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Road Pothole Detection and Location System Based on YOLOv5 and Beidou GPS

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Abstract: Road potholes are harmful to safe transportation, which will cause vehicle damage, poor ride comfort and put passengers in danger. Road pothole detection and result application is one of the key measures to solve the above problems. Therefore, this paper designs a road pothole detection and location system. The system mainly consists of edge computing platform (including detection algorithm), road pothole image acquisition module, positioning module, display module and auxiliary module. The computing platform adopts Jetson Nano. The road pothole detection algorithm adopts YOLOv5 algorithm. The positioning module adopts Beidou GPS module. First, the camera collects the image set of road potholes (or adopts an open image set). The image set is divided into two parts: training set and test set, which are used for training and testing respectively. Then, based on YOLOv5 algorithm, the road pothole images in the training set are trained, and the optimal target detection model is obtained. Finally, the model is used to test the road pothole images in the test set. The open road pothole image set is tested, and the road pothole recognition rate is above 90%. Through this system, road potholes can be accurately detected and the location information of potholes can be recorded. The research results in this paper can be provided to traffic management departments and used in unmanned vehicles, which is of great significance to reduce the impact of road potholes on safe driving of vehicles.

1. Introduction

With the acceleration of urbanization and the booming of transportation industry, the safety and maintenance of road infrastructure has become a key issue in modern urban governance. Road potholes are considerable structural road damage caused by rainwater infiltration into the pavement. Road potholes are harmful to safe transportation, which will make vehicles out of balance and become the main factor inducing accidents. Road potholes can cause vehicle damage, poor ride comfort and passengers are in danger. Therefore, it is of great significance for traffic management departments and road maintenance units at all levels in the country to find and deal with road potholes and other damages in time, which will improve traffic fluency and transportation efficiency.

unmanned vehicle (UV) and intelligent transportation systems (ITS) will undoubtedly affect and change people's quality of life and future travel modes. UV and ITS make people's traffic more coordinated, safe and intelligent [1]. Advanced sensor technology, machine learning and artificial intelligence have played a prominent role in the latest progress of ITS. However, for unmanned vehicles that do not have the ability to deal with damaged roads at present, road potholes will affect the safe driving of unmanned vehicles because of the lack of real-time control of vehicles like drivers. Thus, an unsolved challenge in UV design is to create an efficient and accurate road pothole detection strategy.

Research on road pothole detection systems is mainly concentrated in universities, research institutions, and some innovative enterprises. In the cutting-edge exploration of intelligent transportation and road maintenance, researchers rely on advanced algorithm systems and breakthrough technological innovations to build an efficient and accurate pothole recognition system. By using deep learning algorithms for intelligent analysis of road images and combining multi-source perception technologies such as lidar and high-definition cameras, the system can quickly capture subtle changes on the road surface and accurately identify information such as the location, size, and depth of road potholes.

Reference [2] realizes real-time detection of potholes. Reference [3] can link with the control system of autonomous vehicles to pre-plan avoidance paths, effectively avoiding potential driving safety hazards caused by road defects. It provides an intelligent and scientific solution for urban road safety management, greatly improving road maintenance efficiency and traffic travel safety. Reference [4] studies the detection and maintenance strategies of expressway asphalt pavement damage, analyzes the types and causes of asphalt pavement damage, and points out that comprehensive evaluation should be conducted based on actual conditions, balancing maintenance costs and effects, to select pavement damage detection technologies and maintenance strategies. Reference [5] proposes a road crack and pothole detection algorithm based on improved YOLOv7, which improves detection accuracy and speed but lacks sufficient field tests on urban roads. Reference [6] studies the active obstacle avoidance control algorithm based on pavement pothole detection to reduce the accident rate of vehicles driving on pothole roads. This reference not only detects potholes on the road but also classifies the size of pothole damages, which is applied to the active obstacle avoidance control of intelligent vehicles. Reference [7] conducts research on on-board pavement pothole algorithms for unmanned driving, providing a decision-making basis for the speed control and local path planning of subsequent unmanned vehicles.

A German transportation research institution has developed an IoT-based road monitoring platform. This platform is deployed on public transportation vehicles such as taxis and buses to form a mobile monitoring network. When the on-board detection system identifies a road pothole [8], it will immediately transmit data packets containing information such as the location and severity of the pothole to the municipal road management department in real-time via 4G/5G networks. The management department can intuitively present the distribution of road potholes on an electronic map based on the GIS geographic information system, quickly assess road conditions, and formulate maintenance plans according to priority. This model that combines road pothole detection with on-board GPS improves the timeliness of road defect detection and the efficiency of maintenance work, providing a new solution for the intelligent management of urban roads.

