Research on the technology of intelligent vehicle sensor positioning system in autonomous driving

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Abstract. In this comprehensive exploration of positioning and navigation technologies, we have delved into the intricacies of GPS (Global Positioning System), IMU (Inertial Measurement Unit), and VPS (Visual Positioning Systems) systems, shedding light on their unique attributes and applications. GPS, a global satellite-based system, offers precise positioning on a worldwide scale, although it encounters challenges in complex urban and environmental conditions. Its role in navigation and tracking is undeniable. IMU, characterized by accelerometers and gyroscopes, excels in delivering high-precision positioning over short durations, making it invaluable for applications in aviation, robotics, and virtual reality. However, it is susceptible to drift over time. Visual Positioning Systems (VPS), harnessing computer vision and visual sensors, provide remarkable sub-meter to centimeter-level accuracy when conditions are optimal. Their significance is particularly pronounced in indoor navigation, augmented reality, and robotics, although they may face challenges in less favorable environments. These technologies are not isolated but can synergize to enhance accuracy and reliability. GPS and IMU collaborate to compensate for signal disruptions, while GPS and VPS join forces to tackle urban complexities. IMU and VPS integration offer precise indoor navigation and augmented reality experiences, delivering impeccable positioning and orientation data. Ultimately, the choice of technology hinges on specific application requirements, encompassing accuracy, environmental considerations, cost factors, and the need for complementary systems. As these technologies advance, they hold the promise of revolutionizing navigation across various domains, from autonomous vehicles to immersive augmented reality environments.

Keywords: LiDAR, Radar, GPS, IMU, VPS.

1. Introduction

Self-driving cars are an amazing technology where people can free their hands and reach a place with a command. This remarkable feat is made possible through a sophisticated autopilot system, augmented by an array of advanced computational tools and sensors. Computer vision, odometry, infrared sensors, radar, and global positioning systems (GPS) are among the sensors that are available [1]. Autonomous driving systems rely on complex algorithms to process the information obtained by sensors, enabling the vehicle to understand its location, its direction of travel, and its position in relation to the nearby objects. Automotive radars make it possible to implement adaptive cruise control, blind spot identification, lane change aid, parking assistance, and more by detecting the presence, position, and velocity of other vehicles or objects [2].

2. Active sensor positioning

2.1. LiDAR sensor

Due to its capacity to deliver precise, high-resolution range and angular data, LiDAR has become a crucial localization-assist sensor for automated vehicles [3]. Optical radar is the common name for LiDAR, which is the abbreviation for Light Detection and Ranging. Since its creation in the 1960s, it has been extensively used to map the terrain for aviation and aerospace. Manufacturers of laser scanners created and used the first commercial LiDAR systems in the middle of the 1990s for topographic mapping applications, with pulse rates ranging from 2000 to 25,000 pulses per second (PPS) [4,5].

LiDAR ranging utilizes the Time of Flight (TOF) measurement method, which involves emitting laser pulses. The process begins with the laser transmitter in the vehicle emitting a laser beam. When this laser beam encounters an object, it is reflected back and received by a sensor. Subsequently, the received light undergoes further analysis, including the examination of frequency, spectrum, and phase information, to calculate the distance. By analyzing the diffusion and reflectance of the reflected laser beam, an accurate three-dimensional point cloud map is generated. This map allows for precise self-positioning and the determination of the relative positions of surrounding objects. LiDAR is prized for its high resolution, precision, directionality, and penetration capabilities. The real-time creation of a clear point cloud image with these characteristics greatly assists in autonomous driving.

Most LiDAR systems on the market today employ the TOF measurement method, albeit with infrared light emissions. In this process, the laser transmitter on the vehicle emits an infrared laser beam, which, upon touching an object, reflects back and is received by a sensor. Subsequent analysis of the received light, including aspects such as frequency, spectrum, and phase, enables the calculation of distance. By further scrutinizing the diffusivity and reflectance of the reflected beam, an accurate three-dimensional point cloud map is generated, facilitating the precise determination of the relative positions of the vehicle and its surroundings. Two types of lasers are typically used: the 905nm laser emitted by silicon lasers and the 1550nm laser emitted by indium phosphide lasers. The 1550nm laser, being farther from the visible light range, allows for increased power and extended detection range. However, it is susceptible to interference in rainy conditions due to its high susceptibility to water absorption.

2.2. Radar sensor

Radar, short for radio detection and ranging, is a vital component in the arsenal of intelligent vehicles equipped with millimeter-wave radar systems. Through the use of antennas, these devices transmit and receive millimeter waves using a technique called frequency modulated continuous wave (FMCW). Periodic wideband FM pulses are transmitted by the FMCW radar.whose linearly increasing angular frequency is pulse-dependent [6]. Measuring the difference between the transmitted and received frequencies enables the calculation of the distance to detected objects. When the radar antenna receives the reflected signal, it performs rapid calculations to provide the driver with accurate information in various forms.

