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Research Status of Acoustic Digital Twin System and Its Prospect in the Field of Autonomous Driving

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Abstract: Two-dimensional arrays of bi-component structures made of cobalt and permalloy elliptical dots with thickness of 25 nm, length 1 m and width of 225 nm, have been prepared by a self-aligned shadow deposition technique. Brillouin light scattering has been exploited to study the frequency dependence of thermally excited magnetic eigenmodes on the intensity of the external magnetic field, applied along the easy axis of the elements.

1. Introduction

Automotive assisted driving technology is an important milestone in the automotive industry towards intelligent driving. Multi-sensor fusion technology helps drivers make better driving decisions and avoid driving hidden dangers caused by visual blind spots. At present, the common automotive assisted driving systems in the automotive industry integrate sensor assemblies such as optical radar, depth camera array, ultrasonic sensor array and millimeter-wave radar system [1]. These sensors can accurately provide drivers with detailed driving information in conjunction with high-precision electronic geographic maps. However, when these sophisticated sensors are faced with rain, snow, hail, dust or dense grass, the driver will be confused about the driver assistance system due to the false triggering of the sensor [2]. To avoid providing wrong driving information to the driver, car manufacturers will Turn off driver assistance systems in bad weather. Losing the driver assistance system in a bad driving environment is a great challenge to the driver's psychology and driving skills. In heavy rain and snow, drivers often have traffic accidents due to limited vision and the loss of the driver assistance system [3]. Therefore, it is particularly important to find a new assisted driving solution and make the sensor system of the car assisted driving more robust.

Under the extreme conditions of limited vision, traditional in-vehicle driving assistance devices cannot accurately provide accurate information to the vehicle, so the assisted driving system based on real-time analysis of the sound field has very high research value [4]. Acoustic digital twin system is an emerging field that integrates sensor real-time processing system [5] and digital simulation system [6], especially it has great potential in the fusion of many distributed acoustic sensor signals and time-to-temporal sound field analysis. The digital twin system has received extensive attention from the engineering community since it was first used in the maintenance of fighter jets by the US Air Force Research Laboratory (AFRL) in 2013 [7]. The digital twin system realizes two-way real-time interaction between online simulation and offline operation by building the same physical model as external equipment in the digital system [8,9]. The autopilot system needs to analyze the external situation from time to time and help the driver make optimal driving decisions, while the digital twin system can deduce many driving plans through AI in the digital twin system to increase the safety and reliability of driving decisions.

In terms of autonomous driving, based on the digital twin technology, the acoustic sensor array can be efficiently integrated with the existing sensors of the vehicle assisted driving system and the virtual-real interaction can be performed in real time. The virtual scene part uses road and obstacle information collected by sensors for real-time modeling and simulation to provide input data for artificial intelligence driving algorithms. When one or more sensors fail, the car driver assistance twin system can still provide the driver with driving suggestions based on the external scene information estimated by the artificial intelligence algorithm. In the real scene part, sensor data is fused by a variety of sensor arrays, and external scene information is transmitted to the digital twin system in real time. The information after virtual scene simulation will also display data prompts and synchronized driving scene information through external signal lights and instrument panels. In this paper, the research status of real-time environmental sound field modeling and exchange built by digital twin system is studied, and the current scheme of combining the acoustic digital twin system with the existing driver assistance system and the research development in similar fields are summarized from three aspects, including the digital twin modeling method, data acquisition and multi-sensor fusion, anti-interference, and reliability.

2. Sound Source Localization and Digital Twin System

2.1 Sound Source Localization Technologies

The sound produced by a motor vehicle (such as engine sound, tire noise, exhaust sound, etc.) during driving has obvious motion characteristics, which can reflect the current motion state of the vehicle in real time. By using a microphone array, the time difference between the arrival of the same sound source to different sensors can be recorded. The localization method based on this principle is called Time Difference of Arrival (TDOA) localization method [10]. The advantage of the TDOA algorithm is that only a small number of microphones can be used to determine the position of the sound source, and the data collected by the system requires less calculation and is easy to implement. Due to the distributed sensor layout, there is a corresponding distance difference between adjacent sensors, so it has certain advantages in resisting passive acoustic interference.