Reference [9] develops a pothole detection and reporting system based on deep learning to help road maintenance personnel make informed road repair decisions. The YOLOv5 algorithm is used to detect road potholes, and the locations of road potholes are added to the map. Reference [10] uses YOLOv5 to detect road potholes, extracts the latitude and longitude values of road potholes from the EXIF data of images, and marks them on a data map. Reference [11] uses hardware such as Raspberry Pi, GPS module, and GSM module, and employs CNN, Mask RCNN, and YOLOv3 to detect potholes, which are then transmitted to the road transportation authority via E-mail. It is observed that YOLO is the best real-time object detection algorithm, different from Mask RCNN and CNN algorithms. The road pothole detection system in Reference [12] mainly consists of a Raspberry-Pi, a GPS module, a portable Wi-Fi device, and a web server. When a road pothole is detected, it connects to the Internet to send the image and the location of the pothole to the main database. Reference [13] studies the use of algorithms with various configurations such as SSDTensorFlow, YOLOv3-Darknet53, and YOLOv4-CSPDarknet53 for road pothole detection. It proposes to improve driver safety by detecting road potholes in advance and enhance the performance of autonomous vehicles to ensure the safe travel of future passengers. Reference [14] uses the TMS320C6678 SoC Digital Signal Processor (DSP) to realize road pothole detection.Reference [15] proposes a new method for detecting potholes using smartphone accelerometers and image sensors. Reference [16] designs an automatic pothole detection and alarm system integrating ultrasonic sensors, accelerometers, stereo cameras, and Global Positioning System (GPS) with Raspberry-Pi, and conducts experimental research on two-wheeled electric vehicles. Reference [17] develops a low-cost real-time road pothole detection system, which uses Arduino, ultrasonic sensors, GPS, and GSM modules to accurately identify and report potholes.

In summary, this paper studies the problem of road pothole detection and localization. The hardware architecture is built with the high-performance microprocessor Jetson Nano as the core. Road pothole images are collected by a camera, and the YOLOv5 algorithm is used for road pothole detection. The Beidou-GPS is adopted to record the locations of road potholes. The Jetson Nano edge computing platform provides strong mobile computing capabilities for the system. With the help of model lightweight technology, efficient operation is achieved while ensuring accuracy. The integration of the Beidou-GPS module enables the system to have precise localization functions, providing accurate coordinate guidance for subsequent maintenance work. The system transmits road pothole information to unmanned vehicles in real-time, which is of great significance for reducing the impact of road potholes on the safe driving of vehicles.

2. Hardware design

The system mainly consists of a computing platform (including detection algorithms), a road pothole image acquisition module, a localization module, a recording module, a display module, a computer platform, and an auxiliary module. The overall hardware block diagram is shown in Figure 1. The computing platform's hardware architecture is built with the high-performance microprocessor Jetson Nano as the core, integrating a USB camera, a Beidou-GPS localization module, an NVIDIA display, a mouse, and a keyboard.

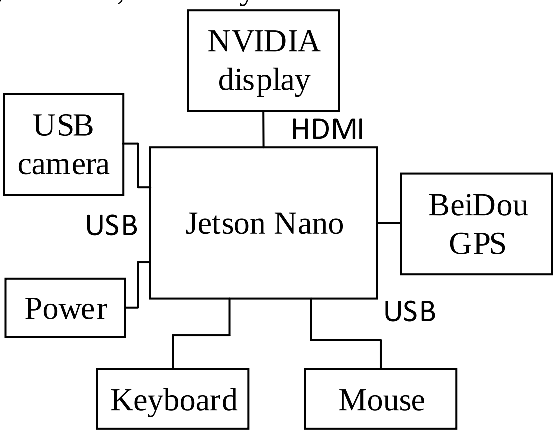


Figure 1: Overall hardware block diagram

2.1 Jetson Nano module

The Jetson Nano module is a small-sized, high-performance artificial intelligence computing platform launched by NVIDIA, designed specifically for edge computing and embedded AI applications. In terms of hardware configuration, this module is equipped with a quad-core Cortex-A57 processor and a 128-core NVIDIA Maxwell architecture GPU, which can provide 472 GFLOPs of computing performance. It is also equipped with 4GB LPDDR4 memory and expandable storage. In terms of interface configuration, it supports multiple interfaces such as Gigabit Ethernet and HDMI to meet the connection needs of different devices. Additionally, the module is equipped with HDMI, USB3.0, OTG interface, and power interface.

