Proceedings of the 2nd International Conference on Software Engineering and Machine Learning
DOI: 10.54254/2755-2721/77/2024MA0054

Automated lane change behavior prediction and environmental perception based on SLAM technology

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Abstract. In the automatic driving system, the external environment of the vehicle is perceived, in fact, there is also a perception sensor that has been silently dedicated in the system, that is, the positioning module. This paper explores the role of SLAM (Simultaneous Localization and Mapping) technology in autonomous vehicles, particularly in automatic lane change behavior prediction and environment perception. It emphasizes the limitations of traditional methods and the advantages of SLAM, especially visual SLAM, for accurate positioning and mapping. The discussion covers SLAM fundamentals, challenges, and the significance of visual SLAM's higher perception ability. Case studies on Waymo and Tesla illustrate the application of visual SLAM in achieving high-precision navigation and lane change prediction. The paper concludes by highlighting future research directions to enhance the intelligence and adaptability of automated lane change systems through advancements in AI and sensor technology, alongside optimizing SLAM algorithms for reliable driving in various scenarios.

Keywords: SLAM (Simultaneous Localization and Mapping), Autonomous Vehicles, Automatic Lane Change, Sensor Fusion, Environment Perception.

1. Introduction

In the development of autonomous vehicles, accurate positioning and mapping solutions are critical, especially in situations involving automatic lane changes and environmental awareness. In order to achieve this goal, SLAM technology has become an important solution. Traditionally, LIDAR and camera sensors have been widely used for positioning and sensing tasks in vehicles. However, the development of liDAR [1] SLAM methods does not seem to have changed much over time. In contrast, visual SLAM [2] technology offers many advantages, including low cost, ease of installation, and powerful scene recognition capabilities. In recent years, there has been growing interest in integrating camera technology into autonomous vehicles to enhance perception and positioning capabilities, particularly for complex tasks like automatic lane changes. This paper examines the intersection of

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automatic lane change behavior prediction and environment perception with SLAM technology. Through an in-depth exploration of visual SLAM, the focus lies on its practical application in predicting lane change behavior and understanding the surrounding environment. By delving into these technologies, we aim to uncover their potential in advancing the field of autonomous driving and paving the way for future innovations.

2. Related work

2.1. Artificial intelligence and autonomous driving

With the development of robotics and artificial intelligence (AI) technology, autonomous vehicles (AVs) [3] have become a hot topic in both industry and academia. Safely navigating requires creating an accurate representation of the surrounding environment and estimating the vehicle's state within it, particularly its positioning. Traditional methods, relying on GPS or real-time kinematic (RTK) positioning systems, have limitations due to signal reflection, time errors, and atmospheric conditions. GPS [4], for instance, suffers from measurement errors up to a dozen meters, unsuitable for precise navigation, especially in complex urban or tunnel scenarios. Although RTK can mitigate these errors by calibrating with base stations, it involves expensive infrastructure.

SLAM is a promising solution for autonomous vehicle (AV) positioning and navigation, estimating vehicle attitude in real-time while mapping the environment. It comes in two main types: LIDAR SLAM and Visual SLAM. LIDAR SLAM, established earlier, is mature for autopilot applications due to its resilience to light changes and ability to perform well in low-light conditions, providing a broad field of view and 3D mapping capabilities. However, its high cost and long development cycles hinder widespread adoption. On the other hand, modern visual SLAM systems can operate on micro PCs, embedded devices, and smartphones. These advancements, coupled with sensor fusion, are driving the evolution of autonomous driving systems, enhancing their safety and efficiency on the road.

2.2. SLAM

SLAM technology is a method of simultaneous localization and map construction using sensors such as lasers. Through equipment such as [5] LiDAR, SLAM systems can obtain real-time distance and direction information in the environment and convert it into point cloud data. These point cloud data represent the positions and contours of objects in the environment. Using this data, the SLAM system is able to determine the robot's location in the environment in real time, and gradually build a map as it explores the unknown environment. At the same time, the SLAM system can calculate the movement trajectory and attitude changes of the robot by comparing the point cloud data at different time points, so as to achieve accurate positioning and map update. The use of lasers enables the SLAM system to obtain high-precision environmental information for more reliable positioning and map construction.

SLAM systems generally work in two main steps: localization and map construction.

1. Localization: The robot determines its position and posture in the environment through algorithms based on the environmental information obtained by sensors, such as the point cloud data obtained by Lidar. This is usually done using probabilistic methods such as particle filtering or extended Kalman filtering.

