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Using sensor fusion technology to realize pedestrian recognition and hazard assessment

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Abstract. The prevailing technology for pedestrian recognition in unmanned driving, predominantly reliant on LiDAR, confronts the dual challenges of elevated expenses and limited anti-interference capabilities. To surmount these obstacles, this paper introduces an inventive fusion methodology that harmonizes inputs from visual cameras, 4D millimeter wave radar, and thermal imaging sensors. The advantages and promising development prospects of 4D millimeter wave radar over laser radar are comprehensively elucidated. By leveraging advanced signal processing algorithms, a robust mathematical model is formulated, facilitating the synthesis of information from a multitude of distinctive feature parameters. In tandem, an assessment of the hazard index is executed using the analytic hierarchy process, enriching vehicular safety and driving efficiency. This innovative approach strives to foster the progression of autonomous vehicle technology and expedite its commercial assimilation into the burgeoning autonomous driving market. By harnessing the synergistic capabilities of multiple sensor modalities, the proposed fusion technique not only addresses the existing limitations but also charts a transformative course towards a safer and more efficient autonomous driving landscape. Through the amalgamation of these cutting-edge technologies, this research aspires to carve a path for the accelerated evolution and widespread deployment of autonomous vehicles.

Keywords: autonomous driving, pedestrian recognition, multi-sensor, 4D millimeter wave radar.

1. Introduction

With the rapid development of cutting-edge technologies and concepts in materials science, artificial intelligence, microelectronics, nanotechnology, and other fields, Intelligent autonomous driving has become an inevitable trend in the development of the automotive industry, with broad application prospects and important social value. However, its security issue remains one of the biggest key factors restricting its commercial application. In actual road environments, autonomous vehicles cannot fully perceive and judge road and traffic conditions like human drivers through their senses during driving. Moreover, pedestrians, as one of the most active and uncertain road participants, are often the main factors causing traffic accidents[1]. Therefore, for autonomous vehicles, it has become a crucial issue to identify and predict pedestrian behavior in a timely and accurate manner, and make risk assessments before making emergency response. Pedestrian recognition technology uses sensors to obtain information about the surrounding environment of the car, analyzes the data through computer vision technology, identifies features such as the position and speed of pedestrians, and controls the driving system to make corresponding decisions based on the result.

Traditional pedestrian recognition technology mostly relies on a single sensor based on LiDAR to collect information. The limitation of this method has been unable to meet the needs of driving safety factor in complex urban road environment and extreme weather. Therefore, the new multi-sensor fusion information processing technology has significant research value, and this method can effectively improve the safety level of pedestrian recognition[2]. This article uses a combination of visual cameras, 4D millimeter wave radar, and thermal imaging sensors for information collection and processing. Using a combination of visual cameras and thermal imaging sensors to collect the number, shape, and posture of pedestrians, and using 4D millimeter wave radar to directly collect the distance and relative speed between pedestrians and the vehicle. At the same time, using Analytic Hierarchy Process to establish a hazard index evaluation model, compared to traditional pedestrian recognition techniques, multi-sensor fusion technology has a higher guarantee of safety coefficient.

2. Principles of pedestrian recognition system using 4D millimeter wave radar, camera, and thermal imaging sensor

2.1. Composition of sensor fusion system

The sensor fusion system's component system comprises multiple sensors that collect information from the environment. These sensors then process the gathered data and convert the analog signals into digital signals for further analysis and integration. As shown in Figure 1, after triple analysis by the motion direction analysis module, speed analysis module, and position analysis module, the digital signals are integrated and processed to control alarms and car steering and braking devices. In addition, install a temperature controller to protect the normal operation of the 4D millimeter wave radar.

