

Progress made in researching autonomous vehicle systems based on BeiDou navigation

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Abstract. The evolution of smart transport systems has made autonomous vehicles a central focus for research. The BeiDou navigation system's highly accurate location data is vital for environmental detection, autonomous vehicle decision-making, and navigation. This research aims to develop and actualize a system for autonomous vehicles to plan routes and evade obstacles, utilizing the BeiDou satellite navigational framework. Consequently, this document introduces an algorithm for planning paths and avoiding obstacles that integrate BeiDou navigation data, capable of adjusting to intricate traffic conditions and enhancing the safety and efficiency of autonomous vehicles. Verification of the suggested algorithm was conducted on the environment simulation platform within the ROS operating system, revealing the algorithm's capability to create the ideal path and successfully evade dynamic obstacles. The practical vehicle testing verifies the algorithm's practicality and steadiness in traffic situations. Ultimately, the document encapsulates the study's findings and outlines prospective research avenues, encompassing the acquisition of both image and depth information, along with conducting image recognition and car tracking.

Keywords: Navigating BeiDou; Autonomous vehicle; Devising routes; Managing to avoid obstacles.

1. Introduction

Autonomous technologies are indeed a sophisticated amalgamation of various technologies, with the key connection being a vehicle's precise positioning. In real-world applications, this position should at least achieve sub-metre accuracy to precisely determine lane identities. China's BeiDou Navigation System, an international satellite-based navigation system, offers highly accurate positioning services, opening doors for autonomous technology advancement.

Research indicates that despite the notable advancements in positioning technology by autonomous vehicles, their precision and stability in intricate settings require further enhancement. The research focuses on investigating the integration of BeiDou navigational tech into unmanned vehicle systems, to augment the environmental perception and decision processes in unmanned vehicles through better positioning precision and dependability. This research encapsulates a BeiDou-based positioning system for autonomous vehicles that ensures centimeter accuracy and stability in changing traffic conditions. It also integrates various path planning and obstacle avoidance algorithms, integrating BeiDou's navigation information to achieve ideal path selection and instantaneous obstacle avoidance in fluctuating traffic contexts. This research will employ sophisticated algorithmic designs, simulations, and actual vehicle trials to assess the efficacy of the suggested system.

This document will initially present the fundamental structure of autonomous vehicles and the foundational elements of the BeiDou navigation system. Following this, we'll elaborate on the research and the experimental framework of path planning and algorithms for avoiding obstacles. The results segment will display metrics and analyses of system performance.

This research is expected to pave the way for innovative navigation technologies in autonomous vehicles, significantly contributing to the development of intelligent transportation systems. By leveraging the BeiDou system's advanced positioning services, autonomous vehicles can achieve unprecedented levels of accuracy and reliability, leading to safer and more efficient travel. The integration of BeiDou with autonomous vehicle technology could set a new standard for the industry, offering a robust solution for navigating the complexities of modern traffic environments.

2. Principles of understanding concerning Autonomous Vehicles and BeiDou navigation

2.1. Creation of an unmanned vehicle system utilizing BeiDou navigation

2.1.1. Comprehensive structure of unmanned vehicles

The fundamental architecture of unmanned vehicles primarily (Figure 1) consists of modules like perception recognition, decision-making planning, and control execution, among others. Primarily, the perception recognition unit detects the car's surroundings using cameras, LIDAR (Light detection and ranging), and radar. It then employs BeiDou satellite navigation to pinpoint the car's exact road location. The decision-making module integrates environmental data from various sensors to gather detailed, three-dimensional environmental details. Ultimately, the system, guided by the control and execution module's algorithms, designs the car's travel path, encompassing its speed and direction.

