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Technical Note

Intelligent Closed-Loop Video Monitoring System Based on Multi-Module Collaboration: A Case Study of Jinan Metro

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Abstract: Realizing the automatic recognition of abnormal scenarios in urban rail transit (URT) is extremely important for its safe and effective operation. Taking the successful application of intelligent video system in Jinan Metro as an example, this paper deeply discusses the construction content of the system's platform, and analyzes the closed-loop construction of video compression technology, AI abnormal behavior detection and mobile terminal business. Especially, the video compression technology saves the storage space, the AI system can automatically detect more than 40 abnormal behaviors, and the developed mobile terminal can quickly push warning information, provide disposal measures and generate event reports. The experience of Jinan Metro's intelligent video system together with the effective tactics provides URT operators with meaningful reference for improving the safety level and management efficiency of URT systems.

Keywords: intelligent video surveillance; closed-loop management; anomaly detection; urban rail transit; multi-module collaboration

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1 Introduction

The rapid development of urban rail transit (URT) happens worldwide, especially in China. In recent years, the safety, comfort and efficiency of URT continue to be of critical importance. The video surveillance system, which is widely used in the URT as an important means of ensuring the safe operation, generates unstructured big data. How to exploit these data and achieve rapid and precise perception of abnormal events has gradually become the consensus of the URT researchers and operators. While researchers have evaluated the effects of numerous models on video identification based on publicly available or self built datasets[1-16], there is a lack of effectiveness analysis targeting practical applications, and how to improve the reliability of video applications has become an urgent problem to be solved. Therefore, structuring a new type of intelligent video system is beneficial for improving the safety level and management efficiency of URT operations.

As of the end of 2024, the operating mileage of URT lines in China has exceeded 10, 000 kilometers, leading the world in both URT operation lines and passenger volume. Although China has obtained certain achievements in URT's video data analysis based on advanced techniques such as machine vision and deep learning algorithms, there are still many deficiencies compared with some developed countries. Especially, various application scenarios of URT's video monitoring systems, such as the abnormal behavior of passengers, equipment failure and outburst mass passenger flow, could be explored to improve the service level and operational efficiency of URT.

Taking into account that traditional monitoring methods such as artificial surveillance are unable to meet the high standard requirements for operational security,

constructing the intelligent monitoring system by integrating advanced technologies such as artificial intelligence and machine vision becomes increasingly important to deal with the increasingly severe security and management challenges in URT operation. Actually, while almost all Chinese URT operating lines have installed a large number of video cameras, most of them did not realize the automatic recognition of abnormal scenarios. Right in the above background, taking the successful application of intelligent video system in Jinan Metro as an example, this paper deeply discusses the construction content of the system's platform, and analyzes the closed-loop construction of video compression technology, AI abnormal behavior detection and mobile terminal business. The Jinan Metro case on the intelligent video system together with the effective tactics provides URT operators with meaningful reference for improving the safety level and management efficiency of URT systems.

2 System Design

2.1 System Platform Architecture

The Jinan Metro's intelligent closed-loop video monitoring system synergizes the data platform, AI platform and IoT platform to achieve anomaly monitoring and closed-loop management of metro operations. The system uses AI technology for intelligent video analysis, with the network supporting fast data transmission, and improves the operational efficiency through digital business processes. This architecture could optimize the video data processing process and improve the system reliability through unified standards and security management (Figure 1).