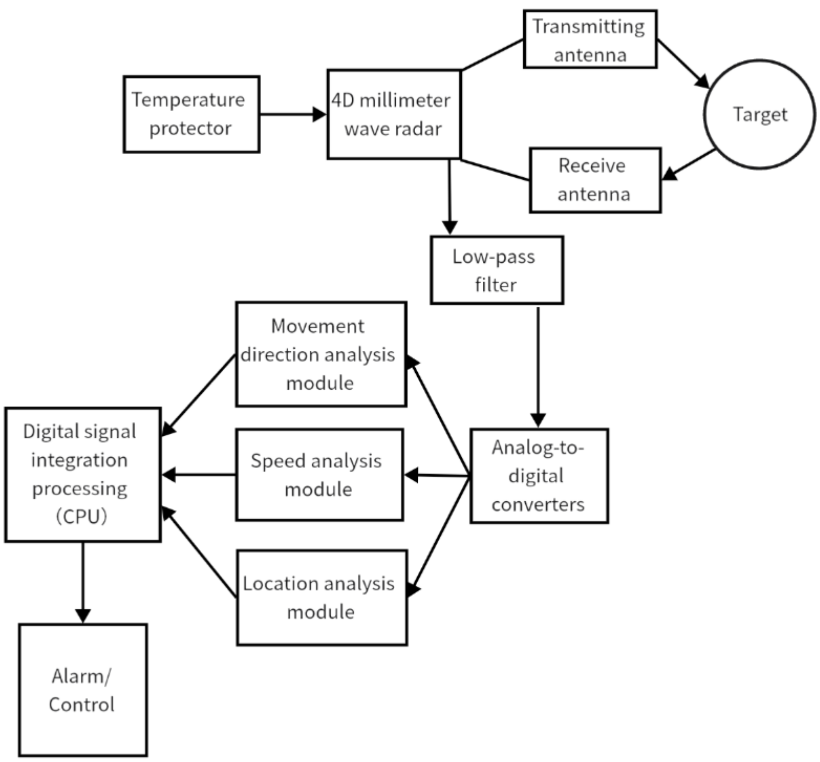

Figure 1. The work task of 4D millimeter wave imaging radar in the system.

Based on the specific requirements of the detection system, the performance parameters of each main component have been determined, and the values of each parameter are shown in the table below.

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Table 1. Component model and parameters.

Part name	4D millimeter wave radar	Camera	Thermal imaging sensors
parameter	-Operating frequency: 905nm -Laser emitters:32 -Horizontal field of view:360 degrees -Vertical field of view: 40 degrees -Horizontal angular resolution: 0.1 degrees -Vertical angular resolution: 0.4 degrees -Maximum range: 200 meters -Minimum range: 0.1 meters -Maximum speed range: 120 m/s -Minimum speed range: 0.01 me/s	- Sensor type: CMOS - Effective pixels: 1920 x 1208 - Pixel size: 2.45μm x 2.45μm - Maximum frame rate: 60fps - Dynamic range: approximately 120 dB - SNR (signal-to-noise ratio): approximately 60 dB - Spectral response range: 400nm-1000nm - Supply voltage: 1.8V (core), 2.9V (analog)	- Thermal imaging resolution: 160 x 120 - Temperature sensitivity: <50mK - Pixel size: 12μm - Image refresh rate: 9Hz or 30Hz - Thermal imaging type: uncooled - Focal length: 6.2mm or 9mm - Field of view: 45 degrees or 32 degrees - Power consumption: <150mW - Output format: programmable SPI digital output - Operating temperature range: -20°C to +50°C - Size: 21mm x 21mm x 11mm

2.2. Function analysis of each component of pedestrian recognition system

Firstly, by using a visual camera to provide clear and accurate image information most intuitively, combined with deep learning to determine the next step of pedestrians and control the car to respond. At the same time, the fusion of point cloud data from 4D millimeter wave imaging radar and camera image data allows for 3D real-time modeling of the complex surrounding environment, enabling precise monitoring of the distance, position, speed, and direction of pedestrian targets. To ensure continuous monitoring, thermal imaging sensors are also incorporated, enabling the system to visually display the surface temperature field of objects, including pedestrians. This provides pedestrian information round-the-clock, reducing the impact of extreme weather conditions and complex road environments on the camera's recognition capabilities.