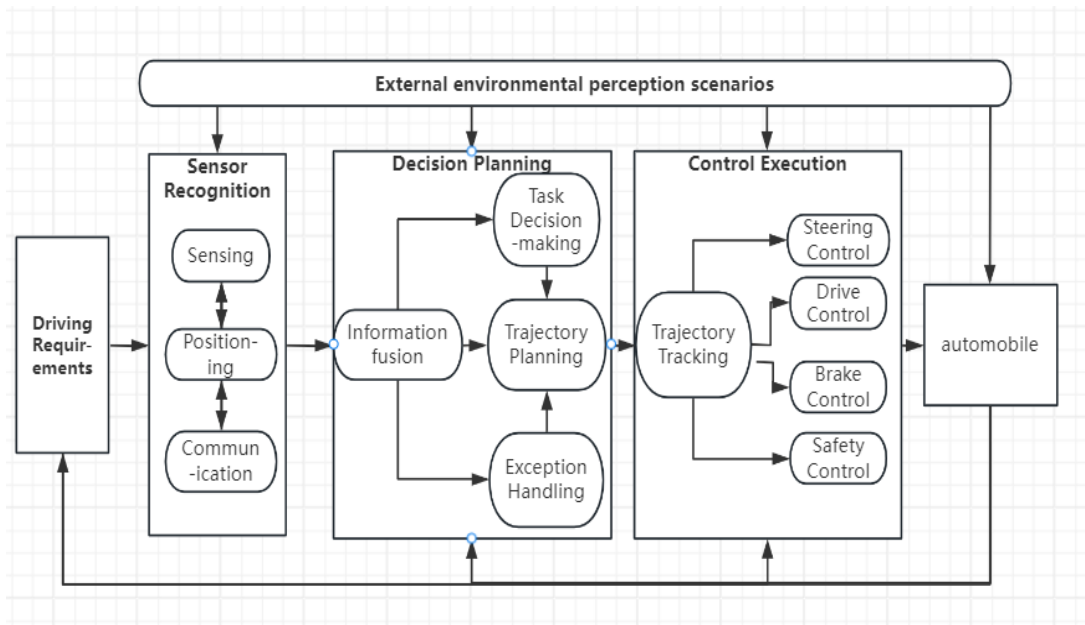


Fig 1. The overall structure of the autonomous vehicle.

The design of the unmanned car's control system primarily incorporates BeiDou positioning technology, hybrid semi-solid LIDAR technology for obstacle avoidance, and software development technology.

2.1.2. Comprehensive System Layout

Essentially, the unmanned vehicle system is a type of autonomous mobile robot, encompassing the control system, drive, actuator, and sensor system from a control standpoint. Comparable to the human brain, the control system primarily executes task and information processing, generates command signals for control, and manages the robot's algorithmic operations, motion control, human-computer interactions, system oversight, and various other tasks. Comprising both internal and external sensors, akin to human senses and nerves, the sensor system primarily handles signal capture and feedback, enabling the robot to perceive its surroundings. The components of the drive and actuator encompass the drive system and actuator, primarily transforming control system commands into necessary signals for the actuator to execute specific actions. Typically, mobile robots operate using DC motors for actuator movement, while other devices employ servo systems for actuator roles.

2.1.3. Design of Sensing Systems

The unmanned vehicle employs sensors like LIDAR and cameras to detect and construct indoor environment maps for gathering data [1]. The unmanned vehicle system primarily utilizes Multi-line LIDAR for perception, offering highly accurate environmental mapping and crucial assistance in its

navigation and route planning. Primarily, the depth camera's role is to identify and pinpoint targets, aiding in the unmanned vehicle's navigation. During the process of planning and navigating paths, ultrasonic sensors play a crucial role in identifying and evading obstacles. Information from IMU units and encoders serves as a benchmark for laser SLAM and path-planning algorithms, aiding in the creation of highly accurate maps and the planning of optimal paths. In situations where multi-line LIDAR faces constraints, the system utilizes a depth camera for road marking and identifying environmental obstacles, aiding the unmanned vehicle in devising and managing its route, thereby creating a strategy for constructing a multi-sensor fusion map. Concurrently, the depth camera can identify fluctuating barriers in its surroundings, enabling it to perform operations to evade obstacles, thereby enhancing the system's stability and dependability, and adjusting to the functioning of unmanned vehicles in varied operational settings.