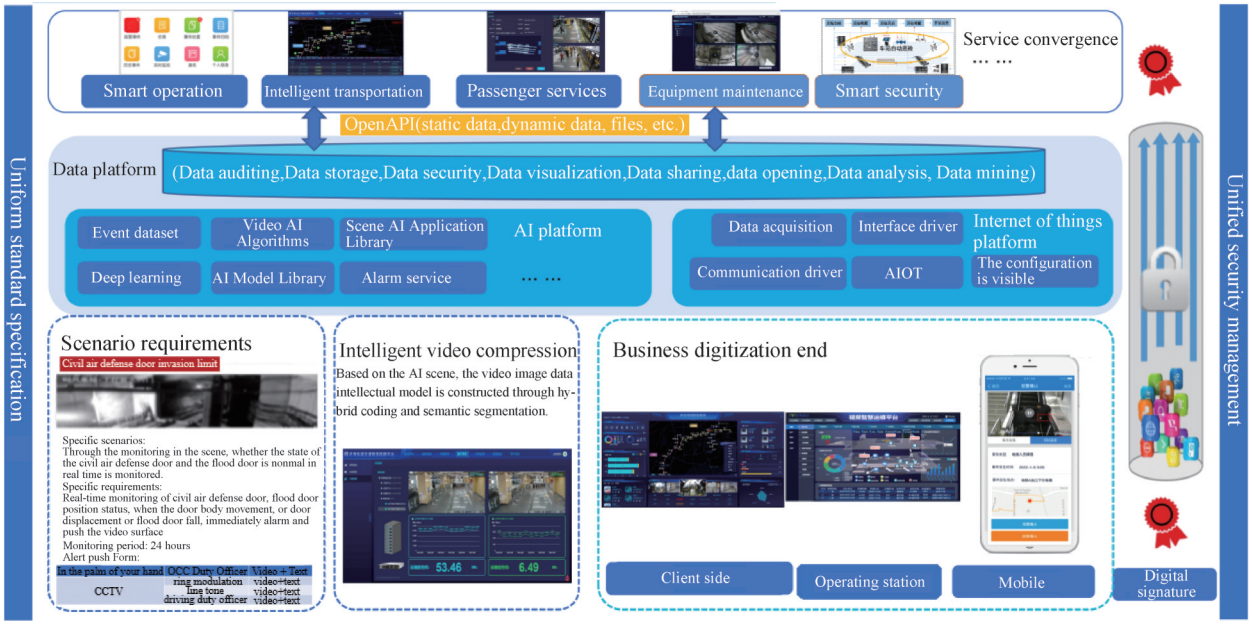


Fig.1 Introduction of the architecture of the system platform

The data platform can deal with various tasks such as data auditing, storage, visualization, sharing, analysis and mining, providing a solid data foundation for the upper-layer applications. The AI platform integrates event data sets, AI algorithms, AI application libraries, deep learning, AI model libraries and alarm services to intelligently analyze and process the video content using optimized AI technologies. The IoT platform can realize the device interconnection and remote management through modules such as data acquisition, communication drivers, interface drivers and configuration visualization. The business digitization module covers the client, operator console and mobile terminal, etc. It improves the efficiency and response speed of business processing by digital means, enabling the advantages of mobile office, fast office and convenient office. In addition, the intelligent video compression technology based on AI scenarios uses hybrid coding, semantic segmentation and other technologies to build a video image data management model to achieve effective compression and optimization of video data, thereby saving storage resources and improving transmission efficiency.

More generally, the platform architecture realizes an all-round upgrade of the intelligent video system of the metro network, mainly through the integration of advanced video compression technology, AI abnormal behavior detection system and mobile terminal closed-loop business process. The intelligent closed-loop video monitoring system by integrating multi-module especially the AI technology shows potential to improve the safety and management efficiency of metro operation.

2.2 Architecture of 5G-based Mobile Terminal Service Closed-Loop System

To enhance metro operational staff's efficiency in handling abnormal incidents and achieve closed-loop

management of operations, a 5G network-based mobile terminal has been developed. This device enables real-time reception of video feeds and incident handling recommendations, facilitating rapid on-site response and resolution by operational personnel.

The 5G network, with its high-speed, low-latency, and high-capacity characteristics, meets the requirements for rapid video information transmission. In metro environments, 5G ensures stable communication between mobile terminals and the monitoring center, enabling real-time video streaming. The mobile terminal integrates video reception, event handling recommendations viewing, disposal tracking, and report generation functions. When the AI system detects abnormal behaviors and triggers alerts, the monitoring center pushes relevant video information and handling suggestions to mobile terminals via 5G. On-site staff execute disposal based on recommendations and provide feedback through the terminal. The system automatically generates incident reports to achieve closed-loop operational management (Figure 2).

