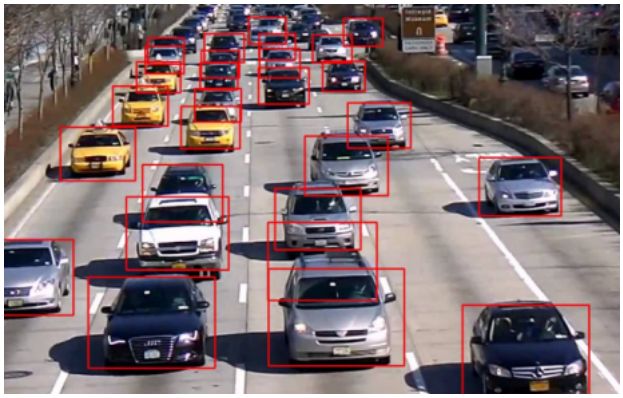

Figure 1. Deep learning based object detection and image recognition

Khan *et al.* comprehensively analyzed the Histogram of Oriented Gradients (HOG) feature and Local Binary Pattern (LBP) feature of the image and used the Support Vector Machines (SVMs) algorithm to detect the vehicle in the region of interest of the image (as shown in **Figure 2**) [1]. Shi *et al.* constructed the CBAM-YOLOv5 model and used the distance intersection ratio non-maximum suppression method instead of the weighted non-maximum suppression method to improve the detection effect of the model on invading targets [2].

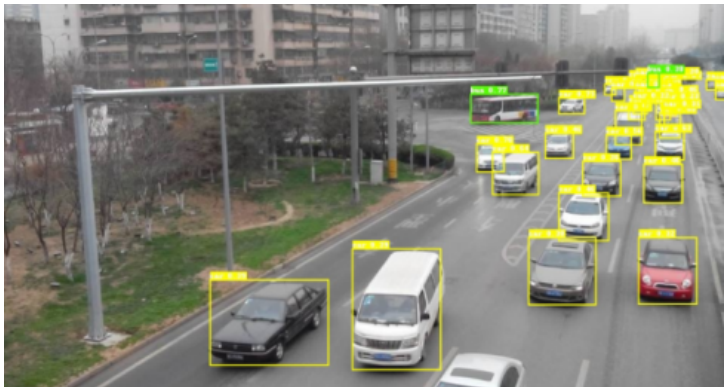

Figure 2. Paddle method for vehicle detection

In general, highway foreign body intrusion detection technology based on deep learning has garnered significant attention and research from universities, laboratories, and enterprises both domestically and internationally. Although there are still some technical challenges, such as dealing with complex environments and improving real-time performance, ongoing research, and technological advancements are expected to yield more innovative solutions in the future, providing enhanced protection for driving safety.

1.3. Research objectives

Given the safety problems that may be caused by foreign objects on the highway, this paper mainly studies the detection and distance measurement of foreign objects on the road and realizes the detection and measurement of foreign objects through deep learning and auxiliary lasers under certain circumstances. The data of the two are displayed on the vehicle screen to assist the driver to avoid and improve the safety of highway driving [3].

2. Technical description

2.1. Foreign body identification

In the practical application process, the relevant technology can be used to realize foreign body recognition. Through semantic segmentation technology, it is possible to extract the road detection area, and then accurately depict the road condition. Firstly, the road image needs to be pre-processed, covering de-noise, grayscale, region growth method, and edge detection, which lays the foundation for subsequent semantic segmentation and target detection. After the pre-processing is completed, the deep learning algorithm can be used for semantic segmentation to extract the road area. Such algorithms are typically based on Convolutional Neural Network (CNN) models such as faster Region-based Convolutional Neural Network (R-CNN), Segment Network (SegNet), Deep Labelling (DeepLab), etc. These models are trained on a large number of road image data and can accurately identify road areas.

After extracting the road area, the road needs to be monitored in real-time to find potential foreign objects. At this time, target detection technology (object detection), such as You Only Look Once (YOLO), Single Shot MultiBox Detector (SSD), R-CNN, etc., can be used to detect these targets. These target detection algorithms have high accuracy and real-time performance in complex environments, and can quickly identify foreign objects. Once foreign objects are detected, corresponding measures can be taken in time, such as early warning, positioning, removal, etc., to ensure road safety and smooth traffic flow [4].

