Technical Analysis of Intelligent Vehicle In-Vehicle Navigation Systems

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Abstract. With the high-speed development of the intelligent vehicle industry, people's requirements for transportation efficiency and transportation safety are also increasing. In-vehicle navigation technology can assist drivers to complete driving tasks safely and efficiently, which is the focus of current research. The purpose of this paper is to summarize the technical principles of intelligent in-vehicle navigation systems, and to explore the principles and application status of in-vehicle navigation technology from three aspects: environment analysis, positioning analysis, and path planning analysis. This paper concludes that in the current research, environment analysis technology still exists in the intelligent development space. This paper argues that the center of gravity for the future development of intelligent in-vehicle navigation technology is in environment analysis technology. Through this technology, intelligent vehicles can autonomously analyze the surrounding environment and react to the dynamic environment, which can effectively improve transportation efficiency and safety. The research in this paper summarizes the current results in the field of intelligent in-vehicle navigation, and points out the key development direction in the future.

Keywords: Navigation Technology; SLAM Algorithm; Obstacle Avoidance; Localization Algorithm; Dijkstra's Algorithm and Its Improvements

1 Introduction

In recent years, networks and computers have been realized in society on a large scale, and have become an indispensable tool for human daily life. At the same time, with the human requirements for driving safety, driving comfort and other requirements continuing to improve, the intelligent vehicle industry has also entered a high-speed development stage, intelligent, Internet-connected new automotive industry is gradually moving towards commercialization, the relevant technology has also become a hot research topic [1].

At present, there is a large amount of research literature on navigation systems and intelligent driving, but there are fewer comprehensive narratives on intelligent driving navigation technology, and there is still room for further classification and summarization. For intelligent vehicles, navigation system is one of the keys to ensure their driving performance [2]. This system mainly contains three basic sections of

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surrounding environment analysis, positioning analysis, and path planning analysis, and involves a variety of algorithms, which is an important guarantee for the stable development of intelligent driving technology. At present, the intelligent driving industry is developing at a high speed, and people have researched and summarized a variety of algorithms, and it is difficult to summarize from the algorithm perspective, which is not convenient for readers to understand and analyze; and from the perspective of the basic plate, it is able to expound the related technology of intelligent driving navigation in a relatively clear and concise way.

The purpose of this paper is to summarize the current comprehensive research results of in-vehicle navigation systems, analyze their application in smart driving, and put forward the focus of future development. Firstly, this paper discusses the environment analysis technology and related algorithms and gives a brief introduction to the simultaneous localization and map construction (slam) algorithm in combination with the current demand for realizing autonomous vehicle obstacle avoidance technology. Secondly, this paper introduces all kinds of commonly used algorithms from the perspective of localization analysis, and briefly explains the role of Kalman filter algorithm. Then, this paper analyzes the path planning technology, takes Dijkstra's algorithm and A* algorithm as an example to introduce the working principle of the current commonly used path planning algorithms, and at the same time, summarizes some characteristics of algorithms that are used in specific situations. Finally, this paper looks forward to the future development of in-vehicle navigation technology and believes that in the future, intelligent tools can be applied in a large number of environmental analysis techniques to provide users with a safer and more efficient driving experience.

2 Environmental Analysis Technology and Related Algorithms

Environmental analysis technology refers to the vehicle navigation system relying on sensors and data processing software, detecting the environment in which the service object is located and modeling and analyzing the results obtained, providing basic conditions for the subsequent positioning of the navigation system as well as the path planning service. This technology is the embodiment of the intelligence of intelligent vehicles, which can help drivers grasp the information of the surrounding environment faster and more accurately, and assist drivers in responding to environmental changes. In the actual environment, environment analysis technology can provide environmental information for intelligent vehicles. It is the prerequisite for its utilization of obstacle avoidance-related algorithms. Therefore, the efficiency of the algorithm related to environmental analysis technology will directly affect road traffic safety [3]. At present, the industry believes that the slam algorithm can realize high-precision environmental analysis technology and assist vehicles in obstacle avoidance. This section will introduce information about slam algorithms and obstacle avoidance technology.