2.2 Beidou-GPS localization module

The Beidou-GPS module is shown in Figure 2.

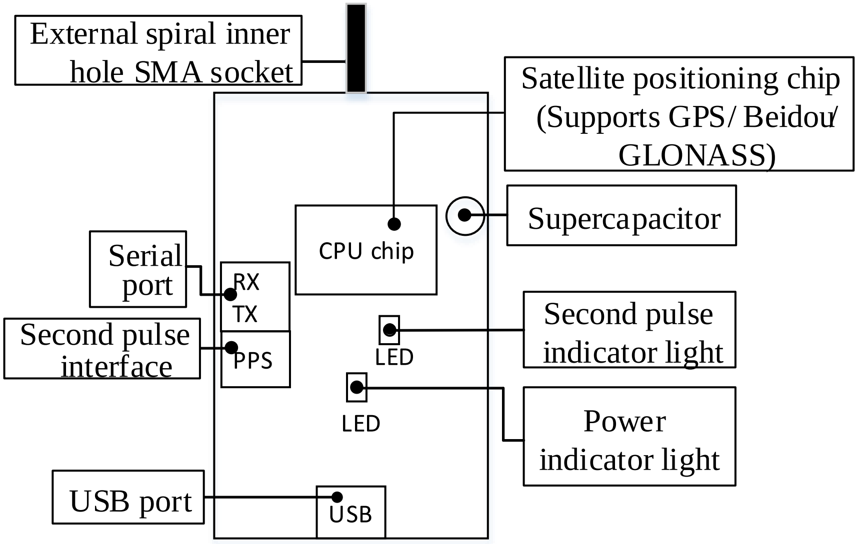


Figure 2: Schematic diagram of Beidou-GPS localization module

The selected GPS module is a Beidou-GPS localization module. This module is a device highly integrated with GPS and Beidou satellite localization functions, combining the advantages of both systems. By receiving signals from multiple satellites and performing a series of complex calculations, it accurately determines position coordinates, including longitude, latitude, and altitude, with a localization accuracy reaching the meter level. It can also provide high-precision timing services at the nanosecond level. Through the Beidou-GPS module, the real-time location information of potholes can be obtained, providing accurate data support for road maintenance.

2.3 Display module

The selected display module is an NVIDIA display. The Jetson Nano is connected to the display via an HDMI interface, which is used for debugging real-time detection programs and displaying detection results, facilitating parameter adjustment.

2.4 Camera module

In this system, a USB camera is selected as the road pothole image acquisition module. Its main specifications include: a resolution of 1028p, a frame rate of 30FPS, a pixel resolution of 640x480, a focal length of 4mm, a sensitivity of ISO1000, and a signal-to-noise ratio of 48dB. The image size is set to 640x640. The USB camera is connected to the Jetson Nano via a USB port.

2.5 AGNSS assisted localization module

The AGNSS (Assisted Global Navigation Satellite System) assisted localization module is a technology that can improve the localization performance of global navigation satellite systems. This technology uses the network to transmit various auxiliary data such as satellite ephemeris and time to the device, enabling the device to quickly and accurately search for and track satellite signals. In this way, it can shorten the time required for localization, improve localization accuracy, and save power consumption. The AGNSS assisted localization technology is widely used in multiple fields such as intelligent transportation, logistics tracking, mobile payment, and emergency rescue.

3. Road potholes detection based on YOLOv5 algorithm

3.1 Target detection principle based on YOLOv5

First, the camera collects the target image set (or adopts the public image set). The image set is divided into two parts: training set and test set. The training set is used for model training, and the test set is used for model testing after training. Then, based on YOLOv5 algorithm, the training set images are trained, and the optimal target detection model is obtained. Finally, the model is used to test the test set images to verify the effect of the model. The target of detection in this paper is road potholes, and the main content of this paper is road potholes detection and location.

3.2 Training performance indicators

A public road pothole dataset is selected as the training image set and the test set. After training, the training results are obtained, as shown in Figures 3-6.