2. Mapping: When the robot moves, it uses the data obtained by the sensor to build an environment map. This can be a two-dimensional or three-dimensional map, representing information such as the location of objects in the environment, obstacles, and so on. Maps usually exist in the form of raster maps, point cloud maps, or topological maps.

The main problems to be solved in SLAM system include data association, motion estimation, environment modeling, state estimation and so on. [6] Data association refers to how sensor data acquired at different points in time is matched to the same object; Motion estimation refers to how to estimate the motion trajectory of the robot according to the sensor data. Environmental modeling is to convert the data acquired by sensors into maps; State estimation is based on sensor data to estimate the position and attitude of the robot.

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The development of SLAM technology enables robots to navigate and explore autonomously in unknown environments, which has important practical significance. It has a wide range of application prospects in industry, military, service robot and other fields.

2.3. Visual SLAM

Visual SLAM technology is unique in that it uses image information obtained by vision sensors and extracts features in the environment, such as corners, edges, textures, etc., through complex image processing and computer vision algorithms. These feature points can not only be used to locate the robot's position in the environment, but also to build a map of the environment, so as to realize the understanding and navigation of the environment.

Compared with traditional SLAM technology, Visual SLAM has higher perception ability and environment understanding ability. Traditional SLAM usually relies on point cloud data obtained by sensors such as Lidar, and although it can provide a certain degree of environmental information, it is difficult to capture environmental details and texture information due to the limitations of sensor resolution and sampling density. [7] Visual SLAM, on the other hand, can obtain high-resolution image data through image sensors to more accurately extract environmental features and achieve more accurate positioning and map construction. In the field of autonomous driving, Visual SLAM plays a key role. It can help autonomous vehicles achieve positioning and navigation in unknown environments, improving vehicle autonomy and safety.

In the process of driving, Waymo vehicles constantly receive new image data from the sensor and match it with the previous map through Visual SLAM algorithm, so as to update and correct its own position. This enables Waymo cars to accurately locate and navigate a variety of complex road environments, including city streets, highways, and more. With Visual SLAM, Waymo vehicles are able to navigate autonomously with high accuracy and constantly update and improve their maps to adapt to changing road and traffic conditions. Combining the functions of these modules, the visual SLAM system can realize autonomous positioning and mapping in unknown environments, and provide key position perception and environment understanding capabilities for automatic driving, robot navigation and other applications. (figure1).

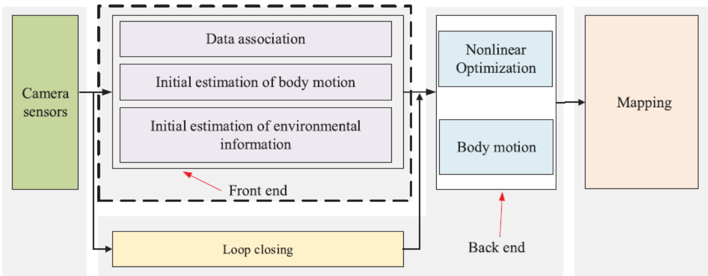

Figure 1. Visual SLAM system architecture diagram

Visual SLAM's front end, called visual odometry (VO)[8], estimates camera motion and feature direction between adjacent frames. It's crucial for accurate attitude estimation with fast response. The algorithm involves three steps: (i) constructing a scale space using Gaussian difference pyramid to identify points of interest, (ii) determining position and proportion of each candidate to identify key points, and (iii) assigning a pointing feature to a key point to obtain a descriptor.

Visual SLAM systems typically use image data from single or multiple cameras as input. These images can be color, depth, or RGB-D. By analyzing them, the system extracts features, calculates camera motion, and builds environment maps. Additionally, it can fuse other sensor data like LiDAR or IMU to enhance accuracy and robustness.

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2.4. The importance of automatic lane changes

Automatic lane change is an important function of automatic driving system, and its design should consider the influence of urban road lights, obstacles and other traffic vehicles on lane change behavior. In order to effectively formulate lane change rules for specific working conditions, the driver's lane change behavior can be simulated, and the influence of surrounding vehicles on lane change vehicles can be considered [9].This approach allows for a more comprehensive consideration of the surrounding environment and vehicle dynamics, improving the performance and reliability of automated lane change systems for a safer and smarter autonomous driving experience.

