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Application of Multi-Source Remote Sensing Technology in Smart Transportation

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Abstract. Under the background of deepening urbanization, the rapid growth of traffic flow poses a great challenge to the traffic monitoring system. However, the development of intelligent transportation systems (ITS) integrates advanced information technology and multiple remote sensing technologies, thus opening up a new path for efficient urban traffic management. This study explores in depth the applications of unmanned aerial vehicle remote sensing technology, LiDAR technology, and airborne remote sensing technology in autonomous driving technology, traffic flow monitoring, road condition assessment, and vehicle environment perception. This paper analyzes that UAV remote sensing technology can provide a wide field of vision and accurate environmental awareness for autonomous vehicles by carrying high-resolution cameras and sophisticated radar devices, so as to enhance the response ability of autonomous vehicle to complex traffic scenes. This article also analyzes the application of LiDAR technology in achieving precise vehicle positioning and navigation, as well as road information collection. This technology utilizes laser pulses to generate high-precision 3D point cloud maps, providing accurate distance measurement and environmental modeling for autonomous vehicles. The airborne remote sensing technology can be applied in road condition assessment, accident detection and response, environmental monitoring, and traffic congestion analysis due to its high-resolution monitoring capability, wide coverage, and fast response characteristics. Multi-source remote sensing technology plays a vital role in improving the efficiency of traffic monitoring, optimizing traffic flow management, and promoting the advancement of autonomous driving technology.

Keywords: Remote Sense; Intelligent Transportation; Faster R-CNN; LiDAR.

1. Introduction

In the process of urbanization in the 21st century, cities and towns worldwide are experiencing unprecedented expansion, and with it, urban transportation systems are becoming more complex. The sharp rise in urban population density not only leads to a substantial increase in traffic flow but also puts forward a new test for the management and supervision of transportation. To address these challenges, Intelligent Transportation Systems (ITS) have emerged, aiming to improve traffic management's intelligence level by integrating advanced information technology, sensor technology, and data processing capabilities.

In the ITS, real-time data collection and analysis is a core function that helps monitor and manage the traffic flow more efficiently. In this process, multi-source remote sensing technology plays a key role. The so-called multivariate remote sensing technology is a technology that integrates data from a variety of platforms and sensors to obtain more detailed and comprehensive land and traffic-related information. Data sources may include but are not limited to, satellite remote sensing, unmanned aerial vehicle (UAV) remote sensing, airborne remote sensing, and ground station sensor networks.

Satellite monitoring has a broad field of vision and macro-Angle, which can generate a macro picture of urban traffic flow and road congestion. Because of its flexible deployment mode and high-resolution data capture ability, UAVs can provide the relevant image data of traffic events in a specific area in real-time. Airborne remote sensing combines the advantages of the first two, using the advanced equipment mounted on the aircraft to achieve continuous monitoring tasks; The main function of the ground base station sensor network is to monitor and record the information of traffic flow and traffic speed in real time.

The significance of multi-source remote sensing technology is that it provides continuous and real-time monitoring capabilities, which play an irreplaceable role in understanding complex traffic patterns, predicting traffic flow, evaluating road conditions, and coping with emergencies. For example, traffic choke points and high-traffic areas in cities are identified by analyzing satellite images. Using the high mobility of the UAV, it can fly to the accident scene and take relevant photos the first time. Aviation monitoring can realize seamless monitoring of a wide range of traffic conditions. In addition, the operation of the ground base station sensor network provides a solid foundation for accurately mastering the traffic flow dynamics of each road.

Light Detection and Ranging (LiDAR) is an emerging multi-source remote sensing technology that emits laser pulses and uses echo signals to generate high-precision 3D topographic maps and point cloud data. LiDAR technology has significant advantages in traffic flow analysis, vehicle motion estimation, and road condition assessment, and it can provide fine spatial data and accurate measurement means. In addition to its wide application in traffic engineering, LiDAR technology also shows great potential in urban planning, environmental monitoring, and disaster management. In addition, combined with advanced computer vision algorithms such as the Faster R-CNN target detection model, vehicles can be automatically identified from remote sensing images to assist in real-time monitoring and analysis of traffic flow. The development of this series of technologies opens up a new way to realize the effective mining of huge and complex remote sensing data.

This study analyzes the application of multi-source remote sensing technologies in ITS, aiming to provide a comprehensive perspective for researchers and practitioners through the comprehensive analysis of existing literature. This study provides an understanding of the status quo, application potential, and future development direction of multi-source remote sensing technology in ITS.

2. Traffic Data Analysis Based on Satellite Remote Sensing Images

Traffic flow monitoring can help to fulfill "smart transportation" in many ways, including providing real-time data to support decision-making, improve traffic efficiency, and prevent traffic accidents. Satellite remote sensing technology can be used to monitor traffic flow, with the advantages of wide area coverage and real-time data collection.