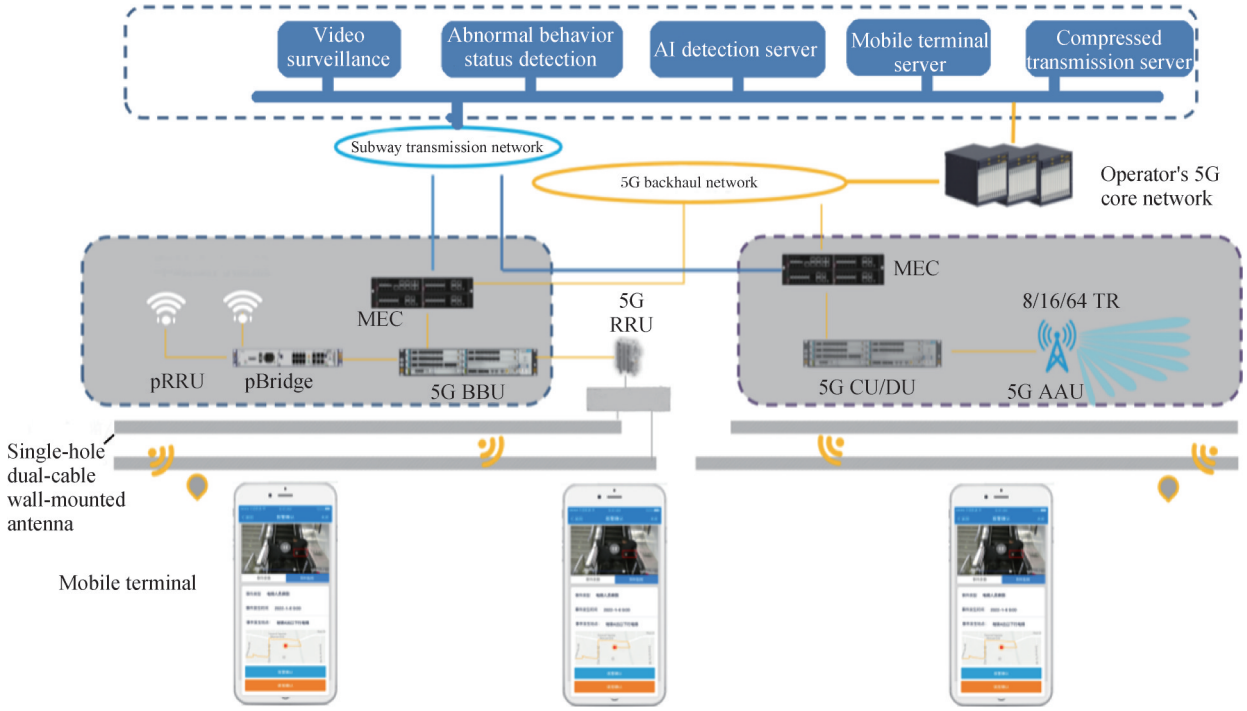


Fig.2 Networking architecture of the mobile terminal

Through practical implementation, the 5G network-based closed-loop mobile terminal service has enhanced the handling efficiency of abnormal incidents. The substantially reduced response time enables rapid restoration of metro operational order, improving both passenger satisfaction and operational safety.

2.3 Architecture of Alarm Handling based on Mobile Terminals and AI Algorithms

There are various types of abnormal events in the metro, such as falls, fights, and large passenger flows. These events require a full range of work, including active detection, push for alarm videos, alarm confirmation, alarm handling, and alarm archiving. Currently, the discovery and handling of abnormal events are basically all done manually, which leads to the pain points of delayed perception and low handling efficiency. Therefore, the full-process alarm handling based on mobile terminals and AI algorithms is of great significance. This paper expounds a video surveillance alarm processing flow based on AI algorithms. Through an AI algorithm, real-time video data is analyzed to identify abnormal behaviors and trigger the alarm process to achieve rapid response and handling. The system supports the synchronization, storage and analysis optimization of alarm data, aiming to achieve rapid identification and response of abnormal behaviors through intelligent means (Figure 3).

The process begins with the rule configuration of the AI algorithm and the real-time startup of the intelligent analysis task. Through the analysis of the video stream by the AI algorithm to monitor anomalies, once potential abnormal behaviors are detected, the system first archives the results according to the type for convenient later analysis. The system simultaneously activates the alarm service to synchronize data and services and issue alarms through video platforms and mobile terminals. This process supports rapid and personalized retrieval of key events, ensuring the precise distribution and efficient handling of alarm information. The closed-loop alarm handling process not only enhances the automation level of alarm information processing, but also improves the efficiency of security management and the speed of emergency response through rapid alarm receiving and real-time handling suggestions, providing strong