2.1.4. Design of the Control System

Attaining autonomous driving capabilities in unmanned vehicles necessitates the design, implementation, and testing of a proficient control system. The unmanned vehicle's control mechanism is bifurcated into two distinct tiers: the basic control and the advanced control. Control at the base primarily governs the movement of unmanned vehicles, encompassing aspects like motor and wheel speed regulation. The primary role of high-level control lies in activities like devising pathways and identifying targets. This document opts for the STM32 microcontroller, a bottom-layer control system noted for its scalability, stability, and compatibility with diverse communication protocols [2]. The primary role of high-level control lies in orchestrating the unmanned vehicle's path and autonomously evading obstacles, encompassing aspects like route planning and decision-making in obstacle avoidance. This document utilizes ROS (Robot Operating System) as an advanced control system, offering benefits like modularity and cross-platform compatibility, aiding in the creation and execution of path planning and independent obstacle avoidance algorithms.

2.2. The foundational concept of navigating BeiDou

2.2.1. Structure of the BeiDou satellite navigation system

The initial component consists of the space-based BeiDou satellite, primarily delivering specific temporal signals, distance data, and the satellite's immediate coordinates; the subsequent segment is the terrestrial control section, primarily tasked with space satellite data analysis; the third segment is the terrestrial user, primarily gathering and processing diverse satellite signals to deduce the user's precise location via computations. Combined, these three components form the BeiDou satellite navigation system [3].

Satellite positioning operates on the concept that if a device capable of receiving satellite signals, like a mobile phone, is held in a specific location on Earth, the crucial step is to ascertain the distance from the satellite to the user's terminal. This is achieved by initially using the satellite's Ephemeris Data to obtain the immediate coordinates of the satellite data (x_1, y_1, z_1) [4].

Next, calculate the gap between the satellite and the user's endpoint: dispatching the electromagnetic wave signal for distance measurement, determining its travel speed, and then multiplying this electromagnetic wave from the satellite to the mobile phone to calculate the distance between the satellite and the user [5].

Ultimately, the three-ball intersection principle dictates that a minimum of three satellites should simultaneously transmit electromagnetic waves from the Earth to a user [6]. Upon receiving the satellite's signal at the circle's center, the satellite-user distance becomes the circle's radius. In this process, three orbs can form two points of intersection. The user must be situated at the junction of these three orbs. Subsequently, based on common sense geography, a non-standard point can be disregarded if it doesn't align with common sense, allowing for the identification of the alternate intersection point as the ground point's location, which is the intersection principle of the three spheres. Figure 2 illustrates the derivation of the user terminal's three indeterminate coordinates (x, y, z) , aligning with the BeiDou system's positional concept.

