Research on Road Surface Inspection System for Lightweight Design

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Abstract

Given the problems of low efficiency, heavy workload, and hidden safety problems associated with manual inspection, this paper proposes a multi-sensor fusion road inspection system for lightweight design. The system adopts a high-definition industrial camera and GNSS / IMU joint positioning terminal to realize the accurate acquisition of high-definition images of roads and real-time location data. At the same time, this study uses the lightweight disease detection model to optimize the inspection process and improve coordination efficiency. Acquisition application results show that the system in common cracks, pits, and other pavement disease detection realizes the rapid, precise data acquisition and, through the task management function, significantly improves the inspection efficiency and data accuracy for the road management department and maintenance unit provides timely and accurate maintenance data support, promote the road maintenance of intelligent management level.

Keywords

Lightweight Design; Road Surface Disease; Industrial Camera; Satellite Positioning; YOLOv8n; Road Surface Maintenance.

1. Introduction

In recent years, with the increasing number of road maintenance tasks, the traditional manual inspection methods have gradually been unable to meet the needs of modern road management due to their low work efficiency, inaccurate data collection and high safety risks of inspection personnel[1-2]. Although the inspection method based on mobile terminals improves the problem of data digitization, it still has limitations[3], such as relying on manual identification, low efficiency and insufficient data consistency. Therefore, realizing the efficient, accurate and low-cost inspection has become a research hotspot.

Given the problems of low efficiency, inaccurate data and hidden security risks of traditional inspection methods, in recent years, domestic and foreign scholars have gradually focused on the research of road inspection systems based on multi-sensor fusion. Zimmer et al.[4] propose the InfraDet3D system to achieve high-precision 3D target detection and localization by fusing dual LIDAR and camera data on the A9 test track in Munich, Germany, effectively improving the perception of road infrastructure. In addition, Cavnue[5] arranges sensor arrays every 200 meters on the Michigan I-94 highway to monitor road conditions and traffic flow in real-time and provide timely and accurate road maintenance decision support for government departments. In domestic research, Liu Hao[6] research based on HD monitoring, industrial cameras, laser radar, edge computing terminal, combined inertial navigation integrated lightweight road inspection equipment; its identification target contains eight kinds of common road diseases, traffic signs, road marking, road debris, road structures, road events and prohibited vehicles and other targets. Zhu Xiaofeng et al.[7] used the "Beidou + GPS" double star positioning device, binocular visual perception device and edge computing equipment to design a vehicle-mounted device for foreign body detection on the

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expressway. Qin Qingfei[8] et al. developed an intelligent garbage picking up and road inspection system in the central isolation zone, which effectively avoided the potential safety risks brought by the inspection personnel crossing the expressway. Together, these studies demonstrate the significant advantages of multi-sensor fusion technology in improving the efficiency and safety of road inspection.

Lightweight design has been an important direction in the research and development of inspection equipment in recent years[9]. By installing lightweight collection equipment on ordinary vehicles, large-range and high frequency data collection can be realized without affecting the regular operation of the vehicles. This system has the advantages of convenient installation and low cost, but it also can adapt to complex road conditions and meet the needs of daily inspection and emergency monitoring[10-11]. In addition, in the vehicle inspection platform, the need to use a lightweight pavement detection model to match the power of the limited vehicle acquisition system needs a series of model optimization technologies to ensure the detection accuracy, significantly reduce the model number and calculation complexity, makes the detection algorithm on the edge computing platform. Fine-tuning for specific pavement diseases (such as cracks, pits, etc.) to effectively improve detection accuracy and stability[12-13]. Therefore, the research of this paper aims to optimize the design and integration scheme of lightweight inspection equipment further and explore its actual performance in complex road conditions to provide more efficient and intelligent technical support[14-15] for road maintenance and safety supervision.

2. Materials and Methods

To realize the lightweight design of inspection equipment, this research developed a set of integrated HD industrial cameras and global navigation satellite system (GNSS) positioning technology of road acquisition system, including the integration of lightweight design acquisition hardware and supporting software design, to synchronize road images and positioning data, thus significantly improve the data accuracy and real-time, effectively eliminate the single sensor possible error, and then realize the rapid acquisition and quantitative analysis of common pavement diseases (such as cracks, pits, etc.).

(1) System Composition

HD industrial camera: The CMOS image sensor with high dynamic range and global shutter function is selected to ensure that high-quality images are obtained under complex light conditions such as shadow, overcast days, and direct sunlight.

GNSS positioning module: The high precision GNSS receiver, combined with the inertial measurement unit (IMU), is used to realize the accurate measurement of the position and attitude of the vehicle to avoid the problem of positioning signal failure in the tunnel under the bridge.