2.1 Introduction to Slam Algorithm

Slam algorithm is an algorithm that allows intelligent vehicles to rely on their own environmental analysis technology to obtain environmental information and real-time localization. This algorithm enables intelligent vehicles to complete localization in the absence of map information or map information changes, is the prerequisite for subsequent navigation and positioning technology and path planning technology.

Most of the old-style positioning relies on the inertial positioning system (IMU) for navigation, this system can not grasp the information of the surrounding environment, and the positioning accuracy will be greatly reduced in the process of long-term use, all the shortcomings of the slam algorithm to promote the development of [4]. The initial generation of the slam algorithm relies on a single sensor, and the data collected has a large error [5]. The newer slam technology sensing system is mainly a multi-sensor fusion of LIDAR and camera. The former has strong stability, high detection accuracy and a large sensing range, but it is expensive and unable to deal with the detailed information of the environment and re-localization; the latter is simple in structure and rich in information, but there will be incomplete data collection for the detection of high-speed moving objects [6]. The combination of the two can realize complementary, and then better complete the collection and analysis of environmental data.

2.2 Obstacle Avoidance

Obstacle avoidance is one of the bases for ensuring the safety of intelligent driving, and it is also the most valuable application area of environmental analysis technology. In the actual environment, the driver's driving skills have a great impact on safe driving. When an unexpected situation occurs, the driver is likely to cause traffic accidents due to lack of concentration or too late to react. However, if environmental analysis technology is used in intelligent vehicles, a large number of sensors are installed, and the data is analyzed by the onboard intelligent computer, it is possible to react quickly to unexpected road conditions, thus greatly improving safety.

The realization of obstacle avoidance ability also relies on various types of algorithms, such as the rapid expansion random tree (RTT) algorithm, predictive collision detection algorithm, and tentacle algorithm, etc., which are based on the sensors and the computer's ability to perceive and analyze the surrounding environment, i.e., based on the environment model data provided by the slam algorithm [7]. Taking the predictive collision detection algorithm as an example, this class of algorithms is based on deep learning and model foundation, analyzing and projecting based on the current data, and can predict the obstacles that may appear in the future, so as to effectively realize the demand for obstacle avoidance in dynamic environments [8].

3 Positioning Analysis Technology and Related Algorithms

Positioning analysis technology, that is, relying on specific equipment and technology, to determine the position of the object in space. This technology mainly uses various physical signals (e.g., electromagnetic waves, sound waves, etc.), known reference points (e.g., satellites, base stations, etc.) or its motion state (e.g., IMU), and calculates the location of the target object through data processing and analysis by computers [9,10]. Currently, there are various kinds of algorithms related to this technology, and in this section, three technology platforms, namely satellite-based localization algorithms, base station-based localization algorithms, and inertial navigation algorithms are described. In addition, the slam algorithm summarized in the previous section can also be used for autonomous positioning.

3.1 Satellite-Based Positioning Algorithms

Pseudorange positioning algorithms are heavily used for civil navigation. Satellites continuously send signals to the ground, mainly including the spatial position of the satellite and the time of sending. Since the signal propagation speed is the speed of light, after the user receives the signal, the distance from the satellite to the user is calculated based on the product of the signal propagation time and the speed of light. This distance contains various error factors and is known as pseudo-distance. This algorithm is relatively simple, does not require the support of a large number of complex hardware devices, and can provide users with positioning services in open environments. However, in complex environments, the error of this localization algorithm is large [11]. At present, this technique is still widely used.

The precision single-point positioning (PPP) algorithm is a high-precision single-point positioning technique. It utilizes precise satellite orbits and clock products, combined with pseudorange and carrier phase data observed by the user's receiver, through a series of deep algorithms to deal with the errors in the data, including pseudorange error, whole-week ambiguity of carrier phase, etc. PPP does not need to rely on additional base stations to assist in localization, but rather improves the localization accuracy by means of a worldwide high-precision product and a highly complete error model [12,13].