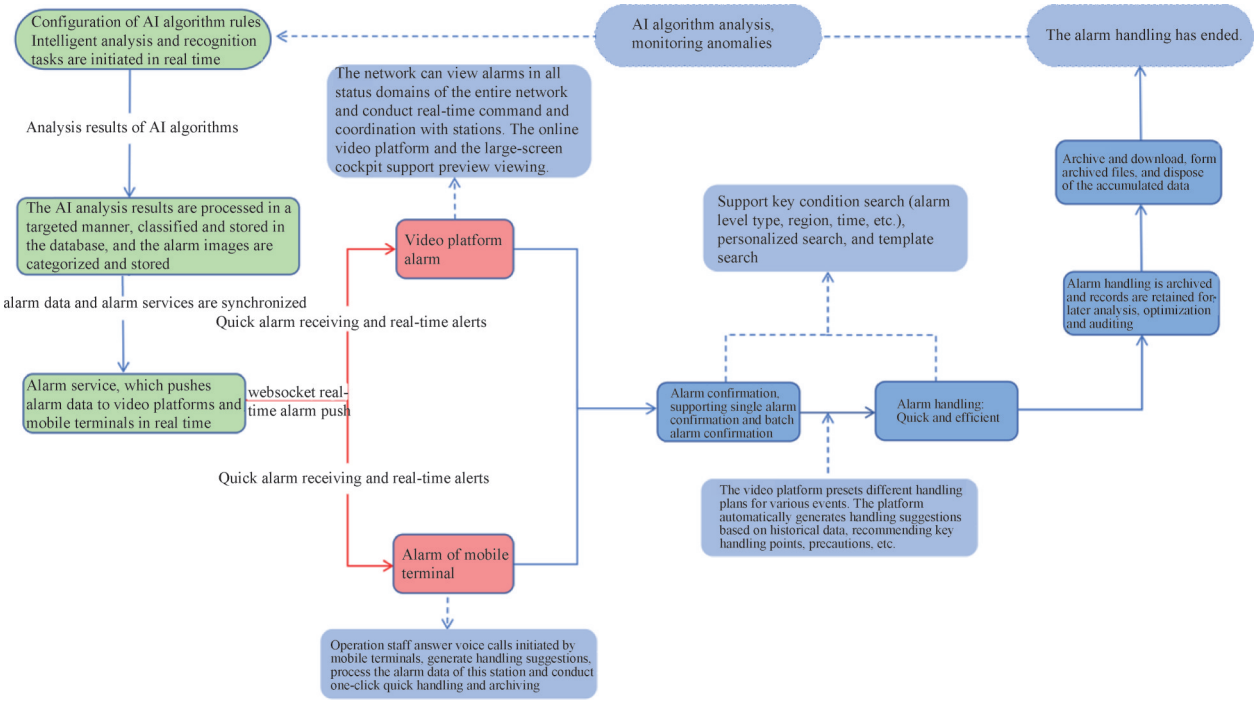


Fig.3 Control diagram of the whole process of AI alarm management

technical support for building a comprehensive and multi-level security guarantee system.

3 Function Analyses of the System

By integrating the status perception function of the metro network, including the alarm cases of lines, stations and intervals, the intelligent display board realizes the display of alarm flashing, alarm overlay and alarm details on the electronic map, which improves the convenience and intuitiveness of human-computer interaction to quickly grasp the alarm information. In addition, the system has a dynamic real-time alarm data scrolling table function, which simplifies the alarm handling process. The event dashboard integrates alarms, personnel, events, AI data and operational scenarios, provides an intuitive display of information such as AI alarm events, abnormal event monitoring locations, on-duty person in charge and event disposal progress, etc. It supports modular design and flexible configuration of display information. The alarm management system uses AI algorithms to automatically display alarm data and record the entire process information of alarms, supports instant communication with mobile terminals, and realizes the functions of quickly receiving alarms, displaying real-time alarm information, and disposing and archiving historical alarms.

3.1 Alarm management

The alarm management realizes the automatic pop-up of alarm data based on artificial intelligence algorithms, and records the whole process information from the birth to the disposal of the alarm. The alarm management module supports instant communication with the mobile terminal, which can quickly receive alarms, display real-time alarm information and dispose of historical alarms. In addition, it supports both free-text and template-based retrieval of alarm information, as well as quick access to the historical record database (Figure 4).



Fig.4 Alarm management

3.2 Smart patrol management

The intelligent patrol system incorporates multiple AI algorithm models to achieve business empowerment, and supports one-button opening, one-button closing, one-button daily inspection, fire inspection and protection zone inspection. In the process of inspection, the current inspection status and inspection results can be displayed, and the inspection path can be marked under the electronic map according to the latitude and longitude. If there is an alarm in the process, the detailed alarm information can be displayed, and the system can prompt the on-duty staff to take timely action (Figure 5).