In addition, the equipment is integrated and installed on the onboard computer of the inspection vehicle, and the cooperative operation of the HD touchscreen control is realized between the acquisition camera and the positioning module to provide the image information with high-precision positioning information.Integrated design.

(2) Integrated Design

The HD industrial camera is integrated with the GNSS positioning module in a compact enclosure to achieve the device's lightweight and modular design. A magnet suction cup is installed at the bottom of the shell to facilitate the quick installation and disassembly of the equipment while ensuring its stability during vehicle operation(Figure 1).

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(a)front view of the equipment

(b) Side view of the equipment

Figure 1. Integrated patrol inspection equipment

(3) Lightweight image recognition model

Real-time image detection of the images stored in the in-car computer. To adapt to the limited computing power resources of onboard computers, the original YOLOv8n model is used as the baseline, and the improved Ghost-YOLOv8n is used to build a lightweight architecture with a characteristic reparameterization mechanism by replacing the traditional convolution of the backbone network part with the Ghost convolution module.

Specifically, this paper introduces the Ghost module in the Backbone and Neck modules of YOLOv8n to build a lightweight architecture with a feature weight parameterization mechanism, optimize the network structure, and improve the target identification accuracy of the model while maintaining the lightweight features.

This study provides a systematic performance comparison analysis for the YOLOv8n target detection algorithm and its improved version of the Ghost module. In the experiment, the data set independently collected by the lightweight inspection equipment was used as the benchmark, and the standardized test (TensorRT 8.6 acceleration, FP16 accuracy mode was conducted on the NVIDIA Jetson AGX Orin edge computing platform). The test result pairs are shown in Figure 2 and Figure 3.

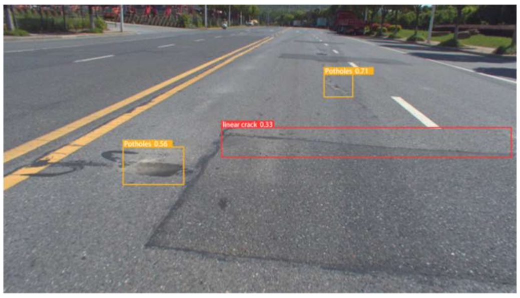

Figure 2. Informer YOLOv8n detection picture

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Figure 3. Imfied YOLOv8n detection picture

According to the figure, the improved Ghost-YOLOv8n model significantly improves detection accuracy, and the rate of misdetection and missed detection has also decreased. This suggests significant progress in the accuracy of target recognition.

(4) Task Visualization Platform

In order to make the collection task more quantitative and standardized, avoid omission and repeated collection, and improve the efficiency of highway daily inspection management, this paper developed a visual inspection system for road collection tasks. This design has significant advantages, including the quantitative collection task, ensuring the scientific and quantifiable setting of the collection task, and real-time update through color coding, effectively avoiding omission and repeated collection, improving work efficiency and data integrity. The system interface is shown in Figure 4.

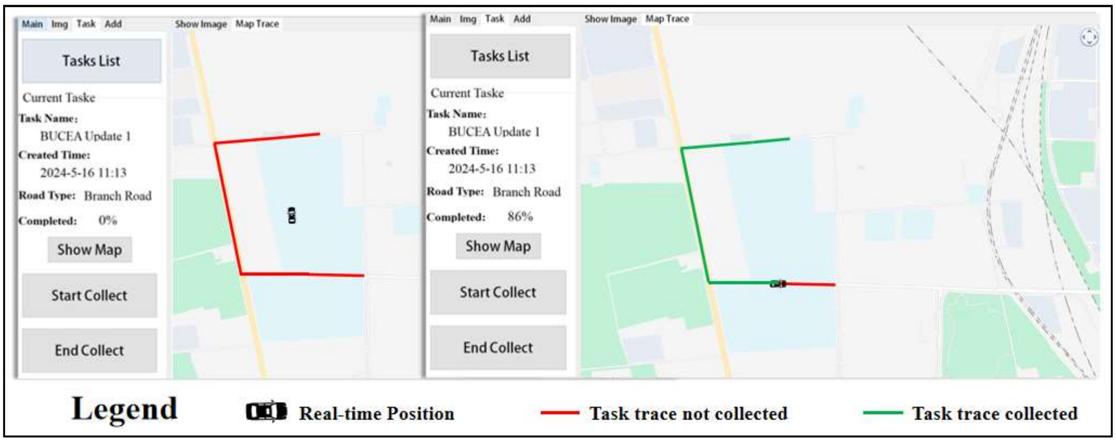

Figure 4. Acquisition task system interface

The system is an information management platform integrating offline map display, acquisition path delineation and collection. Users can access it on the desktop, which consists of three basic modules: inspection task creation, inspection task management and inspection task collection.

