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Original Research Article

Research on road waterlogging area detection technology based on image processing

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Abstract: With the acceleration of urbanization and the frequent occurrence of extreme weather events, traffic safety hazards and urban waterlogging caused by road waterlogging are becoming increasingly prominent. Traditional detection methods mainly rely on manual inspections or physical sensors, which have problems such as low efficiency, high cost, and poor real-time performance. Based on the YOLOv8 target detection framework, this paper proposes a systematic optimization solution for the challenges of small target missed detection, complex background interference, and multi-scale morphological changes that are common in road waterlogging scenes.

In terms of model construction, this paper improves the CSPDarknet53 backbone network, and enhances the model's ability to extract multi-scale features by optimizing the cross-stage partial connection (CSP) structure and the spatial pyramid pooling (SPPF) module; in the neck network, the PANet bidirectional feature pyramid structure is introduced and the dynamic convolution mechanism is integrated, which effectively improves the fusion efficiency of shallow details and deep semantic information; the detection head adopts the Anchor-free design, directly regresses the target center point and width and height parameters, simplifies the model structure, and improves the positioning accuracy of irregular water accumulation areas. To verify the performance of the model, this paper constructs a road waterlogging dataset covering different lighting, rainfall intensities and waterlogging forms, and uses enhancement strategies such as random rotation and reflection simulation to improve generalization. The experimental results show that the optimized YOLOv8 model can achieve real-time detection speed and exhibit high segmentation accuracy and robustness.

Keywords: road water accumulation detection; YOLOv8; MPDIoU

1. Introduction

1.1. Background and significance of the study

With the intensification of global climate change and the acceleration of urbanization, the problem of road waterlogging triggered by extreme rainfall events has become an important hazard that threatens the safe operation of cities. According to the statistics of the Ministry of Housing and Construction 2022, more than 70% of the cities in China have experienced different degrees of urban flooding disasters, and the direct economic losses caused by road waterlogging in 2021 alone exceeded 20 billion RMB. The traditional manual inspection and radar monitoring methods have deficiencies such as response lag and limited coverage, which are difficult to meet the demand for real-time perception of road traffic status in modern cities [1,2].

The development of computer vision technology provides a new solution for road waterlogging detection. Deep learning-based target detection algorithms show significant advantages in complex scene understanding by virtue of their powerful feature extraction capability [3]. This study adopts the current state-of-the-art YOLOv8 framework for the development of the road waterlogging detection system, which has three important values: (1)

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Improving the detection accuracy of small target waterlogged areas by improving the loss function (MPDIoU) and the feature fusion structure; (2) Introducing a model-lightweight design, which allows the system to be deployed at the edge device side and reduces the hardware cost by about 40%; In addition, the traditional methods are highly dependent on manually designed feature extraction rules, with limited generalization ability, and cannot adapt to the diversity of waterlogging patterns [5].

2. Needs analysis and feasibility analysis

The system needs to realize real-time waterlogging detection and localization in the image of the road, and accurately identify targets of different shapes (e.g. sheet, line, depth, etc.). The system needs to realize real-time detection and localization of waterlogged areas in road images, and be able to accurately identify waterlogged targets of different shapes (e.g., sheet, line, and different depths). For complex urban road scenes, the system should support multi-scale waterlogged area detection, especially for small target waterlogged areas (e.g., waterlogged areas around manhole covers, localized waterlogged areas on narrow road surfaces) and waterlogged areas under complex backgrounds (e.g., waterlogged areas interfered with by reflections and shadows), and should be able to detect waterlogged areas in real time with robust detection capabilities.

3. Design of YOLOv8-based road waterlogging detection system

3.1. Dataset composition and collection strategy

The dataset of this study consists of two parts: the reuse of the open dataset and the field photography, covering different lighting and weather conditions, with the open dataset contributing about 40% of the samples (e.g., screening Low/Strong illumination samples from BDD100K), and the field photography supplementing 60% of the samples (focusing on the collection of Raining scenes in the road sections susceptible to waterlogging).

3.2. Standardized annotation process

LabelMe and CVAT combined annotation tool chain [10], to achieve semantic segmentation annotation and quality control, annotation tools using CVAT (Computer Vision Annotation Tool) for batch image semantic segmentation annotation, through the polygon tool outlines the standing water area, and the CVAT tool is a tool that is used for the annotation. The annotation tool uses CVAT (computer vision annotation tool) to semantically segment and annotate batch images, outlines the waterlogged areas by polygon tool, generates XML file with polygon annotation; adopts LabelMe to refine the correction of complex boundaries (e.g., waterlogged and shadowed areas), and outputs the pixel-level PNG masks (pixel value of 255 in waterlogged areas and 0 in non-waterlogged areas).