The capability of radar to perform these functions stems from the inherent nature of electromagnetic waves, which typically travel in straight lines at the speed of light and bounce back upon encountering obstacles. Radar, operating with millimeter-wavelength electromagnetic waves, exhibits robust adaptability to adverse weather conditions such as rain and fog, without experiencing interference. In contrast, laser radar excels in precise positioning, modeling, and identification tracking, offering strong obstacle recognition capabilities. Radar, however, faces challenges in distinguishing between pedestrians and other obstacles, as it possesses relatively moderate obstacle recognition abilities Omnidirectional cameras with a 360° field of view can reduce field of view change errors and design algorithms that are more robust against severe weather and illumination conditions [7].

Both radar and laser radar excel in long-distance detection and nighttime operations. Furthermore, compared to LiDAR, millimeter-wave radar possesses the additional capability of detecting the relative speed of target objects, although this is not the primary function of LiDAR.

2.3. Comparison of LiDAR and Radar sensor

LiDAR and radar represent two distinct sensing technologies, each playing vital roles in a multitude of applications, including autonomous vehicles and remote sensing. A comparative analysis of these two technologies reveals several key aspects differentiating them.

Firstly, with regard to their operating principles, LiDAR relies on laser pulses to determine object distances through time-of-flight measurements, while radar employs radio waves, often in the microwave spectrum, to gauge distances, speeds, and directions of objects via Doppler shift and time delay analysis.

Secondly, in terms of wavelength, LiDAR operates within the infrared spectrum, employing shorter wavelengths (ranging from 700 nm to 1,550 nm) to achieve high-resolution imaging but remains susceptible to atmospheric interference. On the other hand, radar operates in the microwave spectrum, with wavelengths spanning from millimeters to centimeters, facilitating superior penetration through adverse weather conditions like rain, fog, and snow.

Regarding spatial resolution, LiDAR excels by offering high-resolution three-dimensional point clouds with intricate details, rendering it suitable for precise mapping and small object detection. Conversely, radar generally provides lower spatial resolution and may face challenges in discerning fine object details.

Concerning environmental factors, LiDAR's performance can be hindered by factors such as rain, fog, and dust, which scatter and absorb laser light, thereby diminishing its range and accuracy during adverse weather conditions. Radar, however, exhibits greater robustness in challenging weather, making it suitable for applications where visibility is limited.

In terms of cost, LiDAR systems tend to be more expensive due to the complexity of laser technology and the necessity for precise scanning mechanisms, whereas radar systems are generally more cost-effective and find common use across a wide spectrum of applications.

Lastly, both LiDAR and radar find application in diverse domains. LiDAR's strengths shine in high-resolution 3D mapping and precise object detection, with applications spanning autonomous vehicles, forestry, archaeology, and urban planning. Radar, on the other hand, is favored for long-range detection and resilience in adverse environmental conditions, finding utility in aviation, maritime navigation, weather forecasting, and military surveillance.

In summary, the choice between LiDAR and radar hinges on the specific requirements of an application and the trade-offs between resolution, range, cost, and environmental considerations. Both technologies possess distinct advantages and limitations, rendering them suitable for varying contexts, thus necessitating careful selection based on individual project demands.

3. Passive sensor positioning

3.1. GPS positioning

GPS, short for Global Positioning System, was developed by the United States in 1973 and completed in 1993. It was originally designed for military navigation and positioning services, but was later opened to the world. GPS positioning principle is relatively simple, but it is very complex, in simple terms, is at least three satellites in the same time to measure the distance you for three satellites, respectively can say to three satellites for the center of the radius of the distance your location, so three garden will have an intersection, and the intersection is the orientation of the orientation. The GPS positioning satellite transmits the signal through radio waves, the electromagnetic energy travels in a vacuum at the speed of light, and the receiver determines how far it travels by recording the time the signal arrives. Because the electromagnetic wave is very fast, so the receiver and the satellite need to synchronize to the point of very precision, so each satellite needs to be equipped with a very accurate clock, that is——the atomic clock, which can reach every 20 million years only one second error. Due to the interference of structures, vehicle-mounted GPS locators are unable to receive GPS satellite signals due to changes and signal attenuation caused by electric clouds, as well as reflection caused by glass curtain walls, under underground garages, tunnels, and overpasses, for example [8]. Moreover, in fact, when electrical

signals slow down through the atmosphere, especially through the ionosphere or the troposphere, the positioning becomes more inaccurate.

3.2. IMU positioning

Inertial measurement unit is known as IMU. The combination of an accelerometer and a gyroscope sensor is known as an IMU sensor. It is used to find motions and gauge their force in terms of rotational and accelarating speeds. IMU Usually contains a gyroscope, accelerometer and the magnetometer. Strictly speaking, IMU provides relative positioning information, which is the trajectory and posture of moving from one place to another. So if the IMU and GPS are combined to play a bigger role, For example, when a car reaches a place and loses a satellite signal, When the GPS cannot perform the normal positioning, IMU may nevertheless maintain sub-meter positioning precision for many seconds and buy the autonomous vehicle crucial time to cope with anomalies. In the case of relative positioning failure, IMU may execute trajectory deduction on the outcomes of relative positioning, preserving relative positioning accuracy for a while, and assuring the safety of autonomous driving. When the signal is strong, the GPS can deliver high-precision positioning data on a worldwide scale, but when the signal is shielded, blocked, or interrupted, it is unable to deliver positioning results that are accurate enough. The inertial navigation system can solve data problems autonomously, without relying on outside knowledge, and quickly produce highly accurate positioning results [9].