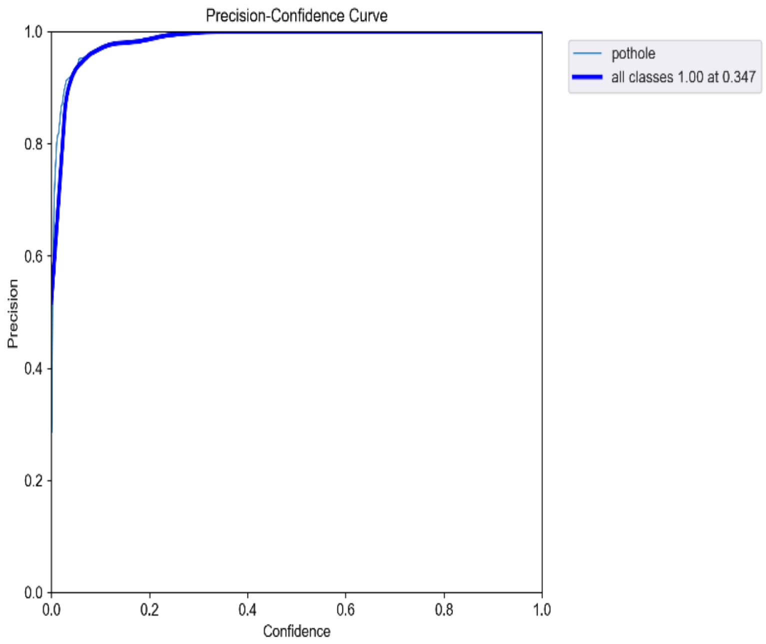


Figure 3: Precision-Confidence curve

As can be seen from Figure 3, after 300 rounds of training, the accuracy has been continuously improved with the improvement of confidence. When the confidence is close to 1, the accuracy has reached 100%.

As can be seen from Figure 4, the improvement of confidence will reduce the recall rate, and the reduction of recall rate also means that the accuracy of other aspects will be improved during training.

