



Research on Linkage Control Technology Between Platform Doors and Vehicle Doors Based on Long-Distance Wireless Communication

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Abstract. With the acceleration of urbanization, BRT, Autonomous rail transit and tram have been widely adopted for their core advantages such as short construction cycle, less infrastructure investment, strong urban adaptability and outstanding comprehensive transportation capacity^[1]. However, the signal system of the existing traffic system has a single function and lacks the linkage control function of train doors and platform doors. Although the relevant national standards put forward requirements for wireless linkage control, there are no requirements for the architecture design, functional indicators, parameter specifications, etc. of the linkage control system, resulting in the lack of a unified basis for engineering applications. Most of the current wireless linkage schemes rely on short-range wireless communication technology, but they have the disadvantages of poor adaptability, high failure rate and high cost. In order to solve the above problems, a platform door and door linkage control system and method based on remote wireless communication are proposed. The system is composed of on-board equipment, ground equipment, and wireless communication links. It uses Lora, 433MHz and other long-distance wireless technologies to achieve a communication distance of 300m~500m and improve the tolerance of parking errors^[2]. With a simplified configuration of "one set of on-board equipment per vehicle and one set of ground equipment per station", it realizes linkage control of double-sided platform doors and vehicle doors. Through Ethernet communication, it adapts to the mixed operation of coupled and uncoupled vehicles, and improves the alignment isolation equipment^[3]. In addition, for the security of data transmission, encryption algorithm is introduced. The results show that the system has strong adaptability to the environment, simple structure, wide adaptability to working conditions, and safe communication. It provides an effective solution for the linkage control of platform doors and doors in medium and low volume transportation system, and has broad engineering application value and popularization significance.

Keywords: Long-distance Wireless Communication, Platform Door-Vehicle Door Linkage Control, Medium and Low-Capacity Transportation Systems, LoRa/433MHz Technology, Public Key Encryption

1 Introduction

In recent years, with the rapid development of urbanization, there are more and more urban traffic congestion problems, which seriously affect the travel efficiency of residents and the quality of urban operation. The medium and low volume transportation systems represented by BRT, autonomous rail transit and tram have attracted extensive attention from cities. These systems have the advantages of short construction period, low infrastructure investment, flexible adaptability to different urban road conditions, and strong comprehensive transportation capacity, so they have become an important part of solving urban traffic problems.

Passenger boarding and alighting safety is a key issue in the operation of medium and low volume traffic system. The safety of platform doors is an important equipment to ensure the safety of passengers. However, the existing signal systems of such transportation systems are relatively simplified and lack the core function of linkage control between vehicle doors and platform doors. This means that the opening and closing of platform doors and doors cannot be synchronized, so it is easy to cause passengers to fall into the track or get stuck between doors and other potential safety hazards^[4].

Although the Ministry of Housing and Urban-Rural Development's CJ/T 342-2010 "Rapid Public Transport (BRT) Platform Screen Doors" and the Ministry of Transport's JT/T 933-2014 "Rapid Public Transport (BRT) Platform Safety Doors" have put forward relevant requirements for wireless linkage control, specifying that platform doors should be equipped with corresponding wireless receiving devices. These standards do not require the architecture design, functional indicators, parameter specifications and other key contents of the linkage control system. Due to the lack of unified standards, the technical solutions adopted in various engineering projects are inconsistent, and the system compatibility is poor, maintenance is difficult, and operation and maintenance costs are high^[5].