2.3. Comparison between 4D millimeter wave radar and LiDAR

The pedestrian recognition system with 4D millimeter-wave radar established in this paper still has some gaps in its imaging effect compared with the current commonly used LIDAR-centered technology. Conventional 77GHZ 4D millimeter wave radar has a wavelength of 3.9mm while LIDAR is 905nm, 1550nm, not only that, the angular resolution of 0.1 degree and more number of point clouds make LIDAR far more accurate and resolved than 1 degree of 4D millimeter wave radar. Therefore, the latter needs to work in tandem with the help of visual cameras to cross-reference corrections.[3]

However, the biggest problem with LiDAR is how the internal mechanical rotating components can ensure durability in various bumpy scenarios of the car under the premise of extremely high precision requirements. In contrast, cameras and millimeter waves do not have this problem. 4D millimeter wave radar is solid state without any mechanical parts, so its service life and maintenance costs are more advantageous compared to LiDAR. According to Torsten Lehmann, the executive vice president and general manager of the RF processing business unit at NXP Semiconductors, the advancement of 4D millimeter-wave radar technology has led to remarkable achievements. This radar can achieve an impressive detection range of up to 300 to 350 meters, allowing for extensive coverage. Furthermore, it

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possesses the unique capability to accurately map the environment in 4D, providing a high resolution similar to that of lidar. Additionally, the 4D millimeter-wave radar can generate a clear and comprehensive point cloud array simultaneously, resulting in an enhanced perception of the surroundings[4]. This study aligns with the notion that 4D millimeter-wave radar is on the path to becoming the mainstream technology for pedestrian recognition.

3. Methodology

3.1. Calculate data collected by 4D millimeter wave radar

Assuming that the 4D millimeter wave radar emits electromagnetic waves with a frequency of f, the distance between pedestrians and the radar is d, the speed of pedestrians is v, and the phase difference between the electromagnetic waves reflected by pedestrians and the emitted electromagnetic waves is ϕ, then:

$$\phi = 2\pi \frac{2d}{\lambda} + 4\pi \frac{vT}{\lambda} \tag{1}$$

where λ is the wavelength of the electromagnetic wave, and T is the time difference between transmitting and receiving the electromagnetic wave.

It can be seen that the phase difference ϕ contains the distance and speed information of the pedestrian.

The distance between the traveler and the radar d is calculated from the phase difference ϕ :

$$d = \frac{\lambda}{4\pi}\phi \tag{2}$$

Derive the phase difference ϕ from time t to obtain pedestrian speed information:

$$v = \frac{\lambda}{4\pi T}\frac{d\phi}{dt} \tag{3}$$

Among them, $\frac{d\phi}{dt}$ represents the derivative of phase difference with respect to time,

which can be calculated through signal processing algorithms. This formula can simultaneously calculate the location and speed information of travelers, so it can be used to measure 4D millimeter wave radar.

When the point cloud information is sufficiently rich, 3D or 2D networks such as Voxelnet, Center Point, Point Plar, etc. are used for feature extraction and recognition. Through deep learning training system, establish reasonable thresholds for pedestrian height, weight, and movement speed. When the parameters of the tested object meet the threshold range, the system confirms that the tested object is a pedestrian.[5]

4. Process and result

After confirming that the identified object is a pedestrian, the Analytic Hierarchy Process (AHP) is used to evaluate the hazard index.

Step 1: Establish a hierarchical structure

Target level: Reduce pedestrian hazard index.

Factor level: distance between people and vehicles, speed, relative direction of movement between people and vehicles, whether pedestrians pose a danger, and the number of pedestrians around them.

Step 2: After obtaining specific conditions, construct a judgment matrix

Construct a 5-by-5 judgment matrix A, where A_{ij} represents the importance of the i-th factor relative to the j-th factor, which satisfies the following conditions:

$A_{ij} = 1/A_{ji}$, Namely, matrix A is a reciprocal matrix, $A_{ii} = 1$, the importance of any factor relative to itself is 1.