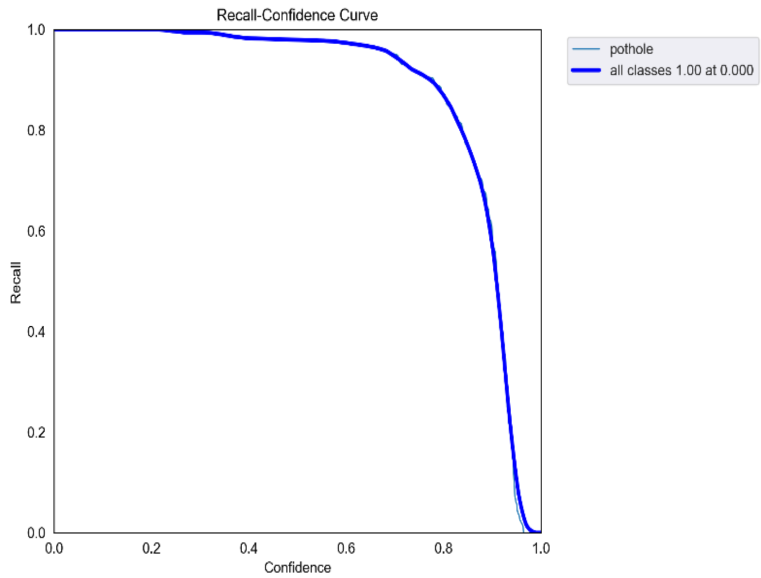


Figure 4: Recall-Confidence curve

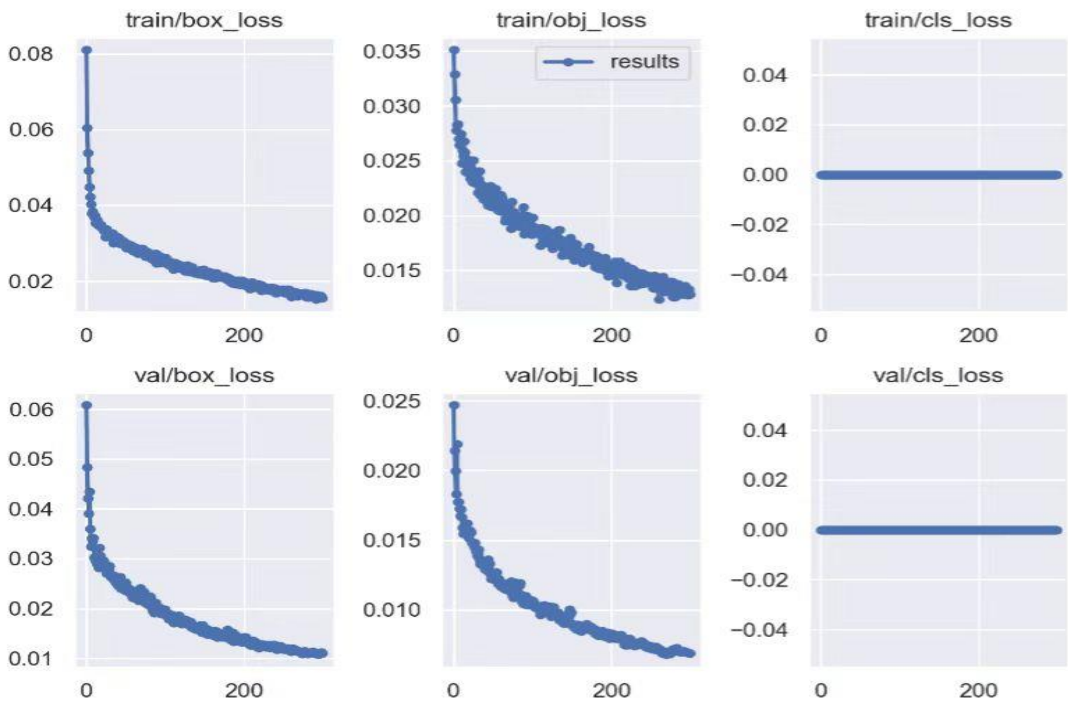


Figure 5: Overall parameters 1

It can be accurately seen from Figure 5 and Figure 6 that the Loss value and Precision value of pothole detection in this training. MAP@0.5 and mAP@0.5:0.95 reflect the accuracy with confidence of 0.5 and 0.5-0.95 respectively, and mAP_50 is stable around 0.8 after 300 rounds of training, so it is not difficult to see that the actually measured accuracy parameters can be applied to engineering practice after the training is completed.

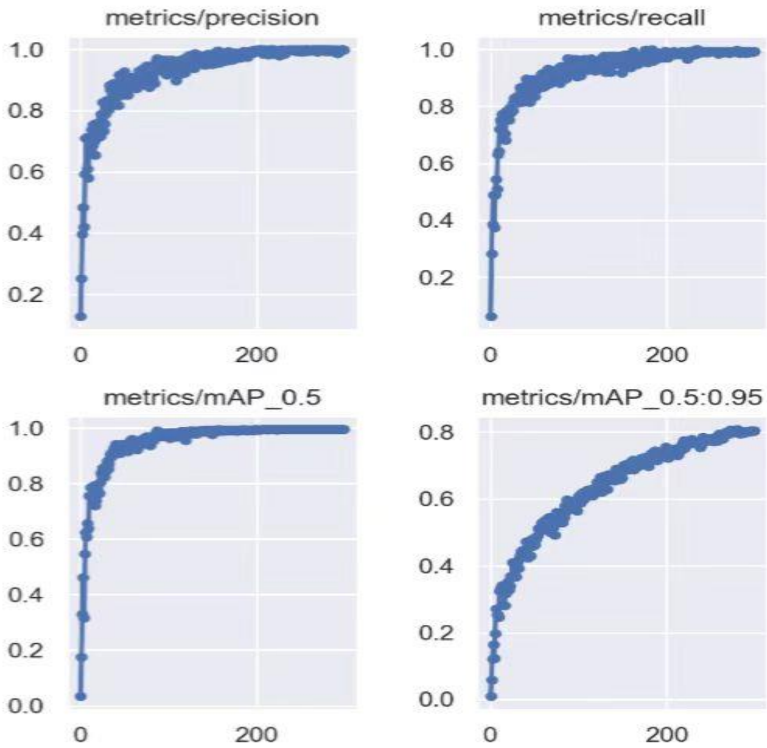
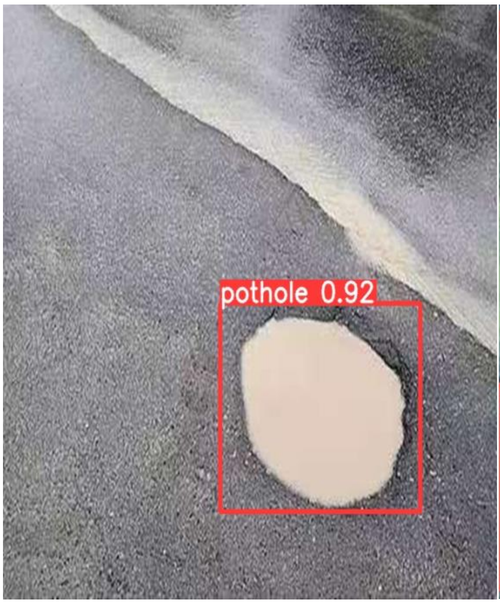