Some research shows that real-time traffic flow can be directly monitored by analyzing the number of vehicles on the road, which is easy to conduct and accurate and is especially suitable for daytime traffic flow monitoring. First, the objects in the high-resolution images taken by the satellite are classified. Then, the Faster R-CNN technology is used to select and identify the vehicles in the high-resolution images taken by satellites, which can achieve a high enough recognition accuracy and obtain accurate traffic flow information [1, 2]. The Faster R-CNN technique is a newly developed technique that uses deep convolutional networks to find special patterns in images, and the analysis method is more efficient and accurate than the previous R-CNN technologies.

Some studies have also shown that the traffic flow can be effectively calculated by analyzing the lights from cars on roads and other information in the video taken by the satellite. Satellite video analysis can obtain information continuously over a specific period, compared with the analysis of an instant remote sensing image. This helps prevent data collection results from greatly deviating from the average value due to short-term traffic congestion or traffic flow decline, improving the validity and authenticity of traffic flow information [3].

The above two methods of analyzing traffic flow by identifying vehicles in satellite images or videos are only suitable for daytime monitoring, and the effectiveness of these monitoring methods is greatly reduced at night.

Research showed that when monitoring nighttime traffic flow, Pearson correlation analysis can be applied to analyze the correlation between traffic flow and nighttime lighting conditions. So, collecting nighttime light information through satellite remote sensing to calculate road traffic flow is feasible and can support traffic operation and future transportation planning [4]. Some research showed that the trained CNN can detect vehicles in the night image. The labeled daytime images can be used to better detect the cars in unlabeled nighttime images. To effectively obtain the night traffic flow information [5]. In conclusion, satellite remote sensing technology can monitor traffic information, such as road traffic flow both in daytime and night, and effectively promote the construction of smart transportation.

3. Application of Unmanned Aerial Vehicle Remote Sensing in Vehicle Autonomous Driving

Autonomous driving technology is an important part of smart cities. By interconnecting autonomous vehicles with other intelligent infrastructure (such as smart traffic lights and smart parking systems), autonomous vehicles can monitor road conditions in real-time and coordinate with each other to optimize traffic flow. These advantages make this mode of transportation safer and more economical [6].

UAV remote sensing can be equipped with high-resolution cameras and radar to obtain a wide range of road information in the air. With its accurate environmental perception, high-precision digital maps, and three-dimensional environment modeling abilities, UAVs can help autonomous vehicles perceive and respond to complex traffic scenarios more safely and effectively and play an important role in autonomous driving. By collecting the maximum flight speed, endurance time, maximum take-off, and landing speed of the latest two UAVs, it can be seen that advanced UAVs could track low- and medium-speed vehicles (less than 80 km/h) for a long time (Table 1), which makes it possible to use UAV remote sensing technology to track cars and assist vehicles in autonomous driving.

Ultra-Wide Band (UWB) technology can be used to control the relative position of the UAV and the vehicle, control positioning errors within an acceptable range, and return to the cars accurately. These UAVs can also use radar to obtain information on blind spots in the car, helping vehicles detect potential safety hazards in advance and efficiently assist in autonomous driving [7]. UWB is a new technology in the field of positioning that usually uses low-power pulse waves to transmit data, significantly reducing operating costs and facilitating a wide range of applications. UWB always has a bandwidth larger than 20% on center frequency, which means that it can measure distance. It is an ideal technology that can be used to construct ITS [8].

As for automatic parking, the Topsis entropy weight method can be used to establish a mathematical model, which can be used to plan a better parking route for the vehicle itself. With the help of UAVs to expand the car's field of vision and detect information in the surrounding environment, the vehicle can be safely and automatically parked. Compared to human drivers, this automated parking technology has an advantage in complex situations [9]. In addition to the interaction between drones and cars, effectively using the information in drone remote sensing images is also important for autonomous driving and smart city construction. The research shows useful information can be extracted by classifying each object in the UAV remote sensing image, such as road contour, obstacles, and slope. This helps establish a digital map and better assist the automatic driving of automobiles [10].

Table 1. Characteristic of two UAVs

Product name	Max flying speed	Max takeoff speed	Endurance	Definition
inspire2	94km/h	9m/s	27min	1080p
inspire3	94km/h	8m/s	25min	1080p/60fps

4. Application of LiDAR in Autonomous Driving

Light Detection and Ranging (LiDAR) technology is a relatively new application in ITS, but automakers have given it much attention. Multi-source remote sensing technology is frequently employed in this context. LiDAR, a remote sensing technology, measures distance using laser pulses. It has become crucial for cars to accurately detect their surroundings and has played a major role in advancing autonomous driving.

