Intelligent Detection of Urban Road Underground Targets by Using Ground Penetrating Radar based on Deep Learning

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Abstract. Ground penetrating radar (GPR) is widely used in the field of intelligent road detection because of its non-destructive detection method, which is based on an electromagnetic wave reflection mechanism. However, this method requires large-scale data processing and also relies on manual judgment, which is time-consuming and laborious. To solve this problem, this paper analyzes and studies the GPR images of underground pipelines and uneven settlement of urban roads by means of road surface measurement and laboratory tests. The radar image data set is constructed by collecting radar images and denoising and marking them. Then, Deep Feature Selection Net is adopted to improve the fast region-based convolutional neural network (Faster R-CNN) to enhance the network's ability to extract features from radar images. Finally, by comparing with the improved faster R-CNN model, it is found that the automatic identification rate of underground pipelines and uneven settlement in urban roads increases, reaching more than 80%.

Keywords: Urban Road, GPR, Deep Learning, Faster R-CNN, Deep Feature Selection Net

1. Introduction

With the rapid growth of urban road mileage and the growth of its service life, many road collapse accidents have occurred around the world in recent years, causing huge casualties and property losses. Besides, various municipal pipelines in the underground space of the city are complicated, and the traditional destructive detection methods such as drilling core sampling are no longer applicable due to their time and energy consumption[1]. By contrast, GPR is widely used in the fields of physical exploration, intelligent road detection, and so on because of its detection mechanism[2-3]. However, the method mostly depends on the experience of the checker, and the period of fine quantization is long. Therefore, it is necessary to establish an efficient and accurate method for the rapid and comprehensive detection of urban roads, and timely grasp the status of urban road underground diseases, which is of great significance to ensure urban road safety.

At present, underground target detection methods based on GPR are mainly divided into two categories: traditional machine learning and deep learning method. The former one includes the extraction of a hyperbolic feature detection method based on HoF transform and Haar-based feature
learning algorithm, etc. The method of hyperbolic feature detection based on the Hough transform is limited by the huge amount of computation caused by processing and discretizing a large number of parameters. The automatization and accuracy of GPR image underground target detection based on feature orientation histogram and feature learning algorithm need to be further improved.

In contrast, image target detection based on deep learning has made breakthrough progress [4] and is gradually popularized in the field of image recognition. In terms of GPR image target detection, some scholars proposed an in-depth learning method based on Faster R-CNN for underground target detection with hyperbolic echo characteristics [5]. Although there is no need to manually depict target features and the detection accuracy is significantly improved, this kind of method is consistent with the traditional GPR target detection method and usually relies on the location in the GPR image to extract hyperbolic echo features, so as to realize the identification and extraction of single-class underground targets such as pipelines [6] and landmines [7]. The distribution of urban road underground targets is unknown and complex, and the existing methods cannot accurately locate and extract multiple categories of buried targets, and the timeliness cannot meet the actual requirements of urban road buried objects survey in terms of detection efficiency, target types and extraction accuracy.

After the above analysis, this paper adopts the multi-mode high-similarity annotation algorithm to establish the urban road radar image data set and then adopts Deep Feature Selection Net to improve Faster R-CNN to automatically identify the uneven settlement and pipeline in the radar detection results, so as to realize the intelligent radar detection.

2. Image recognition model of GPR based on deep learning for urban Road Pipeline
The intelligent GPR target detection automatically method based on deep learning mainly includes the process of image acquisition, data set establishment, model construction, and improvement. Finally, the recognition results are optimized from different perspectives, and the results before and after improvement are compared and analyzed. The flow chart is shown in Fig. 1.

![Diagram](image)

Fig. 1 Main Process of GPR Intelligent detection

2.1. Obtain GPR Image Data Set
By feature learning of massive sample sets, deep learning can extract multi-modal information of GPR images, so as to realize intelligent recognition and classification detection of signals. Therefore, it is very important to build a massive sample data set. In order to obtain mass road GPR images, this paper obtains radar images through simulation and real measurement. In the aspect of GPR image analysis and research of radar image acquisition for real measurement, it mainly includes model detection and field detection. Model detection is to collect road samples of buried pipelines in the laboratory. Field detection is to collect radar images of the existing vacated sections on real roads or road test sites, as shown in Fig. 2. The acquisition results can be used to compare the simulated radar images and preliminarily construct the training set of deep learning neural networks.
Five hundred original GPR images were collected and preprocessed. First of all, the additional useless information such as the blank and text description of the image is deleted. Then, 187 images with an underground pipeline were selected as the sample data set. Although a considerable sample size has been obtained, the comprehensiveness and diversity of the sample set are still limited due to collection conditions and road factors. Then, the collected images were rotated and folded in different angles, and the real small sample data set was enlarged. Finally, 1683 GPR images of pipelines and uneven settlement were obtained, providing an effective sample size guarantee for the later training of deep learning networks.