Figure 6: Overall parameters 2

4. Test results

4.1 Road pothole test on computer



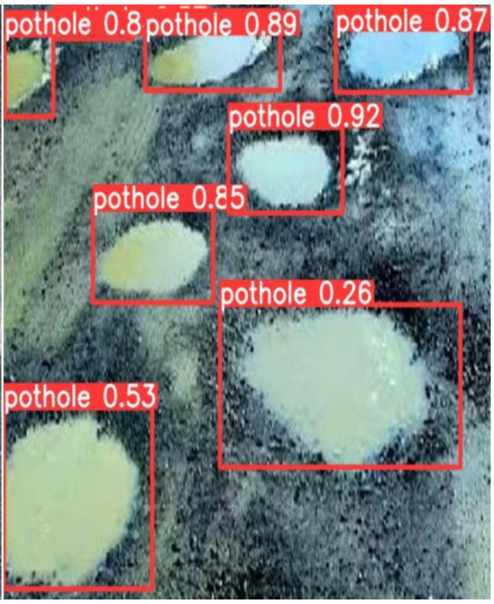


Figure 7: Single road potholes Figure 8: Multiple road potholes

The computer's operating system is Windows 11. The graphics card is NVIDIA GeForce MX330 with a computing power of 6.0. The version of PyCharm is 3.8.0, and the version of Python is 3.9.13. The image dataset contains 628 images with a size of 640x640. The Linux version deployed on the Jetson Nano is Ubuntu 18.0.

Next, the training model obtained on the computer is tested, and single, multiple and road potholes with buildings are tested respectively. Their test results are shown in Figure 7-9 respectively.

Figure 9: Other buildings

The training image dataset contains more than 600 images. 100 images are selected as samples for testing. The road potholes in these 100 images are of various types and sizes, and the pothole recognition rate is as high as 90% with an average confidence of 0.9.