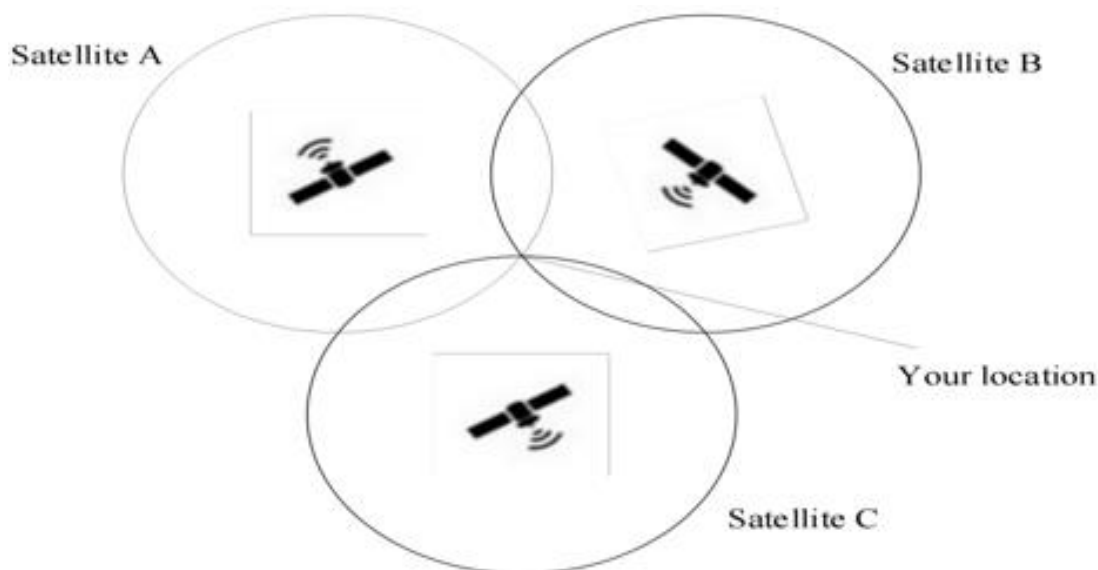


Fig 2. Schematic Diagram of the Three-Sphere [5].

2.2.2. Benefits and Characteristics of the BeiDou System

The BeiDou system functions as both a receiver and transmitter, encompassing both navigational and positional capabilities, along with communication features. At the heart of the system lies the ground control center, responsible for computing user data, uploading it to satellites, and subsequently receiving satellite signals to relay back to the user’s post-calculation, akin to the interaction between a mobile phone and a base station. The distinction between the user group and other navigational tools lies in the BeiDou system's dual roles in positioning and communication. Its superiority lies in meeting the user's communication requirements. Comprising three orbits (Table 1), this system allows the satellites within each orbit to work in unison [7].

Table 1. Comparison of the Four Major Global Navigation Systems.

Name	BeiDou-3	GPS	GLONASS	GLONASS
Country/Region	China	United States	Russia	Europe
Completion Time	2020	1994	1996	Expected 2020
Number of Satellites	30	24	24	30
Functions	Positioning, Navigation, Timing, Message Communication, International Search and Rescue	Navigation, Measurement, Timing	Positioning, Navigation, Speed Measurement, Timing	Positioning, Navigation, Timing, Search and Rescue
Anti-Jamming Capability	Strong	Weak	Strong	Strong
Coverage	Global	Global (98%)	Global	Global
Advantages	Short Message Communication	Highest Market Share in Civil Use	Strong Positioning Performance near the North Pole	Non-military Control, Real-time High Precision Positioning
Positioning Accuracy	10 meters	5meters	5 meters	1 meter
Speed Accuracy	0.2 meters/second	0.1 meters/second	0.1 meters/second	0.1 meters/second
Timing Accuracy	20 nanoseconds	10 nanoseconds	20 nanoseconds	20 nanoseconds

The selection of BeiDou navigation as the system for this study was due to its ability to yield detailed data, which aids in data retrieval and resolution, ensuring precise positioning and minimizing errors in experiments.

3. Path planning and obstacle avoidance control system design for driverless vehicles based on BeiDou navigation

3.1. Study on Strategies for Steering clear of obstacles in Unmanned Vehicles

3.1.1. Identifying barriers using multi-line LIDAR and illustrative analysis

Observing the unmanned vehicle during driving primarily involves using multi-line LIDAR to scan the environment. This research employs the Sprint 16-line LIDAR (RS-LiDAR-16). Utilizing LIDAR, this radar system scans the nearby environment to gather 3D data on obstacles faced by unmanned vehicles. It achieves a peak data output of up to 320,000 points per second, concurrently emits and captures high-frequency laser beams, and executes real-time 3D imaging by rotating 360 degrees. This process ensures precise 3D spatial point cloud data and object reflectance, followed by processing and analyzing the obstacle's point cloud details, acquiring the unmanned vehicle's point cloud data, and subsequently processing and analyzing it. Once the obstacle point cloud data is acquired, it undergoes processing and analysis to ascertain the unmanned vehicle's safe transit zone.

RoboSense's road test revealed the effectiveness of the LIDAR experiment: a Tesla vehicle fitted with RoboSense's 16-wire hybrid solid-state LIDAR traversed a 5-kilometer stretch of an actual main road in Shenzhen's Nanshan District, primarily evaluating the LIDAR's capacity to gather immediate environmental information, oversee road signage, and manage diverse road configurations and traffic scenarios during its functioning. As the vehicle operates, the LIDAR-gathered real-time point cloud data will appear on the car's screen, encompassing comprehensive details of the adjacent road surface. Furthermore, the car's computer is equipped with deep learning algorithms that enable the system to pinpoint the intended object and create a mark.