2.2. Offset alert

The lane departure warning system aims to alert drivers who deviate from the lane markings while driving to prevent traffic accidents. The system first detects the lane lines. In **Figure 3** and **Figure 4**, the lane lines are detected from both the input image and the real-time segmentation image.

Figure 3. Input image

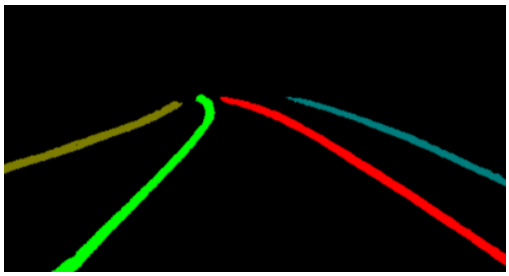

Figure 4. Real-time image segmentation

However, factors such as lighting conditions, weather changes, and camera contamination all impact the image processing algorithm, necessitating continuous adjustment and optimization to ensure the accuracy and stability of the early warning system. In this context, the application of deep learning techniques such as Convolutional Neural Net-

works (CNNs) and Recurrent Neural Networks (RNNs), is particularly important. These techniques can effectively extract image features and identify lane lines, thereby improving the accuracy of early warning systems [5].

Additionally, by analyzing the driver's behavior and the response to the early warning signals, the early warning strategy can be further optimized, and the effectiveness of the warnings can be improved. Simultaneously, integrating the Lane Departure Warning System (LDWS) with other Driver Assistance Systems (DAS) helps build a comprehensive driver assistance system, offering more intelligent offset warnings and enhancing overall driving safety.

3.1. Research content

In-depth research and development of the highway foreign object intrusion detection system will effectively improve the safety of the highway and greatly reduce the traffic accidents caused by foreign object intrusion. The system is mainly divided into the following parts.

(1) Detection module: Real-time monitoring of road conditions by using equipment such as laser radar and binocular camera groups. When an abnormal object is detected, an alarm is issued in time to remind the driver to pay attention.

(2) Data analysis and processing module: The collected monitoring data is collected to the terminal server and processed by the deep learning algorithm to determine whether the foreign body is potentially dangerous. If it is judged to be a dangerous object, the system will automatically trigger warning measures.

(3) Warning module: According to the type, location, and other information of the foreign body, a warning signal is sent to the driver through a mobile terminal such as a mobile phone application or Bluetooth device, or a vehicle terminal is used to remind the driver to take emergency measures such as avoidance.

We plan to utilize deep learning techniques in machine learning to detect foreign objects on highways and assist drivers in taking avoidance measures. To achieve this, we will install an ultra-wide-angle lens and a narrow mirror head in front of the vehicle. The ultra-wide-angle lens is effective for capturing scenes at close range with a broad field of view, while the narrow mirror head is suitable for capturing long-distance scenes. Together, these components will provide both a comprehensive view of nearby surroundings and a detailed observation of distant areas.

We plan to install a set of binocular cameras behind the vehicle. By employing binocular stereo vision, we can determine the distance between the vehicle and foreign objects in the same lane, as well as vehicles in adjacent lanes. This information will be fed back to the driver in real time through the onboard display. The system calculates distance by analyzing the parallax between the two camera images, enabling direct measurement of the scene in front without needing to identify the specific type of obstacle. Consequently, necessary warnings or braking can be implemented based on changes in distance information.

To address the impact of lighting on visual recognition, we will also equip the vehicle with lidar on the roof. This provides an additional layer of distance detection capability, especially useful at night or in low-visibility conditions such as sandstorms, fog, and other extreme weather. The initial approach for foreign object recognition will involve using GANs and YOLO, complemented by relatively small residual networks.

Laser radar, also known as lidar, uses lasers as the carrier. Its working principle involves obtaining distance information by measuring the time difference between the transmitted signal and the echo signal reflected by the target. Due to its small size, high precision, and fast response, lidar is widely used in three-dimensional modeling, terrain mapping, autonomous driving, and other fields. Currently, laser ranging methods are primarily classified

into the pulse method and the phase method, depending on the ranging system used. In the context of detecting foreign objects on highways, lidar offers advantages such as high accuracy, rapid response, and immunity to variations in lighting conditions.

3.2. Key issues

(1) The configuration of the ultra-wide-angle lens and the narrow mirror head must be adjusted to the appropriate working angle to ensure that the distance range can be observed, and strive for simple operation and excellent stability.