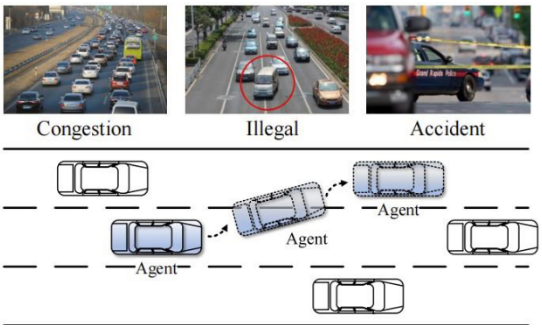

Figure 2. Auto lane change model diagram

Therefore, SLAM technology plays an important role in the automatic lane change of vehicles, and its key is to provide accurate environment perception and vehicle positioning, and provide necessary information support for the decision and control of automatic driving system(figure2).SLAM technology can realize high-precision positioning of vehicle position, including the position of the vehicle lane and the relative position relationship with the surrounding vehicles, so as to ensure the accuracy and safety of lane change decision.

During automatic lane changes, [10] Waymo's system analyzes the movement trajectory and speed of surrounding vehicles based on the information provided by SLAM technology to determine the best lane change timing and path, and ensures the safety of lane changes by maintaining a safe distance from surrounding vehicles. Tesla's autopilot system uses advanced sensors and AI algorithms for environment perception and vehicle control, and its automatic lane change function is an important part of the autopilot system. By conducting experiments on the Tesla system, the role of SLAM technology in automatic lane change can be further verified, and its applicability and performance in different scenarios can be explored.

3. The application of SLAM technology in Tesla automatic lane change

Tesla recently announced a high-profile update to its Autopilot system, adding an automatic lane change feature. The launch of this feature means that Tesla cars can autonomously change lanes on highways without human intervention. At present, this feature has begun to push the upgrade through OTA (Over-The-Air) in the United States, bringing a more convenient and safe driving experience for Tesla owners. In this section, we will delve into the application of SLAM technology behind Tesla's automatic lane change feature and its importance in environmental perception.

3.1. Tesla Sensors detect the surrounding environment

Tesla vehicles are equipped with a variety of sensors, including radar, cameras, ultrasonic sensors, and LiDAR. These sensors are responsible for detecting vehicles, obstacles and road signs around the vehicle.

There are a large number of LiDAR [11] sensors on the market today. As shown in Figure 3, the LiDAR sensor uses an optical signal to measure distance, which is calculated based on the round-trip delay (τ) between the signal emitted by the laser and the signal reflected by the target. Since the speed of light (c) is previously known, the distance to the target (R) can be calculated using an equation.

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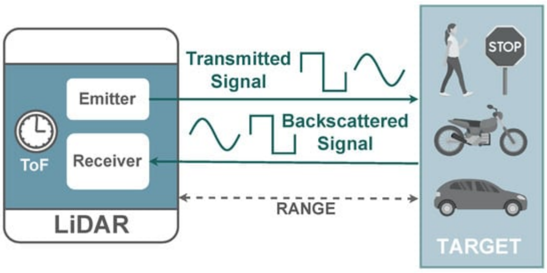

Figure 3. How LiDAR works

According to the principle shown in Figure 3, Tesla's autopilot system uses a variety of sensor technologies to sense the surrounding environment, including radar, cameras, ultrasonic sensors, etc. Among these sensor technologies, different methods may be used to measure the round-trip delay, known as time of flight (ToF), to obtain information about the distance between the target object and the vehicle.

Tesla's Autopilot system may utilize one or more of these sensor technologies to sense its surroundings and perform actions such as automatically changing lanes. The choice of these sensor technologies may take into account factors such as cost, performance, and scope of application to enable a safe and efficient autonomous driving experience.

3.2. Tesla LiDAR data collection

As one of the key sensors, LiDAR outputs point cloud data, which is an accurate 3D image of the vehicle's surroundings. This point cloud data plays a crucial role in autonomous driving tasks, such as object detection and classification, and collision avoidance.

Object detection and classification: [12] Object detection and classification is an important task in LiDAR output point cloud data. First, the raw data needs to be transformed into a point cloud structure, and then point clustering or segmentation is performed to group the points according to common characteristics. This step identifies the set of points that may represent the object. Further processing, such as filtering or deleting redundant data, can then be done to reduce the amount of data to be processed later. These functions are key components of autonomous driving systems that help vehicles drive intelligently and avoid collisions.