4.2 Road pothole test on Jetson Nano

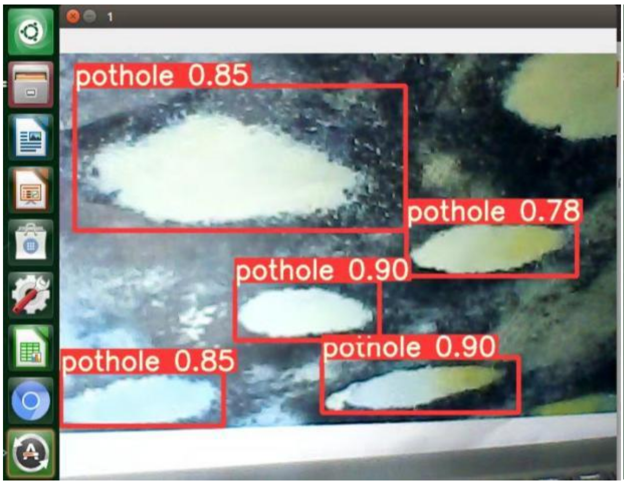


Figure 10: Road potholes detection results

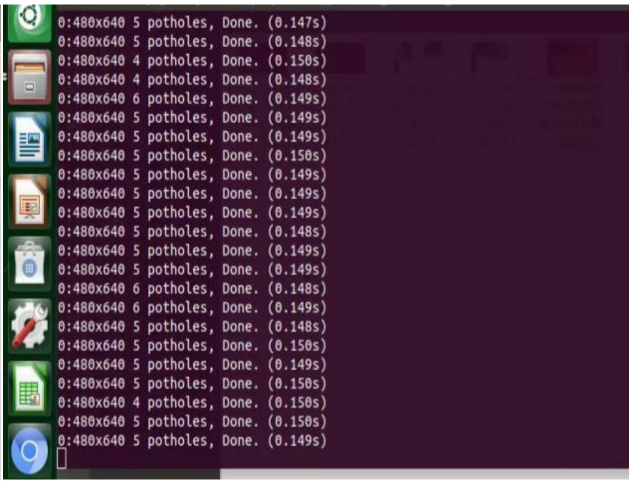


Figure 11: Road potholes quantity record

The environment required for YOLOv5 is configured on the Jetson Nano. Under the same WIFI mode, the weight file from the computer end is transferred to the Jetson Nano. To achieve efficient real-time video stream detection, the YOLOv5s.pt weight file needs to be optimized to generate the YOLOv5s.engine file. After that, the pothole detection function can be realized on the Jetson Nano. Road pothole information is collected by the camera, and after quantification by the Jetson Nano, the information of road potholes can be observed on the NVIDIA display. This information includes the confidence of road potholes, the number of potholes, and the time. The road pothole test results and localization results on the Jetson Nano end are shown in Figures 10 and 11 The screenshot of the location information recorded by the Beidou-GPS module is shown in Figure 12.

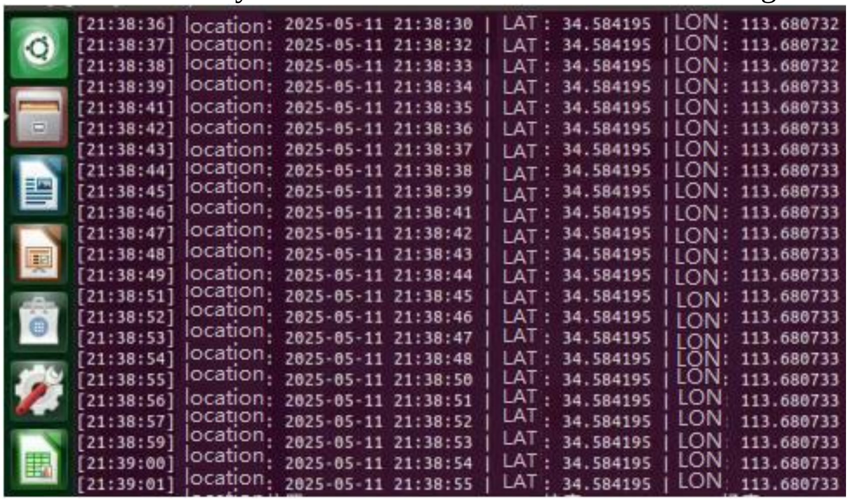
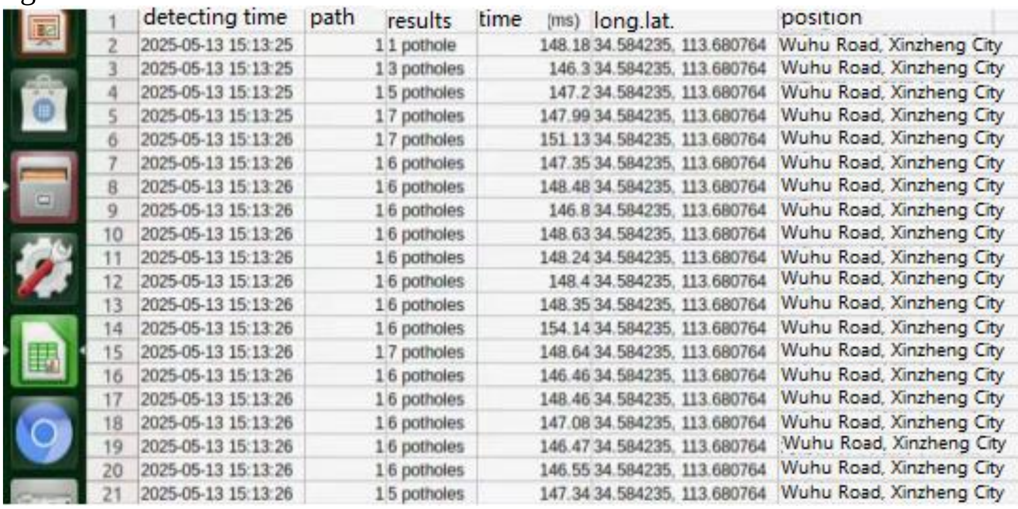


Figure 12: Data reading effect of Beidou-GPS module

On Jetson Nano, the YOLOv5 target detection algorithm is deployed, and the road image is captured in real time with the help of USB camera to realize the accurate identification of potholes. The latitude and longitude information is obtained by using GPS Beidou module, and the latitude and longitude data is converted into specific geographic coordinates by combining with AGNSS-assisted positioning technology. When the system detects a road pothole, it will automatically record the current time stamp, and finally integrate the road pothole information records with the date, time and detailed geographical location. Subsequently, the obtained information is saved in a CSV file. The screenshot of saving detected potholes to the CSV file is shown in Figure 13.