At present, the wireless linkage scheme between vehicles and platform doors in small and medium capacity transportation system mainly depends on short-range wireless technology, including infrared, camera, RFID, etc. Although these technologies can realize the basic linkage between the entire side of platform doors and vehicle doors, they have obvious technical shortcomings. First of all, they cannot handle the complex working conditions of coupled and uncoupled vehicles, and do not have the function of alignment and isolation. When a certain vehicle door or platform door fails, it is impossible to avoid its incorrect opening during the linkage process of other doors. Secondly, infrared and camera technologies are easily interfered by environmental factors such as dust, rain and snow, and foreign object occlusion, resulting in a high linkage failure rate. At the same time, the cleaning and maintenance costs during large-scale application are relatively high. Thirdly, RFID technology is limited by the communication distance (to avoid crosstalk between devices, the communication distance is usually only 50~100cm), which has strict requirements on the longitudinal and lateral errors of vehicle parking. Moreover, it is necessary to deploy ground equipment and on-board equipment on both sides of the platform and the vehicle respectively, leading to a complex system structure, an increase in fault points, and a rise in construction and operation and maintenance costs.

In order to solve the above technical problems, this study proposes a linkage control system and method for platform doors and vehicle doors based on long-distance wireless communication. This scheme aims to improve the tolerance for vehicle parking errors through long-distance wireless communication, simplify the system structure, adapt to various complex operating conditions, and ensure the security of data transmission, thereby providing technical support for the safe and efficient operation of medium and low-capacity transportation systems.

2 System Overall Design

The linkage control system for platform doors and vehicle doors proposed in this study is constructed based on long-distance wireless communication technology^[6], which mainly consists of three parts: on-board equipment, ground equipment, and wireless communication links. The system architecture is shown in Figure 1.

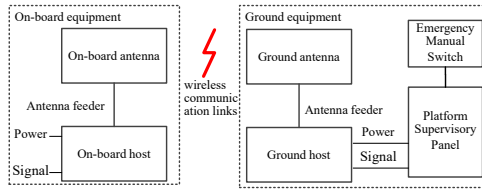


Fig. 1. System Architecture

2.1 On-Board Equipment

As the core control unit on the vehicle side, the on-board equipment is composed of an on-board host, an on-board antenna^[7], and an antenna feeder. The on-board host is deployed inside the carriage, the on-board antenna adopts a shark fin structure and is installed on the top of the train, and the antenna feeder is responsible for signal transmission. The power supply of the equipment is directly provided by the vehicle system to realize two-way signal interaction:

The signals output by the vehicle to the on-board host include: vehicle zero-speed signal, left/right door permission signal, left/right door switch signal, vehicle coupling signal, vehicle lane signal, and each door fault signal;

The signals fed back by the on-board host to the vehicle include: sliding door closed and locked signal, sliding door bypass signal, and each sliding door fault signal.

2.2 Ground Equipment

The ground equipment is deployed on the platform side, consisting of a ground host, a ground antenna, and an antenna feeder, which are integrally integrated into the platform PSL (Platform Supervisory Panel)^[8]. The power supply of the equipment is provided by the platform door central control panel to complete signal interaction with the platform door central control panel:

The signals sent by the ground host to the platform door central control panel include: vehicle zero-speed signal, left/right door permission signal, left/right door switch signal, vehicle coupling signal, vehicle lane signal, and each door fault signal;

The signals fed back by the platform door central control panel to the ground host include: sliding door closed and locked signal, sliding door bypass signal, and each sliding door fault signal.

When the wireless communication is interrupted, the ground station staff can control the opening and closing of the platform screen doors via the Emergency Manual Switch to ensure the safe boarding and alighting of passengers.

2.3 Wireless Communication Links

Considering the complexity of the outdoor application scenario of platform doors and the requirements for real-time and security of linkage control, the selection of wireless communication links must meet the following core indicators:

Environmental adaptability: It should have strong diffraction ability and be able to resist interference such as dust, rain and snow, and foreign object occlusion^[9];

Real-time performance: Fast communication establishment speed and short transmission delay to ensure the synchronization of door linkage;

Communication distance: Supporting long-distance transmission of 300m~500m to reduce the requirements for vehicle parking errors;

Security: Data transmission process needs to be encrypted to prevent information theft or tampering.

