Bidirectional Inductive Dynamic Updating Parking System Based on CH Algorithm

Yilu Yang*, Yi Kong

School of Energy Science and Engineering, Henan Polytechnic University, Jiaozuo, Henan, 454003, China

*yangyilu1004@yeah.net

Abstract. This study developed a bidirectional induction parking system based on the Contraction Hierarchies (CH) algorithm, aimed at enhancing operational efficiency and customer satisfaction in parking facilities. The CH algorithm creates a hierarchical graph structure to accelerate vehicle path queries, effectively finding vacant parking spaces to reduce traffic congestion and optimize parking lot utilization. The system integrates high-performance microcontrollers, sensors, cameras, and communication modules for real-time monitoring and data processing. Using bidirectional search strategies, the system provides the shortest entry and exit paths, significantly improving query efficiency. Experimental results demonstrate that compared to traditional parking systems, this system greatly reduces search times, enhances parking space utilization and traffic flow management efficiency, and improves user experience. This study highlights the effectiveness of CH algorithm-based parking systems in addressing modern urban parking challenges and demonstrates their potential application in intelligent transportation systems.

Keywords: CH algorithm, Bidirectional induction system, Path planning, Intelligent parking system, Real-time data processing

1 INTRODUCTION

With urbanization accelerating and private vehicle numbers rapidly growing, urban parking scarcity has become a critical challenge for city management. Traditional parking systems, relying on manual or basic automated monitoring, are inefficient during peak times, leading to underutilized parking resources and long waiting periods. Current technologies like manual monitoring and sensor-based automation have limitations in data processing and adaptability to dynamic traffic environments. This study proposes a bidirectional induction parking system using the efficient Contraction Hierarchies (CH) algorithm to address these issues. The system aims to optimize vehicle path planning, improve parking management efficiency, reduce travel times, enhance parking space utilization, and lower energy consumption and emissions[1]. By leveraging the CH algorithm, the system enhances real-time parking management, improving responsiveness and accuracy. This innovative solution not only supports urban traffic

G. Chen et al. (eds.), *Proceedings of the 2024 International Conference on Rail Transit and Transportation (ICRTT 2024)*, Advances in Engineering Research 254,
https://doi.org/10.2991/978-94-6463-610-9_7

management but also contributes to the advancement of intelligent transportation systems, providing insights for similar traffic management challenges[2].

2 CH ALGORITHM AND ITS APPLICATION IN PATH PLANNING

The CH algorithm has several significant advantages when applied to medium to large parking lots, which can greatly enhance operational efficiency and customer satisfaction. Firstly, the hierarchical graph structure created during the preprocessing stage accelerates the pathfinding process, allowing vehicles to quickly find the shortest route to available parking spaces, especially beneficial in complex network scenarios[3]. Secondly, the CH algorithm reduces vehicle circling within the parking lot, mitigating congestion and improving traffic flow, thereby enhancing parking efficiency and reducing unnecessary carbon emissions. Additionally, by optimizing parking resource allocation, the algorithm improves overall utilization and prevents overcrowding in some areas while leaving others underutilized. Furthermore, the algorithm supports real-time data processing, dynamically updating paths based on current parking space availability to maintain system responsiveness and accuracy[4]. Moreover, because the preprocessing stage is completed during system initialization and does not require frequent recalculations, the CH algorithm is cost-effective to maintain, easy to integrate, and scalable for future expansions. Most importantly, by swiftly identifying vacant parking spots and providing direct navigation, it significantly enhances customer experience, allowing customers to start shopping or other activities promptly, thereby boosting overall customer satisfaction[5].

3 DESIGN OF BI-DIRECTIONAL GUIDANCE SYSTEM FOR PARKING LOTS

3.1 System Architecture

This parking lot bi-directional guidance system utilizes the high-performance STM32F103C8T6 microcontroller, integrated with HJ-IR2 infrared obstacle avoidance modules, geomagnetic sensors, IP cameras, and Wi-Fi communication modules to monitor real-time occupancy and vehicle information for each parking space. Utilizing the Wi-Fi module, the system uploads data to the management platform in real-time, ensuring timely updates and processing of information. At the entrance of the parking lot, users can select vacant parking spaces via an automatic positioning platform, while the system intuitively displays parking space statuses using multi-colored LED lights, significantly enhancing user experience and operational efficiency of the parking lot[6]. System framework as shown in Figure 1.