(2) The installation and debugging of the binocular camera group is designed to realize the distance judgment function and ensure its stable and normal operation.

(3) Ensure the distance detection of lidar at night or in low visibility weather or extreme weather, and many tests prove its feasibility.

(4) For the production of virtual demonstration animation, to facilitate a more intuitive performance of the use of the system.

3.3. Technical route

3.3.1. Distance measurement

This project plans to use binocular stereo-vision technology to accurately determine the distance between vehicles and obstacles in the same lane and between vehicles and vehicles in adjacent lanes. By processing the image captured by the binocular camera, the parallax is calculated, and the distance measurement is carried out on the scene within the visual range. This technology will facilitate real-time monitoring of surrounding vehicles and obstacles and can provide early warning or automatic braking according to changes in distance. Considering that the highway lighting is weak at night and the recognition ability of binocular cameras is limited, we plan to use lidar technology. Lidar is widely used in three-dimensional modeling, terrain mapping, unmanned driving, and other fields because of its small size, high precision, and fast response speed. At present, according to the different ranging principles, laser ranging methods are mainly divided into pulse method and phase method.

3.3.2. Foreign body detection

In the actual situation, the effective image of road foreign body intrusion is far less than the number of samples required to train the deep learning model. To this end, we plan to use a specially labeled GAN to generate a large number of samples to expand the sample library for deep learning networks. After obtaining a sufficient training set and labeling, we will build a V-Optimized V-Net YOLO (VoVNet-YOLOv5) network to identify foreign objects in the image.

3.3.3. Driving assistance

The measured distance and foreign object detection results are visualized on the vehicle screen so that the driver can make emergency judgments. When the front camera detects a foreign object on the virtual track, the onboard screen will display “Please pay attention to obstacles ahead.” When the driver is about to change lanes and turn on the turn signal, the system automatically measures the distance to the vehicle in the adjacent lane. If the distance is less than the safe range (such as 200 m), the onboard screen will display “The distance to the vehicle behind is too close, please wait for the lane change.” In this way, we have achieved the goal of assisting driving, guiding the driver, and striving to achieve the goal of semi-automated driving without excessive driver reaction.

3.3.4. Emergency braking system

When a potential hazard is identified, the system will automatically take emergency braking measures to avoid a collision. This is due to the real-time monitoring of the vehicle motion state and the close integration with the vehicle dynamics model.

3.3.5. Blind spot monitoring

Through radar technology, the system can monitor obstacles in the blind spot area of the vehicle in real time and warn the driver on the onboard screen.

3.3.6. Lane departure warning

When the vehicle deviates from the original lane, the system will alert the driver by vibrating the steering wheel or issuing an audible warning.

3.3.7. Adaptive cruise control

This function allows the vehicle to automatically adjust its speed according to the road conditions ahead to maintain a safe distance and adapt to different traffic flow rates.

3.3.8. Automatic parking assist

Through the integration of ultrasonic sensors and high-definition cameras, the system can automatically find parking spaces and complete the parking process under the supervision of the driver.

3.3.9. Driver condition monitoring

Through infrared and facial recognition technology, the system can monitor the driver's fatigue and concentration in real-time, and issue warnings or take intervention measures when necessary.

3.3.10. Intelligent lighting system

According to the weather, road conditions, and driver demand, the system can automatically adjust the brightness and range of the lights to improve visibility at night and in bad weather.

3.4. Innovation

(1) Deep learning in machine learning is used to realize the detection of foreign objects on the highway and assist the driver in taking evasive measures. Deep learning has a strong feature extraction capability, and the application of machine deep learning to highway foreign object intrusion detection is pioneering and breakthrough. The binocular stereo vision technology is used to preprocess the visual image and detect the distance of obstacles, which shortens the image processing time.

(2)Using lidar, the lidar detection distance is long, and under low visibility and extreme conditions, the contour recognition ability is strong, which enhances the accuracy and reliability of the whole system.

4. Epilogue

The application of highway foreign body intrusion detection system will effectively reduce the incidence of traffic accidents caused by foreign body intrusion and ensure the safety of people's lives and property. Additionally,

the system will also help improve the operating efficiency of the highway and reduce economic losses. In short, the highway foreign object intrusion detection system has a wide range of application prospects and development potential. With the continuous progress of science and technology, it is believed that these systems will be widely used in the future and provide a strong guarantee for the safe operation of expressways in China.

Disclosure statement

The authors declare no conflict of interest.

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