Based on the above requirements, long-distance wireless communication technologies such as LoRa and 433MHz are recommended. These technologies have the advantages of low power consumption, long distance, and strong anti-interference ability, which can fully meet the application needs of the system.

3 Door Linkage Control Process

3.1 Door Opening Linkage Process

The data flow of door opening linkage is shown in Figure 2. After the vehicle arrives at the station, the platform door central control panel sends platform door fault signals to the vehicle through the ground host, ground antenna, on-board antenna, and on-board host at a fixed cycle. When the vehicle performs the door opening operation, the linkage process is as follows:

- (1) The vehicle generates zero-speed signal, door permission signal, door opening signal, coupling signal, lane signal, and each door fault signal;

- (2) The above signals are transmitted to the ground through the on-board host, on-board antenna, and ground antenna;

- (3) The ground host generates door opening commands for each sliding door according to the sliding door linkage logic and sends them to the platform door central control panel;

(4) If a certain vehicle door is faulty, the linkage logic will trigger the alignment isolation mechanism, and the corresponding platform door will no longer open in linkage with other doors;

(5) After each sliding door completes the door opening action, the platform door central control panel collects the door opening status signal and fault signal and feeds them back to the on-board host through the original transmission path to complete the closed loop of door opening linkage.

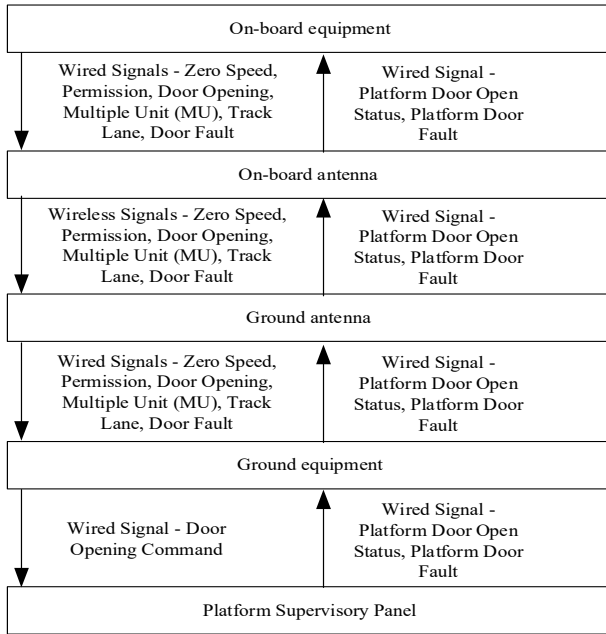


Fig. 2. Door Opening Linkage Process

3.2 Door Closing Linkage Process

The data flow of door closing linkage is shown in Figure 3. When the vehicle performs the door closing operation, the linkage process is as follows:

(1) The vehicle generates zero-speed signal, door permission signal, door closing signal, coupling signal, lane signal, and each door fault signal;

(2) The signals are transmitted to the ground host through the on-board host, on-board antenna, and ground antenna;

(3) The ground host generates door closing commands for each sliding door according to the sliding door linkage logic and sends them to the platform door central control panel;

(4) After each sliding door is closed and locked, the platform door central control panel collects the closing and locking signal, bypass signal, and fault signal and feeds them back to the on-board host through the original transmission path to complete the closed loop of door closing linkage.