When the sound field contains multiple sound sources and is constantly moving, TDOA becomes inapplicable in this scenario, replaced by a sound source imaging technique called beamforming. Beamforming technology [11] constructs a two-dimensional sensor array through multiple sensors. After the acoustic signal is transmitted to the two-dimensional array, the trend of plane sound pressure changes can be observed in real time. The sensors in the array are filtered and weighted and superimposed to draw the sound pressure density image in real time. This enables visualization of multi-point sound sources. The sound field information displayed by beamforming is more intuitive, which is convenient for researchers to quickly obtain the location of the sound source. Combined with the real-time camera technology, the real-time sound source change information can be vividly displayed. Therefore, beamforming technology is also vividly called "acoustic camera".

In some specific traffic occasions, it is necessary to obtain real-time change information in three-dimensional space, and acoustic holography [12] technology is required to capture and reconstruct the entire sound field. Early acoustic holography technology mainly relies on large scale sensors to surround the target sound field at all angles to obtain real-time information of the three-dimensional sound field. This technology is called Spatial Transformation of Sound Fields (STSF) [13]. Usually in the STSF system, the sensor envelope the surface needs to be more than four times the measured area to obtain the sound source characteristic information completely. To optimize the sensor usage rate and reduce the huge amount of data for signal processing, the commonly used technique is

Statistically Optimized Near Field Holography (SONFH) [14]. SONFH technology greatly reduces the complexity of the acoustic system while restoring the sound field information with high precision by using a near-field two-dimensional microphone matrix and statistical optimization.

2.2 Acoustic Based Driving Assistance System

Acoustic assisted driving mainly provides driving assistance for scenarios where visual assisted driving is limited to small spaces or congested roads. Acoustic sensors can detect sound source signals outside the visually impaired range, which makes acoustic assistance more advantageous in emergency handling. To attract the driver's attention and avoid it, emergency rescue vehicles usually use the siren sound, which is difficult to be recognized by the existing vehicle assisted driving system. Acoustic event analysis is a popular research topic in the field of audio signal processing, and the recognition and processing capabilities of car driving sounds and siren sounds have become increasingly mature. Machine learning algorithms based on deep neural networks can effectively and quickly classify acoustic events in different scenarios [15, 16, 17]. Acoustic assisted driving can receive alarm information in advance before the ambulance approaches the vehicle, so it can remind the driver evasive earlier.

Acoustic assisted driving can not only analyze sound source information by passively receiving sound waves, but also realize detection across visual obstacles by transmitting sound waves and receiving echoes, such as acoustic based non-line-of-sight (NLOS) imaging [18]. NLOS realizes the acquisition of object information across obstacles by capturing reflected waves of objects hidden behind obstacles and performing secondary imaging [19,20,21]. The common way to realize NLOS technology is to emit light beams on a specific wall through a laser array, and then collect laser echo information. However, the equipment cost of laser array scanning is high, and the requirements for the environment and experimental scene are also very strict. The experimental equipment based on acoustic NLOS technology [22] can greatly reduce the cost of experiments and development and has higher requirements for experimental sites. compatibility.

Estimating the motion state of the sound source based on the Doppler effect is another important part of the field of acoustic assisted driving. The moving direction of the vehicle during the driving process will be superimposed with the propagation direction of the sound wave. By analyzing the Doppler frequency shift of the sound wave during the transmission process, the moving direction and traveling state of the sound source can be effectively calculated [23]. The advantage of using the Doppler frequency shift to predict the motion state of the target is that when rain, snow and cover obscure the camera or pass through a congested road section, the acoustic assisted driving system can still help the driver to know the dynamic sound source location information. This assisted driving can effectively avoid the threat to vehicle safety caused by sudden accidents.

3. Research Status of Sensor Fusion and Digital Twin

3.1 Sensor Fusion

The car assisted driving system is mainly realized through three different unit levels, these units are the environment perception unit, the car control unit, and the motion actuator. Among them, the environmental perception unit covers a variety of sensors such as optical radar, ultrasonic ranging sensor, millimeter-wave radar, and depth camera [24]. Each of the different sensors installed in a car assisted driving system has its own unique electrical characteristics and limitations, so the perception of the external environment by different sensors may feedback completely opposite results to the system. To make the sensors compatible with each other and the signal processing can be more closely coordinated, the on-board processor uses sensor fusion technology to comprehensively analyze the feedback signals of all sensors.