LiDAR operates on the basic principle of estimating distance by firing a laser, catching the reflected signal, and measuring the time difference. This produces 3D point cloud data (Fig. 1), which gives the onboard computer's data processing center real-time object perception information.

Specifically, LiDAR operates by scanning the FoV (Field of View), usually with the help of one or more laser beams. An amplitude-modulated laser diode with NIR (near-infrared) wavelengths emits the laser beam. The photodetector in the scanner receives the reflected signal after the laser beam is irradiated into the surrounding area and reflected. Quick electronics filter the signal and calculate the distance-proportional time difference between the transmission and received signals. The distance from this time difference may be calculated using the sensor model. Signal processing can adjust for variations in surface material and environmental conditions between the transmitter and receiver, which will cause variations in the reflected energy.

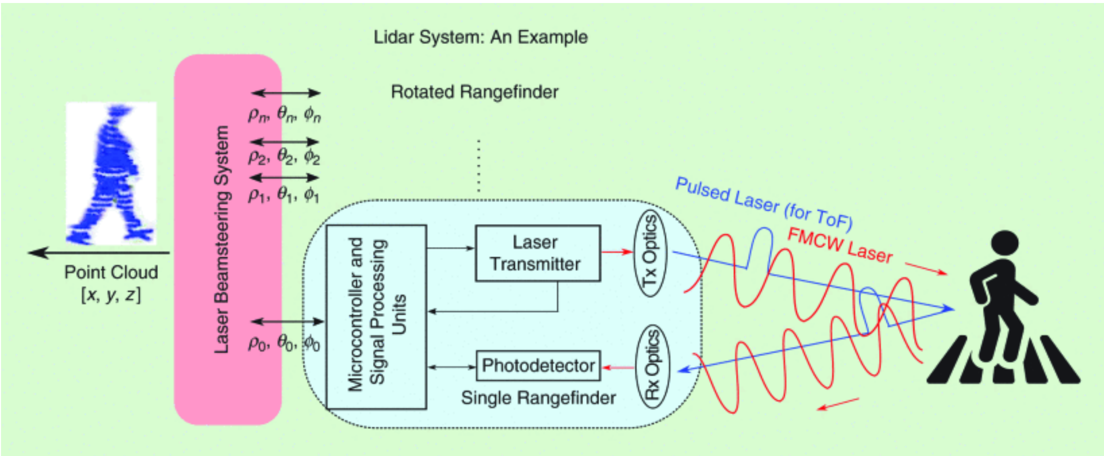

Figure 1. The concept of how Lidar works [11]

LiDAR surpasses other sensors, like cameras and radars, in terms of ranging accuracy. It also provides very dependable physical information (such as object position, velocity, and shape) that satisfies the data accuracy requirements of autonomous driving vehicles, making LiDAR one of the most popular options for a thorough understanding of the vehicle's surroundings (Fig. 2) [12].

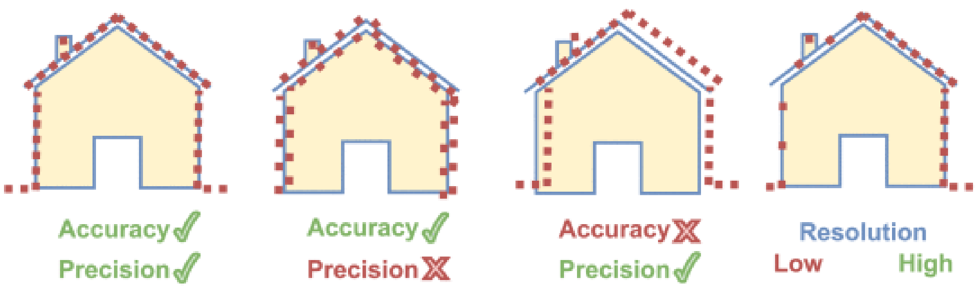

Figure 2. Precision, accuracy, and resolution of a LiDAR sensor [12]

Vehicles can estimate shapes and distances with great accuracy thanks to this technology. LiDAR systems can identify a range of roadside impediments, such as pedestrians, other cars, and immovable objects, allowing for efficient obstacle avoidance. Furthermore, LiDAR data may be used to classify observed items when combined with machine learning, enhancing the vehicle's decision-making abilities.

LiDAR is crucial for navigation and positioning as well. Autonomous vehicles may locate themselves precisely by comparing the resulting 3D point cloud with a high-precision map [12]. This is particularly helpful in places like tunnels and urban canyons where GPS signals might be spotty or inconsistent. LiDAR data also aids in path design by offering comprehensive details about the geometry of roads and any hazards.