3. Experiments

In this experiment, 23.06 kilometers of Luqiu Road from Jingliang Road to Weiyong Road in Daxing District, Beijing, were collected for road inspection experiment. The acquisition interface is shown in Figure 5.

This experiment collected a picture of the road surface for every 20 meters of the vehicle, according to the preset acquisition task track. The average speed of the acquisition process was controlled at 40 km/h~70km/h to maintain the clarity of the image. A total of 1152 road images were obtained during the whole process and saved under the new folder of this collection, as shown in Figure 6. Images were processed with a modified YOLOv8n lightweight model configured locally, and relevant processing results were generated, as shown in Figure 7.

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Figure 5. Surface inspection interface

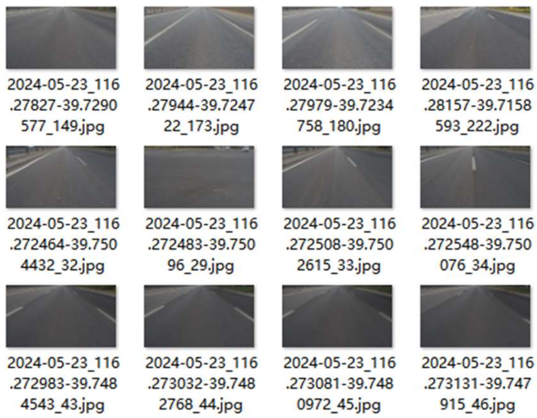

Figure 6. Save the road surface pictures

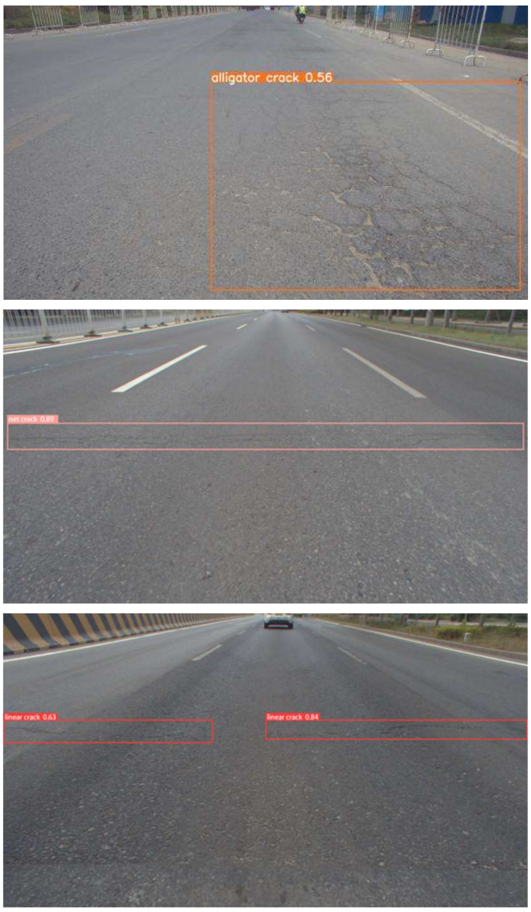

Figure 7. Detection results of road surface images

Using lightweight acquisition software and an improved pavement recognition model experiment, this paper concludes that the lightweight pavement acquisition system designed in this paper can identify pavement surface diseases such as line crack, network crack, crack, and pit groove and meet the requirements of daily pavement inspection. This conclusion verifies the system's effectiveness and demonstrates its great potential in practical applications.

4. Conclusion

Given the problem of low automation level and efficiency in daily road maintenance, this paper innovates and studies a lightweight road acquisition system, namely the inspection mode of "lightweight acquisition + lightweight disease detection model + road acquisition task visualization". Its hardware equipment is light and easy to carry, suitable for rapid deployment in different road environments, whether urban roads, highways, or rural roads, and can efficiently be dealt with. Secondly, the operation interface of the system is simple and intuitive, and ordinary inspection personnel can use it skillfully after simple training, which significantly reduces the labor cost and operation difficulty. The feasibility of the daily inspection test of Luqiu Road has been verified, but there are also some problems. For example, for the problem that two consecutive pictures may capture the same pavement disease, the pavement disease labeling mechanism should be proposed and calibrated according to the crack form. In addition, it is necessary to continue to optimize and improve the algorithm model to improve the detection accuracy.

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