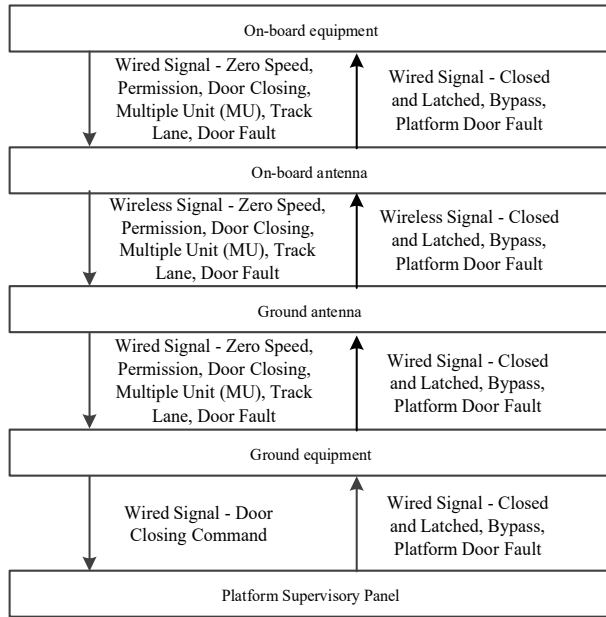


Fig. 3. Door Closing Linkage Process

3.3 Sliding Door Linkage Logic

According to the layout form, platform doors can be divided into four types: side-type, island-type, double-island-type, and one-island-double-side-type. This section focuses on the linkage logic of side-type platforms, and other types of platforms can be implemented by reference.

The coupled vehicle is activated at the C-end, departs from the depot, parks in the up lane, and the driver opens and closes the left door (with the C-end as the front), and the 8 sliding doors of Platform 1 are opened and closed in linkage.

The coupled vehicle is activated at the A-end, parks in the up lane, and the driver opens and closes the right door (with the A-end as the front), and the 8 sliding doors of Platform 1 are opened and closed in linkage.

The schematics of the above two operating conditions are shown in Figure 4.

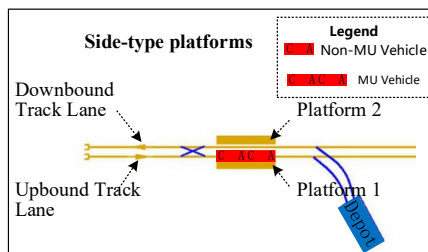


Fig. 4. MU Vehicles Stop at Upbound Track Lane of Side Stations

The coupled vehicle is activated at the C-end, departs from the previous station, parks in the down lane, and the driver opens and closes the right door (with the C-end as the front), and the 8 sliding doors of Platform 2 are opened and closed in linkage.

The coupled vehicle is activated at the A-end, parks in the down lane, and is ready to depart for the depot. The driver opens and closes the left door (with the A-end as the front), and the 8 sliding doors of Platform 2 are opened and closed in linkage.

The schematics of the above two operating conditions are shown in Figure 5.

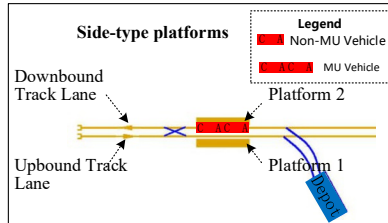


Fig. 5. MU Vehicles Stop at Downbound Track Lane of Side Stations

The uncoupled vehicle is activated at the C-end, departs from the depot, parks in the up lane (near the large mileage end), and the driver opens and closes the left door (with the C-end as the front), and the corresponding 4 sliding doors of Platform 1 (numbered ASD5~ASD8) are opened and closed in linkage.

The uncoupled vehicle is activated at the A-end, parks in the up lane (near the large mileage end), and the driver opens and closes the right door (with the A-end as the front), and the corresponding 4 sliding doors of Platform 1 (numbered ASD5~ASD8) are opened and closed in linkage.

The schematics of the above two operating conditions are shown in Figure 6.

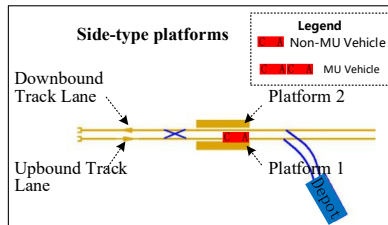


Fig. 6. Non-MU Vehicles Stopping at Upbound Track Lane of Side Stations

The uncoupled vehicle is activated at the C-end, departs from Baishazhen Station, parks in the down lane (near the small mileage end), and the driver opens and closes the right door (with the C-end as the front), and the corresponding 4 sliding doors of Platform 2 (numbered ASD1~ASD4) are opened and closed in linkage.