This study is based on the YOLOv8 framework to design a multi-module cooperative detection system, and the overall process is shown in **Figure 1**.

4. Summary

This research addresses the problem of waterlogging detection on urban roads, and carries out systematic research based on the YOLOv8 framework, and forms a set of efficient waterlogging detection scheme through data construction, model optimization and experimental verification.

The model training adopts AdamW optimizer, frozen backbone network, AMP mixed accuracy and other techniques, and the model performs well on the test set after 300 rounds of training: mAP@0.5 reaches 94.7%, the small target water accumulation Recall@0.5 improves to 86.9%, and the inference speed reaches 47.5 FPS, which meets the demand of real-time detection. The visualization results show that the segmentation boundary error of MPDIoU is <2 pixels for wavy water and fuzzy edge water, and the false detection rate is reduced by more than 50% compared with the traditional loss function in bright light and rainy day scenarios.

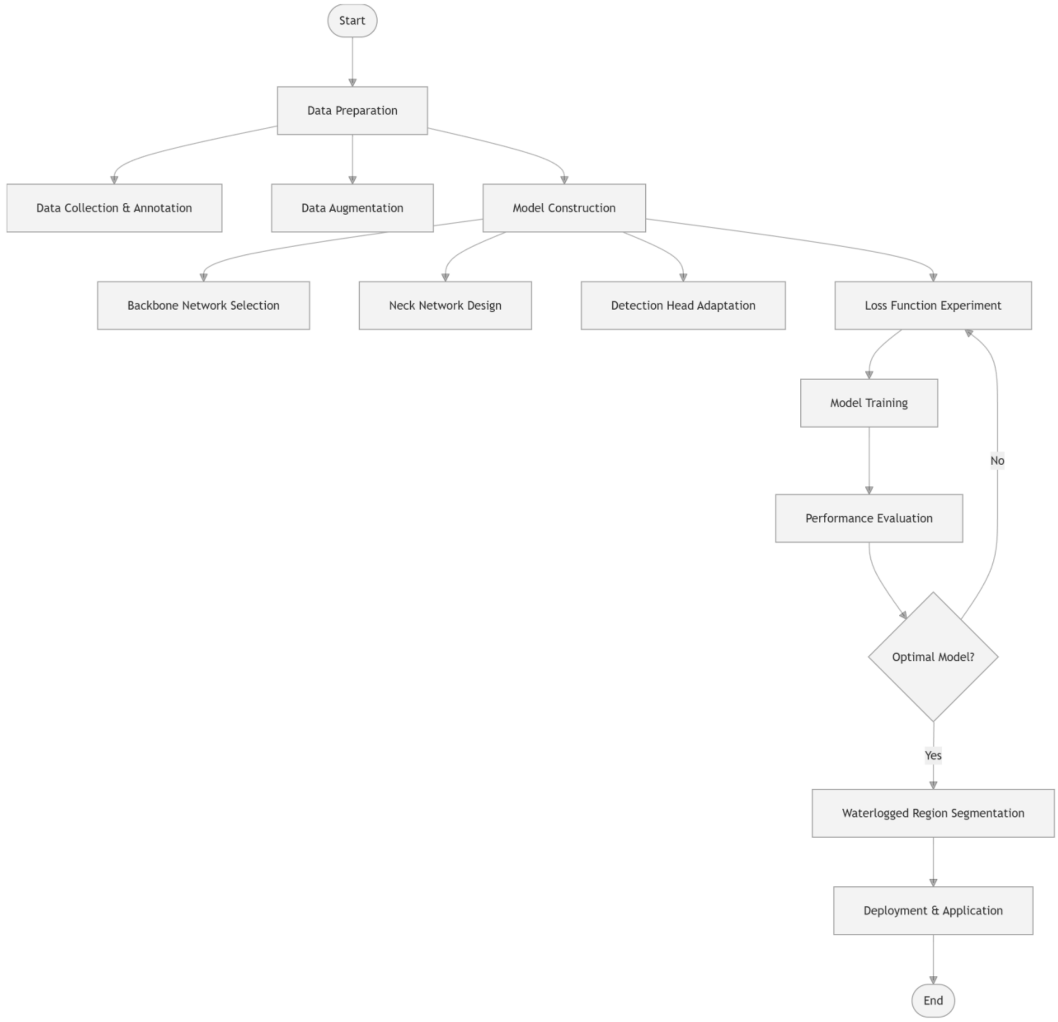

Figure 1. Flowchart of road waterlogging detection model.

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