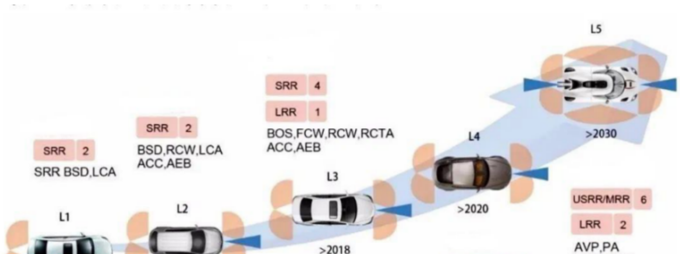

Figure 4. LiDAR sensors capture the surrounding environment

As a Tesla vehicle traverses a city road using autopilot, its sophisticated sensor suite, including LiDAR technology, ensures a safe journey. Approaching an intersection, LiDAR sensors diligently scan the surroundings, capturing detailed data in real-time. This information is swiftly processed by onboard systems, enabling the autopilot to make informed decisions based on dynamic traffic conditions, including pedestrian movement, approaching vehicles, and potential hazards. With unparalleled accuracy and responsiveness, the autopilot system leverages the LiDAR data to calculate optimal

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trajectories and navigate through the intersection safely. It seamlessly adjusts the vehicle's speed and trajectory in real-time, ensuring smooth and confident maneuvering amidst the bustling city traffic.

By leveraging LiDAR data, Tesla's autopilot system calculates optimal trajectories and adjusts the vehicle's speed and direction in real-time, facilitating seamless navigation through complex urban environments. This integration of LiDAR technology exemplifies Tesla's commitment to advancing autonomous driving capabilities, setting new benchmarks for safety and innovation on the road.

3.3. Case scenario

Approaching an intersection, a LiDAR sensor detects a pedestrian at the intersection, as well as another vehicle coming from the side. By analyzing point cloud data in real time, Tesla vehicles' autopilot systems are able to accurately identify these objects and predict their behavior. For example, the system can predict whether a pedestrian intends to cross the road, as well as the speed and direction of oncoming cars. This case demonstrates the use of LiDAR sensors in Tesla vehicles. By capturing and analyzing the point cloud data of the surrounding environment in real time, Tesla's autopilot system is able to accurately identify and classify various objects and make corresponding decisions to ensure the safe driving of the vehicle. Give a schematic that fits this case.

At the same time, LiDAR sensors are also widely used in SLAM (Simultaneous Localization and Mapping) technology. In SLAM, the LiDAR sensor is not only able to sense the structure of the surrounding environment, but also to realize the positioning and map construction of the vehicle in the unknown environment by measuring changes in its own position and attitude. f a lane change is needed to bypass a road obstacle, the system assesses the position and speed of surrounding vehicles based on traffic conditions and selects the best lane change timing and strategy to ensure safety and efficiency.

3.4. Application conclusion

In the Tesla automatic lane change function, SLAM (simultaneous localization and map construction) technology plays a key role. Tesla recently rolled out a major update to its Autopilot system, adding an automatic lane change feature. These sensors include LiDAR, cameras, radar, and ultrasonic sensors that continuously scan and capture data about the environment around the vehicle. When this data is processed and analyzed in real time, the system is able to accurately identify surrounding vehicles, pedestrians, road signs and obstacles, and assess road conditions.

SLAM technology plays a key role in Tesla's automatic lane change feature. Through sensors such as LiDAR, Tesla vehicles can not only perceive the structure of the surrounding environment, but also realize positioning and map construction in an unknown environment by measuring changes in their own position and attitude. This allows Tesla vehicles to more accurately sense their surroundings, allowing them to make intelligent lane change decisions and ensure safe passage. Therefore, Tesla's automatic lane change function not only relies on sensor technology and intelligent algorithms, but also relies on SLAM technology to provide a more accurate and reliable environment perception ability for the vehicle. This combination enables Tesla's Autopilot system to operate safely and efficiently in complex road environments, providing drivers with a more comfortable and convenient driving experience.

4. Conclusion

With the continuous advancement of artificial intelligence and sensor technology, automated lane change systems will more accurately identify obstacles and vehicles in complex road environments and be able to adjust the vehicle's trajectory in real time to ensure safe passage. A new generation of sensor technologies, such as deep learning-based cameras, millimeter-wave radars, and ultrasonic sensors, will provide richer and more comprehensive environment-aware data to the system, making automated lane changes smarter and more flexible. At the same time, SLAM technology will continue to play a key role in providing more reliable support for automated lane change decisions through more accurate environmental maps and vehicle positioning information.

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Future research will also explore how to further optimize SLAM algorithms to adapt to a wider range of road conditions and complex traffic situations, enabling reliable and efficient driving of autonomous vehicles in a variety of scenarios. Therefore, future research will also focus on how to further improve the predictive accuracy and environmental awareness of automated lane change systems through methods such as reinforcement learning and deep learning. By integrating AI technology and sensor data, automated lane-changing systems will be able to more accurately predict the behavior of other vehicles and take appropriate measures when necessary to ensure driving safety.

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