The uncoupled vehicle is activated at the A-end, parks in the down lane (near the small mileage end), and is ready to depart for the depot. The driver opens and closes the left door (with the A-end as the front), and the corresponding 4 sliding doors of Platform 2 (numbered ASD1~ASD4) are opened and closed in linkage.

The schematics of the above two operating conditions are shown in Figure 7.

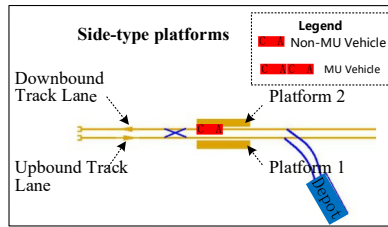


Fig. 7. Non-MU Vehicles Stopping at Downbound Track Lane of Side Stations

4 Wireless Communication Data Encryption

Due to the wireless nature of the wireless communication network, information is easily stolen or tampered with during transmission^[10]. However, signals such as platform door opening and closing commands, platform door closing and locking signals, and bypass signals are related to operational safety. Therefore, certain data encryption measures need to be equipped to ensure the security of data transmission. This study adopts the public key encryption algorithm, and the specific process is shown in Figure 8.

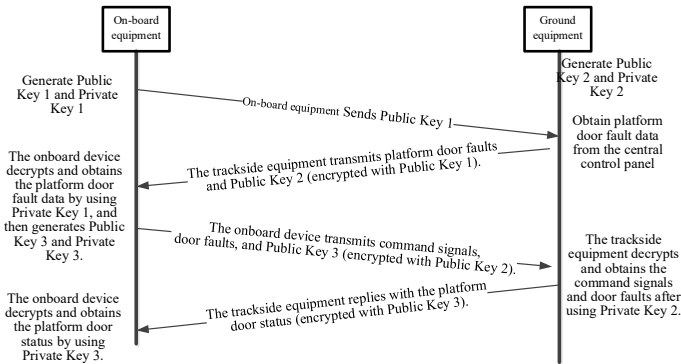


Fig. 8. Public Key Encryption Process

5 SIL Definition and Application Scenarios

5.1 Definition and Application Scenarios of SIL

Safety integrity level (SIL) is the core indicator in functional safety related standards (such as IEC 61508), which measures the risk mitigation capability of safety related systems. It quantifies the reliability of the system to complete the safety function under the specified conditions and within the specified time. For the platform door and vehicle door linkage control system of medium and low-volume transportation systems, its core safety function is to ensure the accurate linked opening and closing of platform doors

and vehicle doors during vehicle operation, and to prevent safety accidents such as passenger falls and pinches. Therefore, the analysis of SIL needs to focus on evaluating the ability of the system to stably realize the safety function under complex operation scenarios.

5.2 Basis for Risk Assessment

The risk assessment of the linkage control system is carried out from the following points:

Severity of hazardous consequences: catastrophic system failures (such as platform door opening error, platform door not opening, and fault door not isolated) may cause casualties or major property losses, and the severity of the failure is "high";

Exposure frequency: the linkage logic is triggered every time the vehicle stops. The daily operation frequency of medium and small volume transportation equipment is high (about 2-5 minutes per trip), and the frequency of personnel contacting dangerous scenes is "high";

Avoidability: it only takes 3-8 seconds to open and close the door. Once the system fails, the time for the driver or platform staff to intervene and avoid risks is very short, and the avoidability is "low".