Sprint 16-wire LIDAR stands out from other LIDAR brands due to its distinctive benefits and characteristics: it integrates hybrid solid-state LIDAR technology, merging the superior efficiency of other mechanical LIDARs with the dependability of solid-state LIDARs. Its compact size and precise measurement abilities render it a formidable contender in these areas, and it surpasses certain premium multi-line LIDARs in competitiveness. Consequently, the Sprint 16-wire LIDAR presents a more economical option while preserving superior performance.

3.1.2. Choosing an unmanned vehicle locator through BeiDou navigation

Based on the operational needs of the unmanned vehicle, it must ascertain its location along with the target waypoint's position and compute the distance separating these two points. In this study, the sensor used to ascertain the unmanned vehicle's location utilizes the RTK580 differential BeiDou satellite receiver. This receiver is compatible with various satellite navigation systems like BDS, GPS, QZSS, GLONASS, and Galileo, guaranteeing precise global positioning.

RTK580 was selected due to its error rate being under 1cm, eliminating the need for a physical DTU 4G card, requiring only a USB cable for direct connection, and the ROS system's plug-and-play nature. Additionally, it's capable of directly translating latitude and longitude into the local ENU coordinate system via the ROS driver [8].

Tsinghua University's study on RTK580's case performance in autonomous vehicles led to the creation of mobile unit cooperative control algorithms through the simulation of an actual car. The RTK580 facilitated a more precise simulation and evaluation of an autonomous vehicle's efficacy in multi-objective cooperative motion control, thanks to its high-precision positioning data. Additionally, Shenzhen University's study employed the RTK580 receiver and UAV-acquired aerial images to transmit to the unmanned vehicle for navigation. The research on ground-air cooperative control highlights how RTK technology could enhance the navigational precision of unmanned vehicles. This demonstrates RTK580's varied uses in unmanned vehicles, ranging from scientific studies to real-world navigation, with RTK580's precise positioning via BeiDou navigation being vital for enhancing unmanned vehicle efficiency.

3.2. Techniques for designing paths and managing obstacle avoidance control

3.2.1. Algorithm for Path Planning and Avoiding Hindrances

This research opts for the AC-QL algorithm, which merges the ant colony algorithm with the Q-Learning algorithm [9, 10]. This integration enables the mobile robot to evaluate not just the impact of Q value in state alteration and action choice, but also the effect of pheromone components in the ant colony algorithm on its subsequent decision-making, enhancing both the precision and rapidity of its path planning.

Within this research, the repetitive algorithm Eq. Utilization of (3-1) involves establishing a novel pheromone matrix $Z(s, s')$:

$$Q^{k+1}(s,a) = Q^k(s,a) + \alpha\{r(s,a) + \gamma \max_{a' \in A} [Q(s',a') + Z(s,s')] - Q(s,a)\} \quad (1)$$

Here are the precise procedures:

Set up the system's parameters for the unmanned vehicle's minicomputer in its path planning, primarily focusing on the quantity of pheromone Y , and the initial Q value, among others.

The primary control unit of the unmanned vehicle determines its initial location in the environment and creates a universal route appropriate for its journey, employing the global path planning algorithm based on the predetermined positional data of both the starting and ending points.

The autonomous vehicle creates the most efficient global route, with the master control module prepared to initiate the action post-loading driving data. Subsequently, the unmanned vehicle obtains instructions from the host computer software to choose the subsequent action and proceed along the intended route, adhering to the pre-established behavioral strategy.

Ascertain the unmanned vehicle's immediate location while navigating the differential BeiDou guide's dirty RTK at the vehicle's forefront, monitor the nearby environment via the multi-line LIDAR, and identify potential hindrances during the task's execution through the same LIDAR. Following the subsequent action a , acquire updated state data s' and receive rewards r from the smart body post-action selection and movement. The procedure focuses on the unmanned vehicle, creating a simulation map to refine the combined evaluation of Q value and pheromone levels using the enhanced Q-table recursive formula (3-9), after which the motion status of the emerging obstacles is differentiated.