Fig.5 Smart patrol management

3.3 Flexible AI rules

The system supports flexible configuration of algorithms, and algorithm task configuration covers algorithm task management, algorithm type selection, computing resource allocation and camera association. AI rule configuration task query can be carried out according to fuzzy query, task type, region, control time and task status, which also supports batch start and stop tasks (Figure 6).

The shortcut algorithm deployment can be implemented as follows: Click Add button > Select

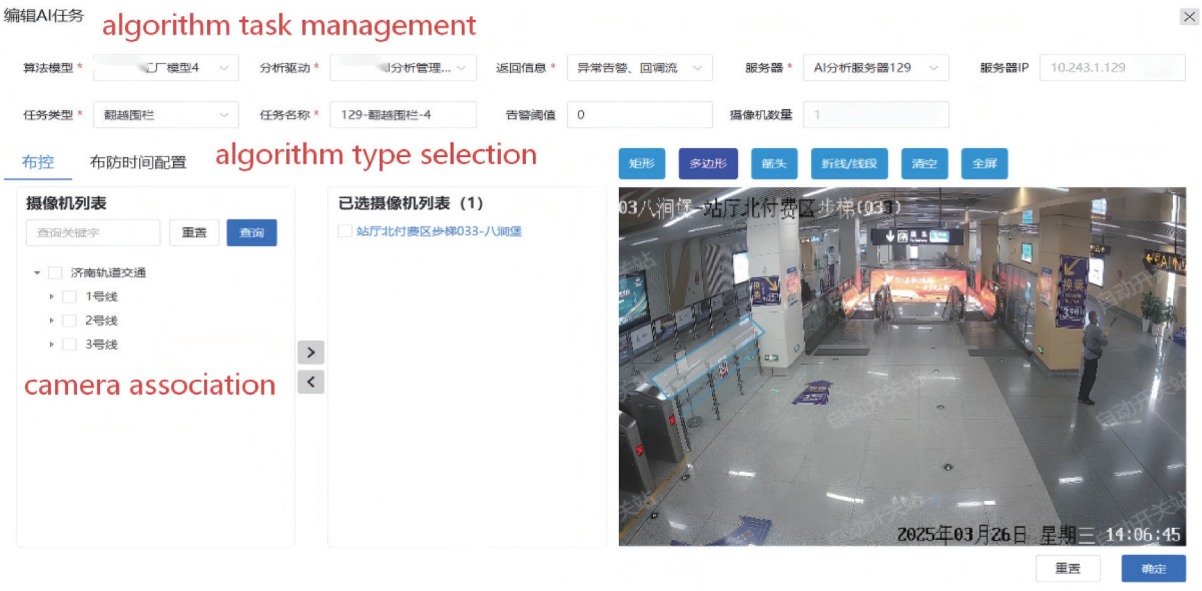


Fig.6 Screenshot of the AI rule configuration

Algorithm model > Select Analysis driver > Select Return information > Select AI Server > Select AI task type > Input AI task name > Input alarm threshold > Select camera > Double click selected camera > Select the shape to be drawn > Draw detection area in the video > Deployment done.

3.4 Hardware and Software Compatibility

The intelligent closed-loop video monitoring system, through multi-module collaboration, deeply integrates hardware such as high-definition cameras, GPU servers, 5G networks, and mobile terminals with software including AI video analysis, alarm management, and IoT platforms. This enables automatic detection of abnormal behaviors, real-time alarm push, and closed-loop incident handling. Data interaction between hardware and software is based on standardized protocols (e. g., RTSP, MQTT, 5G). GPU servers support deep learning model inference such as YOLO (You Only Look Once) and STGCN (Spatial-Temporal Graph Convolutional Network), while mobile terminals receive alarm videos and handling suggestions via 5G, thereby significantly improving metro operation safety and efficiency. Table 1 presents the hardware-software compatibility mapping of the intelligent closed-loop video monitoring system. The system integrates a diverse range of hardware devices—including IP cameras, GPU servers, 5G infrastructure, mobile terminals, storage arrays, display and control units, IoT sensors, and edge AI boxes—with corresponding software modules to enable seamless data processing, intelligent analysis, and closed-loop alarm management. Specifically, IP cameras are paired with AI video analysis and video compression algorithms; GPU servers support deep learning model inference and alarm services; 5G infrastructure underpins the mobile terminal closed-loop system and IoT platform; mobile terminals run alarm management and event reporting applications; storage systems provide data archiving and retrieval capabilities; display and control units host smart dashboards and alarm management interfaces; IoT sensors feed into the IoT platform and AI rule engine; and edge AI boxes enable lightweight model inference for local real-time analysis. This multi-layer compatibility ensures end-to-end system reliability, low-latency response, and efficient coordination across all functional modules.