5.3 Determination of SIL Level

When a component fails, it can quickly detect and send out an alarm without causing dangerous consequences, meeting the requirements of SIL 2 hardware fault tolerance. The specific verification basis is as follows:

Risk Reduction Factor (RRF): SIL 2 requires the system to reduce the risk of dangerous failures by at least 100 times ($RRF \geq 100$). Through the redundant transmission design of key signals (zero-speed signal, door control command) and the fault isolation mechanism, the system's dangerous failure rate is controlled below 10^{-7} per hour, meeting the SIL 2 risk reduction requirement;

Hardware Fault Tolerance (HFT): The system adopts a configuration of "one set of on-board equipment per vehicle and one set of ground equipment per station". Core components (on-board host, ground host) have built-in self-diagnostic functions. When a single component fails, it can be quickly detected and an alarm can be issued without causing dangerous consequences, which is in line with the SIL 2 hardware fault tolerance ($HFT=1$) requirement;

Software safety standards: The system software adopts a modular design. The core algorithms such as linkage logic and post fault isolation have been tested statically and dynamically. The software failure probability is $\leq 10^{-6}$ per operating cycle, meeting the SIL 2 software safety indicators.

5.4 SIL Compliance Scheme

In order to make the system reach SIL 2 level, the following targeted measures are taken in the design and implementation phase:

Redundant signal transmission: Key signals such as zero-speed signals and door opening/closing commands are transmitted through dual channels. The system uses the method of majority comprehensive voting to judge the effectiveness of the signal and avoid single channel transmission errors;

Full-process fault self-diagnosis: On-board equipment and ground equipment real-time monitor the status of hardware (antennas, feeders, hosts) and communication links. When a fault occurs, an alarm is immediately triggered and safety strategies are implemented (for example, suspension linkage and keeping the current state of the door);

Independent safety layer design: The linkage control logic is independent of the vehicle's main control system and the platform door's central control system, avoiding the impact of fault transmission from other systems on the linkage safety function.

6 Engineering Application Verification

6.1 Application Background

To verify the practical effect of the long-distance wireless communication-based platform-vehicle door linkage control system, a pilot was conducted on a medium and low-capacity autonomous rail rapid transit line. The line includes side and island platforms, with coupled/non-coupled vehicle mixed operation, and faces complex environments (dust, rain/snow, etc.). It also has the requirements of parking fault tolerance and operation/maintenance cost control, which matches the adaptive scenario of the system. During the pilot, key data (linkage response, operation stability, environmental adaptability, etc.) was collected for performance verification.

6.2 Application Implementation

As shown in Figure 9, the pilot deployed 12 sets of ground equipment (6 stations, 1 set per station) and 30 sets of on-board equipment (15 vehicles, 2 sets per vehicle). The system uses Lora wireless communication and data encryption to realize the safe transmission of data[11]. After commissioning, it was put into daily operation for over 8,000 hours, covering peak and off-peak periods, as well as complex weather (rain, sandstorms), to comprehensively verify its actual operation performance.



Fig. 9. Application Implementation

6.3 Application Effect Verification

15 running vehicles and 6 test stations operate continuously for 8000 hours, covering all periods such as morning peak, evening peak and night, and covering rainy season rainfall, spring sandstorm and other working conditions. The application status is shown in Table 1.