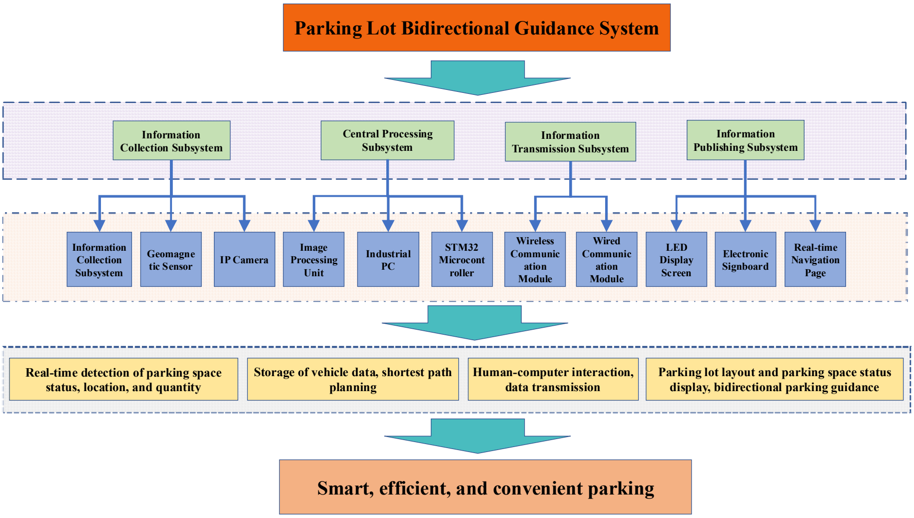

Fig. 1. Bidirectional Guidance System Workflow Diagram.

On the software side, the microcontroller runs the lightweight real-time operating system FreeRTOS on the STM32 microcontroller, responsible for multi-threaded task management and real-time processing of sensor data. The upper computer software is deployed on an industrial-grade PC, which not only processes and stores data from the microcontroller but also manages data using the MySQL database system. It executes the CH algorithm to plan optimal parking routes. Additionally, the system provides a user-friendly graphical interface that allows users to easily view available parking spaces, follow guidance paths, and obtain real-time location and parking information via web or mobile applications.

During the deployment and testing phases, the system undergoes rigorous unit testing and integration testing to validate the independent and collaborative capabilities of all hardware and software components.The on-site deployment phase involves installing and debugging the system in the actual parking lot environment to ensure adaptation to specific operational conditions. The system also plans for regular maintenance and software updates to accommodate environmental changes and meet new user requirements, ensuring stable operation and efficient management during peak periods[7].

3.2 The Application of CH Algorithm in the System

The shortest path guidance in the parking lot uses the CH algorithm for positioning and bidirectional guidance. The specific process of shortest path planning is as follows:

(1) Node Importance Evaluation and Ranking

Firstly, evaluate the importance of each node (in this context, each parking space and road intersection). The formula for node importance is as follows:

$$Importance(v) = \alpha \cdot Degree(v) + \beta \cdot Frequency(v) \tag{1}$$

In the formula, the degree of a node refers to the number of edges connected to the node, and the frequency of its appearance in paths indicates how often the node appears in the shortest paths. Parameters α and β are adjustment parameters used to balance the influence of these two measures.

(2) Node Contraction

For each node in the graph, perform contraction operations in order of importance. When contracting a node, follow these steps:

Calculate all possible paths passing through a node v : for each pair of neighboring nodes u and w, find the shortest path passing through v.

Add Shortcut: If the direct path from u to w is longer than the path passing through v, then add a shortcut edge from u to w ((u , w)).

The condition for adding a shortcut is:

$$d\left(v,w\right) > d\left(u,v\right) + d\left(v,\ w\right) \tag{2}$$

In the equation, $d\left(v,w\right)$ represents the distance from node u to node w .

(3) Construct Hierarchical Graph

Gradually contract nodes to build a hierarchical graph, minimizing the search space for each node during the query phase. In the hierarchical graph, each node is assigned a level value indicating its order in the contraction process.