Fig. 2 GPR and the image obtained

2.2. GPR Image Test model Based on Faster R-CNN

Multimodal high Similarity labeling criteria are a labeling method for multimodal deep learning. This project intends to conduct rapid and accurate labeling of uneven settlement GPR images based on this method, so as to provide accurate characteristic information for model training. The network implementation process is shown in Figure 3. Firstly, the unlabeled training set is used for the convolutional neural network pre-training, and the network is initialized at the same time. Next, it enters the stage of single-mode fine-tuning to optimize the weight of nodes and conduct multi-task learning. Finally, backpropagation is used to update the weight of nodes in each layer.

Fig. 3 GPR Image Coding Process

There are redundancy and noise interference in the source signal, and the deep neural network can excavate the deeper information of the features, but there is still a black box that cannot be interpreted. Combining physical characterization and the strong learning ability of deep learning, the deep feature selection network is adopted to optimize the Faster R-CNN model, so as to improve the network's ability to learn and detect the multi-modal characteristics of GPR images. As shown in Fig. 4, by adding a one-to-one layer between the input layer of the deep neural network and the first hidden layer, the weight value for each dimension feature is obtained, which is used as a measurement standard to strengthen the influence of sensitive features, weaken the influence of redundant noise features, and improve the detection accuracy. In order to realize feature selection at the input level, the original feature set is established by analyzing and studying the GPR image of the road base with the feature of
extraction complexity, the frequency cascade feature of wavelet ridge, and the information entropy feature.

Fig. 4 Deep Feature Selection Network

The deep learning model of Faster R-CNN is built to detect the GPR image analysis and research of radar targeting the uneven settlement defect of road base, which can avoid information loss and improve detection efficiency. Fig. 5 is a schematic diagram of a convolutional neural network, which mainly includes four parts, namely, feature extraction layer, regional generation network, pooling layer, and classification regression layer. Defects due to radar for road base uneven settlement of GPR image analysis and research on the vulnerable to external environmental interference, which makes the image characteristics of difficult to extract, so this project is based on feature extraction layer depth feature selection network improvement, in order to improve the network characteristics of signal multimodal learning ability, at the same time improve the detection efficiency and accuracy.

Fig. 5 Schematic Diagram of Convolutional Neural Network

The region generation network is used to replace the original selective search module to generate the candidate box. The softMax function is used to judge the target candidate box. The regression border is used to adjust the position to get the feature sub-graph. In terms of feature extraction and classification, a combination of convolutional neural network and pooling layer is adopted to normalize feature subgraphs with different sizes and send them to the full connection layer for target detection and position adjustment regression. Using the feature graph output from the pooling layer, the category of feature sub-graph is judged, and the border is regressed again to get the precise target position.
At the same time, the optimal super parameter of the network is to be adjusted to train the network with excellent detection accuracy and positioning ability to better detect GPR images. Finally, mAP (average detection accuracy), a comprehensive pavement damage evaluation index, is used to comprehensively evaluate the detection depth neural network model proposed in this study.

3. Collected GPR Image and Result Analysis
The digital 400MHz pulse radar with a minimum sampling frequency of 5ps was used to examine the test road in the laboratory and part of the open road sections in our university. Part of the data collecting field and GPR image are shown in Fig. 6 below:

Experimental parameters of firm R-CNN were set and adjusted [8] to obtain the target identification accuracy before the model was improved. Then, Deep Feature Selection Net was added to improve fast R-CNN. The model test results before and after the improvement are shown in Tab. 1, which demonstrates that this method helps us to enhance the AP results of underground pipeline and uneven settlement to 87.63% and 84.27% respectively. The identification of pipeline and uneven settlement is shown in Fig. 7. Still, it needs to be upgraded in future research, it can be seen that some pipe, in Fig. 7 (a), and uneven settlement, in Fig. 7 (b), are not identified efficiently.

| Target          | Training Set | Testing Set | AP Results (Before Optimization) | AP Results (After Optimization) |
|-----------------|--------------|-------------|----------------------------------|----------------------------------|
| Underline Pipe  | 1178         | 505         | 0.8342                           | 0.8763                           |
| Uneven Settlement | 1178       | 505         | 0.7852                           | 0.8427                           |

Tab. 1. Faster R-CNN Training Result
4. Conclusion
In order to use ground penetrating radar (GPR) to detect pipelines and uneven settlement in urban roads quickly, this paper proposes an underground target recognition method based on deep learning. By surface measurement and data sets augmented with multimodal high similarity annotation for urban road, underground radar image data sets were established. Faster R-CNN network was improved by using the depth of feature selection network, consequently, the accuracy of deep learning model recognition is improved, which provides efficient and accurate detection methods and theory for the construction and maintenance of the modern intelligent road.

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