Table 1. Quantitative Statistics of Core Data from 8,000-Hour Pilot Operation

Statistical Indicators	Specific Values/Details
Total Number of Operating Cycles	12,800 times (including 3,200 times of coupled operation condition, 9,600 times of uncoupled operation condition; 8,600 times at side platforms, 4,200 times at island platforms)
Total Number of Failures	25 times (failure rate: 0.195%)
Classification by Error Type	1. Instantaneous interruption of communication link: 8 times (accounting for 32%), including bad weather blocking and signal interference; 2. Occasional equipment hardware failure: 5 times (accounting for 20%), including 3 times of poor contact of on-board antenna and 2 times of loose interface of ground host; 3. Signal transmission delay: 3 times (accounting for 12%), maximum delay 80ms (no impact on linkage synchronization); 4. Failure of faulty door isolation: 0 times (accounting for 0%); 5. Other occasional abnormalities: 9 times (accounting for 36%), including 6 times of transient fluctuation of vehicle signals and 3 times of delay of platform door feedback signals
Fault Recovery Time	1. Communication link interruption: average 2.3 seconds (recovered by system automatically switching to standby channel); 2. Occasional hardware failure: average 8.5 seconds (standby module triggered after self-diagnosis); 3. Signal transmission delay: average 1.8 seconds (recovered by system retransmitting signals); 4. Other occasional abnormalities: average 1.5 seconds (automatically recovered after signal stabilization)
Accuracy of Linkage Control	99.80% (among 12,800 operating cycles, only 25 non-fatal failures occurred, no mis-linkage related to safety accidents)
Mean Time Between Failures (MTBF)	1,800 hours
Number of Failures Under Extreme Environments (Rainfall/Sandstorm)	7 times (accounting for 28% of total failures), no linkage failure cases
Encrypted data transmission success rate	100%
Linkage Success Rate When Parking Deviation Exceeds Standard (>±50cm longitudinal/>±30cm transverse)	99.5% (only 0.6 times of linkage delay occurred in 120 over-standard cases, no incorrect opening/missing opening)

From the quantitative data, it can be seen that the system has low failure rate and fast recovery speed during 8000 hours of trial operation, and can maintain high stability even in harsh environments, which fully verifies its robustness and engineering practicability.

6.4 Summary of Application

This pilot application has fully verified the technical feasibility and engineering practicality of the linkage control system between platform doors and vehicle doors based on long-distance wireless communication. The system has excellent performance in complex working condition adaptation, harsh environment response, operational cost control and safety guarantee, and all performance indicators meet or exceed the design requirements, fully satisfying the operational needs of medium and low-capacity transportation systems. At present, the system has passed the acceptance of the operating unit and is planned to be fully promoted and applied in the subsequent line expansion. Practice has proved that the linkage control scheme proposed in this research can effectively solve the pain points of existing technologies, provide reliable technical support for the safe, efficient and economical operation of medium and low-capacity transportation systems, and has broad application prospects.

7 Conclusions

This study proposes a linkage control system and method for platform doors and vehicle doors based on long-distance wireless communication. Through technical innovation and optimized design, it solves the core technical pain points of door linkage in existing medium and low-capacity transportation systems, and its main advantages are as follows:

Strong environmental adaptability: Adopting 300m~500m long-distance wireless communication technology, it can effectively tolerate vehicle parking errors, has outstanding ability to resist environmental interference such as dust, rain and snow, and foreign object occlusion, and significantly reduces maintenance workload;

Simple system architecture: Adopting the configuration scheme of "one set of on-board equipment per vehicle and one set of ground equipment per station", there is no need for double-sided deployment, which simplifies the system structure, reduces fault points, and lowers construction and operation and maintenance costs;

Wide adaptability to operating conditions: Through ethernet communication, it realizes accurate adaptation to the mixed operation of coupled and uncoupled vehicles, supports linkage control of various platform types such as side-type, island-type, double-island-type, and one-island-double-side-type, and has a complete alignment isolation function;

Safe data transmission: Introducing the public key encryption algorithm to realize encrypted transmission of linkage data, effectively preventing the risk of information theft and tampering, and ensuring operational safety.

This system provides a standardized, efficient, and safe solution for the linkage control of platform doors and vehicle doors in medium and low-capacity transportation systems, and has broad engineering application value and promotion prospects.

Declaration of AI-Assisted Technologies

The authors declare that no AI-assisted technologies were used in the writing of this manuscript, and they take full responsibility for the content of the paper.

During the writing of this manuscript, the author used AI tools during the Chinese-to-English translation process and for checking grammar. The authors take full responsibility for the use of these tools and take full responsibility for the content of the paper.

Definitions/Abbreviations

Abbreviation	Full Name
BRT	Rapid Public Transport
PSL	Platform Supervisory Panel
ASD	Automatic Sliding Door
LoRa	Long Range Radio

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