3.3. VPS positioning

High quality images from cameras can be utilized for exact categorization, and in recent years, the most popular classification techniques have been based on in-depth deep learning studies in the area of image recognition [10]. The position and orientation of the device are determined by the VPS system using a mix of computer vision algorithms and a feature or location database that is well-known. Images are captured by the device using cameras or other visual sensors, and then processed using VPS software to identify visual elements in the surroundings. To locate the gadget, compare these functionalities with a database of well-known places. The gadget may occasionally employ additional sensors to enhance its location and direction, such as lasers or inertial measurement units (IMUs).

3.4. Comparison of positioning technologies

GPS, IMU, and VPS represent three distinct technologies integral to positioning and navigation. GPS, grounded in a satellite network, ascertains global positions by triangulating signals from orbiting satellites. IMU, comprising accelerometers and gyroscopes, tracks object movement and location in relation to a reference point through measurements of orientation and velocity. VPS, meanwhile, employs visual sensors and computer vision algorithms to recognize and track environmental visual features, cross-referencing them with a known map to determine device location.

In terms of accuracy, GPS offers global precision but falters in areas with limited satellite visibility, presenting meter-level accuracy. IMUs yield high-precision positioning for brief intervals, albeit prone to drift over time, suitable for relative positioning over short distances. VPS's accuracy hinges on visual feature quality and mapping databases, achieving sub-meter to centimeter-level precision in optimal conditions.

Environmental factors play a role; GPS signals can be hindered by obstructions and adverse weather, rendering it ineffective indoors or in interference-prone environments. IMUs remain unaffected by external factors but may suffer from long-term drift. VPS thrives in diverse settings but faces challenges in poorly lit or featureless areas.

Regarding cost, GPS receivers are widely accessible and cost-effective, often integrated into consumer devices. IMUs span a cost range, with high-precision variants being pricier. VPS technology's cost varies based on sensor quality and software.

Applications for these technologies span navigation, mapping, location-based services, and tracking for GPS; aviation, robotics, virtual reality, and short-term navigation for IMU; and indoor navigation, augmented reality, and robotics for VPS.

Complementary use enhances performance. GPS and IMU merge to bolster navigation accuracy, compensating for short-term GPS disruptions. GPS and VPS complement each other in urban and indoor settings to enhance positioning. IMUs and VPS combine for robust indoor navigation and augmented reality, delivering precise positioning and orientation data.

In summary, GPS ensures global positioning but faces challenges in complex environments, IMU provides precise short-term tracking with potential drift, and VPS relies on visual cues for high precision. Technology selection depends on specific application needs and trade-offs among accuracy, environmental factors, and cost, often resulting in hybrid utilization to optimize performance.

4. Conclusion

In conclusion, this paper has explored three distinct positioning and navigation technologies: GPS, IMU, and VPS, each with its unique operating principles, advantages, and limitations.

GPS, a global satellite-based system, provides accurate positioning on a global scale, but it can face challenges in urban canyons, dense forests, or areas with poor satellite visibility. Additionally, it may be susceptible to signal interference and environmental factors, leading to reduced accuracy. Nevertheless, GPS plays a pivotal role in various applications, from navigation to tracking.

IMU, on the other hand, combines accelerometers and gyroscopes to measure changes in velocity and orientation. While IMUs offer high-precision positioning for short durations, they are prone to drift over time, making them suitable for relative positioning over short distances. IMUs are commonly used in aviation, robotics, and virtual reality.

Visual Positioning Systems (VPS) utilize computer vision algorithms and visual sensors to recognize and track visual features in the environment. VPS can achieve impressive sub-meter to centimeter-level accuracy under ideal conditions, making it valuable for indoor navigation, augmented reality, and robotics applications. However, VPS performance may degrade in poorly lit or featureless environments.

These technologies are not mutually exclusive and can complement each other in various scenarios. GPS and IMU can enhance navigation accuracy when combined, with IMUs compensating for short-term GPS signal loss or inaccuracies. In urban environments, GPS and VPS can work together to improve positioning accuracy, especially in areas with tall buildings or indoor spaces. IMU and VPS can be integrated to offer precise indoor navigation and augmented reality experiences, ensuring accurate positioning and orientation information.

The choice of positioning technology depends on the specific application requirements, taking into account factors such as accuracy, environmental conditions, cost considerations, and the need for complementary technologies. As these technologies continue to evolve and become more integrated into our daily lives, they hold the potential to revolutionize navigation and positioning across a wide range of fields, from autonomous vehicles to augmented reality experiences.

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