Construct a judgment matrix A using the 1-9 scale proposed by Saaty, where 1 indicates that two factors are equally important, 3 indicates that one factor is slightly more important than the other, and

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so on. The larger the value, the more important the former is. The middle numerical value can be used to express the relative importance between two factors.

Step 3: Calculate weights

According to the calculation formula of Analytic Hierarchy Process, a 5-dimensional column vector $w = (w_1, w_2, w_3, w_4, w_5)$ is obtained, where w_i represents the weight of the i-th factor. This column vector can be obtained by calculating the eigenvectors of the judgment matrix A.

Use Python's numpy library to calculate feature vectors. Run the code to obtain feature vector w.

And determine the order of importance of each factor (distance between people and vehicles, speed between people and vehicles, number of pedestrians around, relative direction of movement between people and vehicles, whether there is a danger in pedestrian posture) in reducing pedestrian hazard index.

After the framework is completed, calculate the scores for each factor.

Standardize the scores of each factor within the $[0,1]$ interval and calculate the scores of each factorss_i:

$$s_i = \frac{w_i}{\sum_{j=1}^{5} w_j} \tag{4}$$

Weigh and sum the scores of each factor with their corresponding actual values to obtain a comprehensive score.

Assuming the actual value of the i-th factor is x_i, the comprehensive score of the pedestrian hazard index is:

$$score = \sum_{i=1}^{5} s_i \cdot x_i \tag{5}$$

Among them, s_i represents the score of the i-th factor.

After obtaining the comprehensive score of the danger index, the data processing unit will compare it with the present danger threshold. If the index exceeds the danger threshold, the system will control the car's steering or braking to avoid danger [6].

5. Discussion

The 4D millimeter wave in this system may need improvements in the antenna to increase its angular resolution if it wants to improve its accuracy, and developers will need to fabricate vast arrays and develop specialized processors, which will cope with the high throughput of data. The data pre-processing system should be further improved for the initial collected information. For example, since the sensor mounting position and angle of a driver less vehicle may be biased, the data needs to be corrected to ensure accuracy. For image data, camera calibration methods can be used to calibrate the internal and external parameters of the camera to correct lens distortion and camera posture issues. In order to improve the accuracy of pedestrian recognition, image data can be enhanced, such as enhancing contrast, sharpening the image, removing the background, and so on [2]. At the same time, a series of complete upgrades to the system's digital to analog converters and processors still require a lot of time[7].

6. Conclusion

In conclusion, the integration of the three distinct sensors—4D millimeter wave radar, vision camera, and thermal imaging sensor—through fusion technology significantly amplifies the perceptual sensitivity and scope of unmanned pedestrian recognition systems. This augmentation translates into enhanced pedestrian detection accuracy, predictive capability concerning pedestrian behaviors, and a marked elevation in responsiveness, processing robustness, and fault tolerance.

Nevertheless, it is imperative to acknowledge the boundaries of this study. Despite the promising outcomes demonstrated by the proposed fusion approach, there exists a need for further exploration to address potential complexities associated with sensor synchronization, seamless data amalgamation, and real-time processing within intricate and dynamic environments. Future investigations should be dedicated to refining the fusion algorithms, ensuring the optimal integration of diverse sensor outputs and ultimately fortifying the comprehensive system's efficacy.

Furthermore, an essential avenue for future inquiry pertains to the cost-effectiveness and scalability of introducing the suggested fusion technology into the realm of commercial autonomous vehicles. Understanding the economic viability and potential scalability challenges will play a pivotal role in determining the feasibility of widespread adoption within the industry. This research has initiated a compelling trajectory towards advancing the capabilities of pedestrian recognition in autonomous driving, yet its transformation into practical solutions necessitates continued dedication to addressing these nuances, refining methodologies, and aligning with the dynamic landscape of autonomous vehicle development.

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