(4) Bidirectional Search

During the query phase, a bidirectional search strategy is used to find the shortest path from the entrance to the parking spot. The forward search starts from the current vehicle position S and searches towards the target parking spot T . The backward search starts from the target parking spot T and searches towards the current vehicle position S . During the search, only edges connecting to higher-level nodes are considered, effectively reducing the search space and improving query efficiency. The final path is a combination of the forward search path and the backward search path that meet at a node M , thereby determining the shortest path. The path determination formula is as follows:

$$Shortest\ Path = min(d(S,M) + d(M,T)) \tag{3}$$

Where $d(S,M)$ represents the distance from the current vehicle position S to the meeting node M , and $d(M,T)$ represents the distance from the meeting node M to the target parking spot T .

4 FIELD TESTING

4.1 Testing methods

During the actual testing phase, the parking lot utilizes magnetic sensors and infrared obstacle avoidance modules to monitor the status of each parking space. Different colors such as blue (occupied), red (reserved), and green (available) are used to indicate the status of parking spaces. An IP camera installed above the parking lot provides real-time monitoring of vehicle status, enhancing vehicle security. Coupled with image processing units, it can identify vehicle license plates, further enhancing security measures[7].

The operational workflow is as follows: Upon entering the parking lot, drivers use an automatic positioning platform located at the entrance to visually check the status of each parking space. After selecting an available space, the system uses the CH algorithm to plan the shortest parking route and generates a corresponding QR code displayed on the system (see Figure 2). Users scan the QR code to access the parking route guidance page and complete the parking guidance.

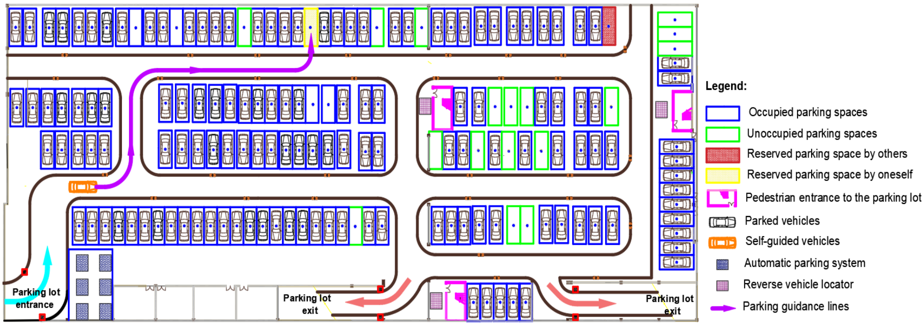

Fig. 2. Automatic Positioning Platform Display Page.

When leaving, drivers enter the underground parking lot through a pedestrian entrance where a reverse car search station is located. Users input the parking space number or license plate number into the station. The system again uses the CH algorithm to plan the shortest path, and users follow the path guidance by scanning a QR code to locate their vehicle, completing the reverse car search guidance (see Figure 3). This system significantly improves parking management efficiency and enhances security, providing drivers with an intuitive and convenient parking and vehicle retrieval experience.

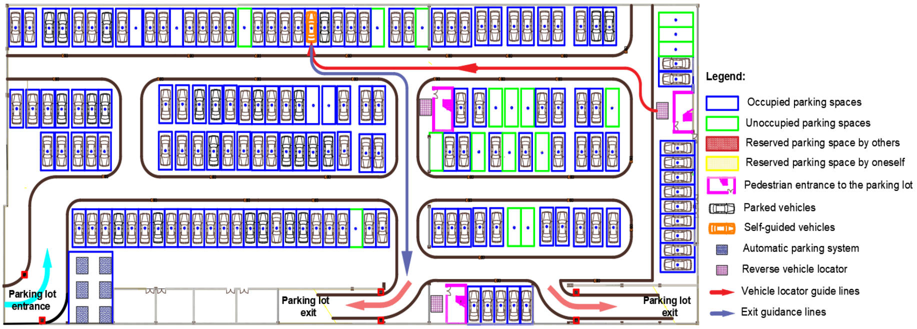

Fig. 3. Reverse Positioning Display Page.

4.2 Test Results

According to relevant statistics, in an extra-large parking lot with more than 1000 spaces, the average time for users to find their vehicles is approximately 15 minutes, and 30% of users are unable to locate their cars. Prolonged search times not only reduce parking lot efficiency but also impact overall user impressions and satisfaction[9]. Test results have shown that the bidirectional guidance system in parking lots significantly outperforms conventional systems in several key performance metrics. These metrics include average time to find a parking space, average exit time, efficiency in managing peak traffic flows, and parking space utilization[7]. These improvements reflect the system's significant enhancements in enhancing user satisfaction and operational efficiency, providing reliable support and guidance for its application and deployment.