Table 1 hardware-software compatibility mapping

Hardware	Software Compatibility
IP Cameras	AI video analysis, video compression
GPU Servers	Deep learning models, alarm service
5G Infrastructure	Mobile terminal closed-loop system, IoT platform
Mobile Terminals (5G handhelds)	Alarm management, event reporting app
Storage (cloud/array)	Data platform (storage, retrieval, archiving)
Display & Control (large screen, workstation)	Smart dashboard, event dashboard, alarm management
IoT Sensors (gate, elevator, door status)	IoT platform, AI rule engine
Edge AI boxes	Lightweight AI models, local analysis

4 Results

The system integrates multiple architectures including a hybrid "3D Convolution + Transformer" model, YOLO-based object detection with dynamic threshold determination, YOLO-POSE (You Only Look Once - Pose Estimation) skeletal point feature inference, and STGCN video classification. These architectures fully exploit the advantages of convolution in extracting spatio-temporal video features while integrating Transformer and other models to process long-sequence information, meeting application requirements across diverse scenarios. Through systematic processes involving large-scale video data collection, data-set construction, data annotation, model training, parameter optimization, deployment, and iterative testing, the algorithms learn characteristic patterns of various abnormal behaviors, achieving practical engineering implementation.

The system is capable of detecting over 40 types of anomalous behaviors, including passenger falls, physical altercations, and unauthorized access. A hierarchical alert mechanism classifies notifications into real-time alerts and preemptive warnings based on severity levels. Through real-time analysis, the system utilizes models to determine the presence of abnormal behaviors and triggers precise alarms. Different algorithm architectures have been adopted for detecting different abnormal behaviors, thus improving the recall rate. Experimental results show that the recall rates for anomalous behavior detection are improved obviously to be higher than 90%. The data comes from the January 2025 test (Table 2).

Table 2 Recall rate results analysis of the algorithms for anomalous behaviors (The data comes from the January 2025 test.)

Abnormal types	Algorithm Description (January 2025)	Recall Rate
Area intrusion	Object detection + Region analysis + Threshold analysis	⩾95%
Passenger flow counting		⩾95%
Door status detection	Object detection + IOU(Intersection over Union) threshold analysis	⩾95%
Button pressing	Object detection + Threshold analysis	⩾90%
Pedestrian counter flow	Head detection + Tracking + Kalman Filter	⩾95%
Personnel falling on flat ground	Object detection + STGCN	⩾90%
Faregate trespassing	Object detection + Threshold analysis	⩾95%
Vulnerable group monitoring	Object detection	⩾90%
Abandoned object detection	Object detection + Threshold analysis	⩾95%
Elevator entrapment	Head detection + Tracking + Threshold analysis	⩾90%

5 DISCUSSION

The intelligent video system of Jinan metro line network studied in this paper has made achievements in video compression technology, AI abnormal behavior detection and mobile terminal business closed-loop construction. Video compression technology saves disk space; AI system can accurately detect a variety of abnormal behaviors. The mobile terminal realizes the rapid response and closed-loop management of business, and improves the safety and efficiency of metro operation.

The software algorithm of this system has been applied in cities such as Suzhou.

Although this study has achieved some results, there are still some shortcomings. For example, the accuracy of AI abnormal behavior detection model in complex scenes needs to be improved. The functions of mobile terminals need to be further expanded. Future research can further optimize the algorithm, improve the performance and stability of the system, and provide more powerful technical support for metro operation.

Author Contributions:

Gang Li: Investigation and reviewing. Junfeng An, Qi Wang, Yunyun Cen: Conceptualization, methodology and software analysis. Jinbao Zhao: writing original draft.

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Data Availability:

The authors declare that the main data supporting the findings of this study are available within the paper and its Supplementary Information files.

Conflicts of Interest:

The authors declare no competing interests.

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