Evaluate if the unmanned vehicle robot impacts the obstacle, and upon collision, it assesses the obstacle's distance and status, determining if the obstacle is stationary or moving. The unmanned vessel keeps the Q-table's data based on the obstacle's distance and condition before returning to step (2); if not, it proceeds with the path-planning activity.

Assess if the unmanned vehicle's location aligns with the present target waypoint, and if so, issue an instruction to halt the engine; if not, the algorithm halts; otherwise, it reverts to step (1).

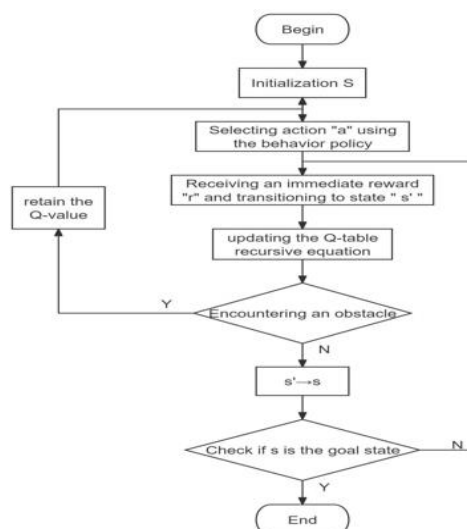


Fig 3. Algorithm Flowchart.

The Autolabor Pro 1 mobile robot, via Shanghai Ocean University's feasibility test of the AC-QL algorithm, is utilized to survey its immediate surroundings, followed by instantaneous data transfer via the multi-line LIDAR to finalize the map's creation, thereby confirming the algorithm's practicality [11]. The trials demonstrated the widespread applicability and steadiness of the AC-QL algorithm in devising paths, making it suitable for real-world use in settings like ROS. In contrast to the conventional Q-Learning algorithm, the AC-QL algorithm excels in managing continuous action spaces, crucial for autonomous vehicles needing precise control. For their path planning and obstacle avoidance, the AC-QL algorithm offers greater adaptability and flexibility than the ant colony algorithm due to its ability to offer immediate path planning and decision-making on obstacle avoidance, unlike the ant colony algorithm, which is limited to specific situations like in static or semi-static settings

4. Conclusion

This document begins by examining the operational needs of unmanned vehicles, drawing from the extensive literature on BeiDou navigation and unmanned vehicle systems, and encapsulating the control strategies for navigating paths and evading obstacles in unmanned vehicles, tailored to their real-world operational conditions. The primary outcomes of the research are outlined below:

The study delves into the pertinent concepts of BeiDou navigation and unmanned vehicles.

Concurrently, research on the trajectory planning of unmanned vehicles utilizing BeiDou navigation is underway. Initially, the focus is on choosing the LIDAR sensor for the unmanned vehicle. Next, the optimal device for signal reception is chosen to position the unmanned vehicle.

This study explores the multi-threaded LIDAR-based obstacle avoidance system and BeiDou navigation-based path planning. It demonstrates, via experimental evidence that BeiDou's navigation system for unmanned vehicles, encompassing positioning, navigation, timing, and short message communication, synergizes with 5G's high-bandwidth, low-latency, and wide-connectivity features. This integration enhances everything's interoperability, and precise teamwork, and ensures the safety and dependability of unmanned vehicles with significant functional needs. Nonetheless, while the BeiDou system offers worldwide services, in certain regions or adverse weather conditions, satellite signals can be obstructed or disrupted, impacting the precision and consistency of positioning, thereby complicating the steady functioning of unmanned vehicles in intricate settings. Furthermore, to enhance the precision of environmental perception and decision-making, the BeiDou system must be amalgamated with additional sensor information from the unmanned vehicle, necessitating the creation of novel algorithms for the ideal amalgamation of diverse sensor data.

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