3.2 Base Station Based Positioning Algorithms

Signal Time Difference of Arrival (TDOA) positioning algorithm is a key technique for utilizing base station positioning, where location information is obtained by calculating the difference in transmission time of signals from the mobile terminal to different base stations. By analyzing the data from at least three base stations, two hyperbolas can be determined, i.e., an equation is obtained. The solution of the equation is found, which is the process of determining the location. In solving the TDOA equation, Chan's algorithm and Taylor's algorithm are also used [14]. This algorithm does not require strict clock synchronization between the transmitter and receiver, so it is less costly to achieve positioning and is more resistant to environmental interference, but it is more complex to compute, and the accuracy also depends on the number and layout of receivers [15].

The Time of Arrival (TOA) localization algorithm is similar to TDOA, and its core principle is to measure the time of the signal from the mobile end to reach the receiver, the main difference from TDOA is that it calculates the time of the signal from sending to arriving at the base station more directly, and determines the circle with three base stations as the center, and the distance of the signal propagation as the radius, and the intersection point of the three circles is the result of the localization. This algorithm is computationally simple and has high localization accuracy under ideal circumstances. However, TOA requires the transmitter and receiver to strictly synchronize their clocks and is greatly affected by the external environment (e.g., multipath effect, noise interference), and the equipment cost is high [15].

In the practical environment, TOA has high accuracy and time requirements and is widely used in radar, sonar, indoor positioning and other environments.TDOA has low cost, so it is widely used in the civil industry, such as mobile communications, UAV positioning, etc., and will also assist satellites to participate in the navigation system.

3.3 Kalman Filtering Algorithm

Kalman filtering is an efficient recursive filtering algorithm that is widely used in areas where dynamic systems need to be measured. It can establish a series of state equations and observation equations based on the error of the inertial navigation system, and rely on different error models to correct the error brought by the inertial navigation system. In addition, it can also correct the error based on the information provided by external information sources such as satellite navigation systems. Therefore, the Kalman filtering algorithm can effectively fuse the data from the inertial navigation system and other navigation systems, and can provide users with more accurate positioning information. When the satellite signal is poor, the inertial navigation system can rely on the Kalman filtering algorithm to independently complete high-precision positioning, which can also provide users with high-quality services [13,16].

4 Path Planning Technology and Related Algorithms

Path planning technology refers to the technology that provides at least one feasible path from the starting point to the end point for the target under the premise of determining the location of the target and its surrounding environment. With the deepening of related research, the path planning technology is not limited to providing users with several alternative paths, but is able to analyze the dynamically changing road conditions through the network and satellite systems, and keep analyzing the appropriate paths for users. At the same time, the path planning technology can also provide users with the shortest time, shortest path and lowest cost paths according to their preferences. In this section, the most commonly used Dijkstra's algorithm and its improved algorithms are analyzed for the application of path planning techniques.

4.1 Dijkstra's Algorithm

This algorithm is mainly used to calculate the shortest path from one node to all other nodes and is a greedy algorithm. It starts from a set starting point, and repeatedly selects and marking the unvisited node closest to the starting point, after which it updates the distance of its neighboring nodes until it reaches the endpoint. In practice, each intersection can be considered as a node, and the time spent, distance traveled or energy consumption of a vehicle's actions between each intersection can be considered as the distance between nodes. It meets the needs put forward by people for path planning technology, and the algorithm is simple and intuitive, so it can be used in urban transportation in a large number of applications. However, its spatial complexity is high and may suffer more in larger environments [17,18]. It also has a non-negligible limitation in that it cannot handle the case of negative edge weights. Currently, people are continuously optimizing the D algorithm, and the A - Star (A*) algorithm described later is one of the optimization results.

4.2 A* Algorithm and D - Star (D*) Algorithm

The A* algorithm is an improvement of Dijkstra's algorithm. Instead of exhaustively enumerating the available nodes, this algorithm utilizes a heuristic function to estimate the distance from the node at the current location to the next node and combines the cost function and evaluation function to derive the node with the smallest combined cost for expansion. This algorithm is significantly more efficient compared to Dijkstra because it embeds multiple functions that can greatly reduce the difficulty of screening individual nodes, thus saving time. However, at the same time, the operational efficiency of this algorithm also depends on the efficiency of these functions. If the heuristic functions are defective, then the efficiency of this algorithm is significantly reduced [19].