1	detecting time	path	results	time (ms)	long.lat.	position
2	2025-05-13 15:13:25	1	1 pothole	148.18	34.584235, 113.680764	Wuhu Road, Xinzheng City
3	2025-05-13 15:13:25	1	3 potholes	146.3	34.584235, 113.680764	Wuhu Road, Xinzheng City
4	2025-05-13 15:13:25	1	5 potholes	147.2	34.584235, 113.680764	Wuhu Road, Xinzheng City
5	2025-05-13 15:13:25	1	7 potholes	147.99	34.584235, 113.680764	Wuhu Road, Xinzheng City
6	2025-05-13 15:13:26	1	7 potholes	151.13	34.584235, 113.680764	Wuhu Road, Xinzheng City
7	2025-05-13 15:13:26	1	6 potholes	147.35	34.584235, 113.680764	Wuhu Road, Xinzheng City
8	2025-05-13 15:13:26	1	6 potholes	148.48	34.584235, 113.680764	Wuhu Road, Xinzheng City
9	2025-05-13 15:13:26	1	6 potholes	146.8	34.584235, 113.680764	Wuhu Road, Xinzheng City
10	2025-05-13 15:13:26	1	6 potholes	148.63	34.584235, 113.680764	Wuhu Road, Xinzheng City
11	2025-05-13 15:13:26	1	6 potholes	148.24	34.584235, 113.680764	Wuhu Road, Xinzheng City
12	2025-05-13 15:13:26	1	6 potholes	148.4	34.584235, 113.680764	Wuhu Road, Xinzheng City
13	2025-05-13 15:13:26	1	6 potholes	148.35	34.584235, 113.680764	Wuhu Road, Xinzheng City
14	2025-05-13 15:13:26	1	6 potholes	154.14	34.584235, 113.680764	Wuhu Road, Xinzheng City
15	2025-05-13 15:13:26	1	7 potholes	148.64	34.584235, 113.680764	Wuhu Road, Xinzheng City
16	2025-05-13 15:13:26	1	6 potholes	146.46	34.584235, 113.680764	Wuhu Road, Xinzheng City
17	2025-05-13 15:13:26	1	6 potholes	148.46	34.584235, 113.680764	Wuhu Road, Xinzheng City
18	2025-05-13 15:13:26	1	6 potholes	147.08	34.584235, 113.680764	Wuhu Road, Xinzheng City
19	2025-05-13 15:13:26	1	6 potholes	146.47	34.584235, 113.680764	Wuhu Road, Xinzheng City
20	2025-05-13 15:13:26	1	6 potholes	146.55	34.584235, 113.680764	Wuhu Road, Xinzheng City
21	2025-05-13 15:13:26	1	5 potholes	147.34	34.584235, 113.680764	Wuhu Road, Xinzheng City

Figure 13: Screenshot of saving detected road potholes to CSV file

5. Conclusion

This paper designs a road pothole detection and localization system. Using the road scene image dataset, the training of the road pothole detection model based on the YOLOv5 algorithm is completed. The trained model obtained in this paper has a confidence level greater than 90%. With the Jetson Nano platform as the core hardware, the hardware system including the road pothole image acquisition module, Beidou-GPS module, and NVIDIA display module is completed. The YOLOv5 algorithm is deployed on the Jetson Nano platform to realize road pothole detection and localization. Field tests show that the system can detect road potholes in real-time and determine the specific location (latitude and longitude) of road potholes using the Beidou-GPS module. This system can be installed in social vehicles. As the vehicle travels, it detects and localizes road potholes in real-time. The research results in this paper can be provided to traffic management departments and applied to unmanned vehicles, which is of great significance for reducing the impact of road potholes on the safe driving of vehicles.

Acknowledgements

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