LiDAR has certain difficulties as well. To lower mistakes and uncertainties in the data collecting process, LiDAR sensors must be calibrated both internally and externally [12]. Under the assumption of human control, the existing planar target-based calibration method is quite accurate; however, it is challenging to recalibrate after practical use. Further research is required to propose potential answers because there is some degree of interference between several LiDAR sensors when operational, which can also impair the measurement accuracy.

5. Application of Airborne Remote Sensing Technology in Traffic Management

Airborne remote sensing technology is a new solution to the huge problems faced by traditional traffic management due to the acceleration of urbanization and the rapid growth of traffic demand. This technology has high-resolution monitoring ability, wide coverage, low cost, strong power, and rapid response, and it is gradually becoming an important tool for intelligent traffic management.

Airborne remote sensing technology uses sensors (such as cameras, radars, and lidar) mounted on the aircraft to obtain data from the ground and the atmosphere. Compared with traditional ground sensors and cameras, airborne remote sensing technology has a wider coverage and higher data resolution, enabling it to monitor and analyze large area traffic conditions on the ground in real-time [13]. Therefore, airborne remote sensing technology has great potential for application in road condition assessment, accident detection and response, accident detection and response, environmental monitoring, and traffic congestion analysis [14].

Airborne LiDAR technology can be applied to road condition assessment, which strongly supports road maintenance and planning. This technology enables high-precision three-dimensional models of the road surface around the vehicle, making detecting cracks and other road damage more efficient and accurate. This technology can improve road safety and extract accurate information about road surfaces.

Regarding accident detection and response, airborne remote sensing technology greatly reduces emergency response time through real-time image data transmission. Traffic management departments can use cameras to quickly identify the location and severity of traffic accidents, quickly and accurately locate the accident scene, and assess the accident situation. The application of LiDAR technology also shows great potential in this field. LiDAR technology has rich spatial information and contains time information [15]. The obtained LiDAR data shows that vehicles with moving characteristics can be extracted. The adaptive 3D segmentation method and binary classification technology can detect local arbitrary patterns on a multi-scale and complex point cloud. Data can be divided to distinguish moving and stationary vehicles effectively and then estimate the speed of moving vehicles.

Environmental monitoring is also an important application field of airborne remote sensing technology. Sensors can detect stagnant water, snow, and ice on roads and assess the impact of air quality on traffic. This information is crucial to early warning of traffic safety hazards. Studies have shown that dynamic spatial data extracted by aerial imaging sensors can effectively support traffic flow estimation [15]. Using Faster R-CNN to detect the vehicle position in the image, the vehicle area can be quickly identified, and an accurate boundary box can be provided to extract the vehicle. Then, FCN technology is combined to segment the image at the pixel level, separate the road from the image to determine the actual area of the road, and identify the traffic flow [16]. After off-highway vehicles are removed, the DBSCAN algorithm is used to find the candidate congestion locations to conduct effective congestion analysis and provide a new solution for traffic management under complex environmental conditions.

The application of airborne remote sensing technology in traffic management has significant advantages, such as improving the efficiency of road assessment accident response, accident response, congestion analysis, and environmental monitoring. However, the application of this technology also faces the following problems: low data processing efficiency, data delay affecting the timeliness of traffic management, high cost of airborne remote sensing equipment and technology, and personal privacy. In the future, airborne remote sensing technology is expected to achieve breakthroughs in many fields. Along with the continuous advancement of sensor technology, new drones will carry more sophisticated equipment to provide higher resolution and wider monitoring range. The application of airborne remote sensing technology in ITS and automatic driving has broad prospects, and it is expected to be deeply integrated with these systems to provide more comprehensive and accurate data support for traffic management and automatic driving.

6. Conclusion

The study shows the application of satellite remote sensing technology in tracking traffic flow and identifying vehicles. Drone remote sensing technology can provide a wider field of view, accurate environmental perception, and high-precision digital maps for driving assistance. Aerial remote sensing technology can enable intelligent traffic analysis, such as accident detection, road condition assessment, congestion analysis and environmental monitoring. Lidar remote sensing technology can provide accurate 3D point cloud data through lidar platforms, enabling onboard computers to assess objects in front of the vehicle for detection, positioning and navigation.

Although the above multivariate remote sensing technology has made incredible achievements in ITS, there are still challenges to overcome, such as limited data processing efficiency, high cost, and privacy concerns. Future advances in remote sensing technology could enable existing UAVs to be upgraded with more advanced equipment, improving resolution and allowing for broader surveillance. In addition, the technology has a wide range of applications in ITS and autonomous driving, which are expected to be closely linked to provide more comprehensive and accurate data assistance for traffic management and autonomous driving.

Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

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