D* algorithm is an improved algorithm of A* algorithm. This algorithm is an incremental path planning algorithm for use in dynamic environments and has the ability to handle dynamic environments compared to the previous two generations of algorithms. It is capable of updating the changes in the environment through incremental search and backward search in a timely manner, so that it is better able to provide the user with appropriate path planning solutions in real-world environments. In addition, it has the significant advantage of reducing the amount of computation by utilizing incremental updating, which ensures the timely updating of information in dynamic environments, which is one of the important reasons why it can be used in a large number of applications with robots, drones, and intelligent driving. Of course, the improvement of algorithmic capability will inevitably increase the algorithmic complexity at the same time, which is one of its non-negligible drawbacks. To address this issue, researchers have proposed a simplified version of the D*Lite algorithm.

4.3 Other Algorithms

In addition to this, the path planning algorithms that are heavily utilized in in-vehicle navigation are the ant colony algorithm and the genetic algorithm. The ant colony algorithm will record the data of vehicle trajectories on each path, and through data analysis, the path that leaves more trajectories is the best path. This algorithm can help users find the optimal solution, but also can effectively solve the congestion problem. However, due to the need to collect data, its convergence speed is slow, the arithmetic complexity is high, and the operation efficiency is low [20]. Genetic algorithm applies the path sets to the genes in the biological genetic model, and through the continuous iteration of the combination of solution sets, so as to find the optimal solution. This algorithm is suitable for path planning problems with complex scenarios and many constraints. Similarly, the performance of this algorithm is limited by various parameters, and unreasonable parameters will lead to reduced computational efficiency [21].

5 Prospect

At present, the intelligent device industry has entered a stage of rapid development, and people are no longer limited to using small intelligent devices such as cell phones and computers. In the civil field, intelligent vehicles have received great attention as a new type of intelligent device, and what can maximize the intelligence of vehicles is the in-vehicle navigation system. Among the three technology segments mentioned in the previous section, the positioning analysis technology and path planning technology have been developed relatively well, while the environmental analysis technology is the bottleneck that restricts the commercialization of intelligent vehicles, and there is a great potential for development. Today's environmental analysis technology can only deal with relatively simple dynamic environments, which means the obstacle avoidance technology can not meet people's expectations, which further leads to intelligent vehicle safety can not be guaranteed.SLAM algorithms can be constructed in real time through the environment map and locate the position of the vehicle, to provide intelligent vehicles with a more accurate perception of the environment. However, the current SLAM algorithms still have major challenges in dynamic environments, light changes, and sensor errors, which affect their reliability in practical applications.

6 Conclusion

With the wide application of intelligent vehicles and the rapid development of the transportation industry, there has been a large output of research on in-vehicle navigation systems, but there is still a lack of relevant summary articles. This paper classifies and summarizes the currently available navigation technologies as well as related algorithms, aiming to make it easier for readers who are initially exposed to this field to grasp the basics of this neighborhood. This paper divides the in-vehicle navigation techniques into three aspects: environment analysis, localization analysis and path planning, and gives a brief introduction to the algorithms that implement the above techniques. In the part of surrounding environment analysis, this paper introduces the method of constructing maps using sensors and slam algorithms, and summarizes the algorithms for realizing the obstacle avoidance ability of vehicles, which is closely associated with intelligent vehicles and still has great research space in the future; in the part of localization analysis technology, this paper illustrates the working principle of the current localization technology based on different algorithms by taking GPS and BDS as examples. In the part of path planning analysis, this paper mainly introduces the definition of this technology as well as the widely used D algorithm and its improvement algorithm. One of the keys to improving the capability of intelligent vehicles in the future lies in the fact that in-vehicle navigation systems need to have the function of helping users to analyze the surrounding environment and realize intelligent obstacle avoidance. This function can effectively assist the user to drive and improve vehicle safety and traffic efficiency, which is very worthy of in-depth research.

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