The commonly used data processing methods of sensor fusion are divided into two parts: random signal processing and artificial intelligence signal processing. The signal processing techniques of random sensor fusion include weighted average method, Kalman filter method, multi-Bayesian estimation method and D-S evidence inference method. The signal processing technology of sensor fusion based on artificial intelligence includes fuzzy logic reasoning method and artificial neural network method. The multi-sensor data fusion technology can effectively eliminate the instability factors of the system caused by the abnormality of some sensors and provide the system with more reliable and stable external environment data.

The weighted average algorithm is the most used technology for low-end sensor fusion systems because of its easy implementation and simple algorithm. The information redundancy contained in multiple sensors is fused by weighted average, which can operate directly on the data source. The Kalman filter method can fuse a variety of different sensor data in real time and is an optimal solution measurement model based on statistical recursion. In addition, the realization of Bayesian estimation method and D-S evidence inference method is to use the data of each sensor as a Bayesian estimation and minimize the likelihood function by calculating the joint probability distribution to realize the fusion of multi-sensor information.

In terms of artificial intelligence signal processing sensor fusion, fuzzy logic inference method uses multi-valued logic to model the uncertainty between sensors, and finally fuses signals between different sensors by generating consistent fuzzy inference. Fuzzy logic reasoning method makes up for some problems faced by probability theory in probability and statistics method, and the processing method of information is like the way of thinking of human beings, so it has excellent application in intelligent decision-making. The artificial neural network algorithm is applied to sensor fusion by constructing a neural network with high fault tolerance and self-adaptive learning. Sexual reasoning mechanism. The artificial neural network sensor fusion system can effectively analyze the large amount of data and nonlinear signals, so it has unique advantages in the analysis and data fusion of various types of sensor signals.

3.2 Digital Twin

Automotive assisted driving digital twin technology refers to the use of in-vehicle digital communication technology to model and map real vehicle information and driving scenarios into virtual space, which can use computer systems to perform online simulation of existing road conditions and upcoming events in the virtual space [25]. Digital twin technology is a virtual-real interaction system based on artificial intelligence and Internet of Things technology. This system is characterized by real-time virtual-real feedback and excellent online real-time simulation optimization. When emerging situation happens, human drivers have limited time for judging emergencies during driving. Using the driver's own conditioned reflexes to avoid traffic accidents requires long-term driving experience and crisis handling capabilities. The vehicle driving assistance system based on digital twin technology can simulate the signals of the vehicle's built-in sensor array online in real time. Through the high-speed information processing capability and powerful computing power of the on-board computer, it can give early warning of potential driving hazards, and use deep neural algorithms to calculate the best driving decisions.

The realization of digital twin technology is mainly realized in two stages: front-end and back-end [26]. The digital twin front-end is responsible for the isometric 3D modeling of vehicles, buildings, pedestrian vehicles, and roads, and uses sensor fusion data for real-time simulation of vehicle information; The digital twin backend is responsible for the interaction of vehicle traffic data, sensor information processing and decoding of model data, and the decoded driving instructions are transmitted back to the cockpit through vehicle-machine interaction.

The advantage of data twinning is that the on-board computer system can simulate the real driving scene of the car in real-time and can obtain more comprehensive driving information according to the synchronous interaction with the sensor system. Moreover, this system could predict its own vehicle and external obstacles follow-up behavior trajectory to avoid traffic accidents. Combined with the relevant characteristics of acoustic assisted driving, the digital twin system can realize obstacle warning and road condition monitoring with a higher detection range through the existing vehicle sensor system and acoustic assisted driving, which further improves driving safety in extreme weather conditions.

4. Conclusions

In this study, we analyze and summarize the application and prospect of acoustic detection in the current popular automotive assisted driving field and make corresponding analysis on the core technologies that may lead to future autonomous driving. Acoustic signal processing can make up for the deficiencies of existing driver assistance systems and has unique advantages in cross-obstacle recognition. With the help of sensor fusion technology and digital twin technology to optimize existing driver assistance technology related research is becoming more and more popular, acoustic assisted driving will also face important applications soon. With the update and iteration of advanced driving technology, safer and smarter autonomous driving systems will soon be realized and help people's daily travel.

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