Table 1. Comparison of Parking Lot Performance.

Performance indicators	Conventional parking lots	Bidirectional guidance system parking lots	Optimization index
Average search time for parking space (minutes)	15	5	300%
Average exit time (minutes)	8	4	200%
Peak-hour traffic management efficiency	50 cars/hour	80 cars/hour	160%
Parking space utilization rate (%)	70%	90%	128.57%

As shown in Table 1. The bidirectional induction system shows significant improvements over conventional parking lots in multiple key metrics: average search time for parking spaces reduced by 300%, average exit time shortened by 200%, peak-hour traffic management efficiency increased by 160%, and parking space utilization rate improved by 128.57%. These optimizations markedly enhance user experience and operational efficiency of parking lots, highlighting the important role and potential application of bidirectional induction systems in modern urban traffic management.

5 CONCLUSION

This study empirically validates the effectiveness and superiority of a bidirectional induced dynamic update parking system based on the Contraction Hierarchies (CH) algorithm. With rapid urbanization, traditional parking management systems have become inefficient and inflexible, failing to meet the increasing demand for parking. The proposed parking system based on the CH algorithm not only optimizes vehicle entry and exit routes, reducing parking search times, but also enhances overall operational efficiency and parking space utilization.

Research results demonstrate that the CH algorithm significantly speeds up vehicle parking and departure, reduces search times compared to traditional systems, and optimizes traffic flow management, thereby directly improving user experience and satisfaction. Furthermore, the algorithm's real-time data processing capability ensures efficient operation of parking facilities during peak hours, mitigating congestion. The system's implementation also highlights low maintenance costs and high scalability, making it suitable not only for large parking lots but also adaptable for future urban planning in response to evolving traffic demands.

In conclusion, the developed bidirectional induced parking system based on the CH algorithm offers an innovative solution to address urban parking challenges effectively, with potential for integration into broader smart transportation systems. Future research could further explore algorithm optimizations and integration with other intelligent transportation tools and systems to achieve comprehensive smart city traffic management.

REFERENCES

1. Loke, S. W., Aliedani, A. On cooperative autonomous vehicles in the urban environment: Issues and challenges for dropping-off and parking [C]. In IEEE World Forum on Internet of Things, WF-IoT 2018, 615-618.
2. Geisberger, R., Sanders, P., Schultes, D., & Vetter, C. (2012). Exact routing in large road networks using contraction hierarchies [J]. Transportation Science, 46(3), 388-404.
3. Kramer, R. Optimization of the energy efficiency of a parking garage [J]. Energy Engineering, 104(6), 23-38.
4. Karimi, R. (2019). Shortest path calculation using contraction hierarchy graph algorithms on Nvidia GPUs [D]. Doctoral dissertation, Louisiana State University and Agricultural & Mechanical College.
5. Rana, S., Painuly, S. Automated Parking Systems: A Review [C]. In Proc. - 4th IEEE 2023 Int. Conf. Comput. Commun. Intell. Syst., ICCCIS 2023, 914-919.
6. Dheeven, T. A., Kumar, P. M., Venkatesh, V., Sailaja, K. A. I. IoT based sensor enabled vehicle parking system [J]. Measurement: Sensors, 31, Article 101009.
7. Deepak, M., Kolur, N., Pavithra, G. S., Deeksha, U., Chethan, M. B. Design of Microcontroller based Smart Car Parking System [C]. In RTEICT 2021, 206-210.
8. Sun, T. (2015). Implementation of an Integrated Vehicle Finding Data Collection System Based on License Plate Recognition [D]. Doctoral dissertation, Zhejiang University.
9. Floris, A., Porcu, S., Atzori, L., Girau, R. A Social IoT-based platform for the deployment of a smart parking solution [J]. Computer Networks, 205, Article 107820.

10. Pérez, B. O. (2015). Delineating and justifying performance parking zones: Data-driven criterion approach in Washington, D.C. [J]. Transportation Research Record, 2537, 148-157.