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RGB-D BASED WORK AREA RECOGNITION MODEL FOR FIREPROOFING SPRAY ROBOT

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Abstract

Fireproofing spray on steel structures is essential for fire resistance, yet it is still manual, exposing workers to hazardous and dusty conditions. Robots have been developed to address these issues, but some systems depend on work area map, which limits real time adaptation. In addition, object level recognition cannot provide surface level work areas. Therefore, we propose an RGB D work area recognition model that classifies work area surfaces on a steel structure beam. On experiment, the model achieves a macro average F1 score of 0.8682. Finally, the proposed model provides surface level work area for fireproofing spray robot.

Introduction

Fireproofing spray on steel structures is a required process to secure fire resistance. Because it is frequently performed at height and under dusty conditions, workers can be exposed to safety risks, and spraying quality can vary with worker's skill level.

Fireproofing spray robots have been developed to address these issues. However, some systems depend on offline preparation, where spraying work files are generated from structural design data in advance and the robot operates only after a working area map is created beforehand (Ikeda et al., 2020). Because the work area must be set up before each spraying task and updated when site conditions change, productivity can drop and real time adaptation during spraying remains limited.

To improve real-time adaptation, recent studies use vision sensing to segment steel structures, but results remain at the object level(Zhu et al.,2022). Such object level recognition does not provide surface level work areas for robot spraying.

Therefore, unlike prior approaches that depend on offline work area map preparation or remain at the object level, this study proposes an RGB-D based work area recognition model that classifies five work area surfaces on a steel structure beam for fireproofing spray robot.

RGB-D based Work Area Recognition Model

This study proposes an RGB-D based work area model for fireproofing spray robot(Figure 1).

Data Preparation

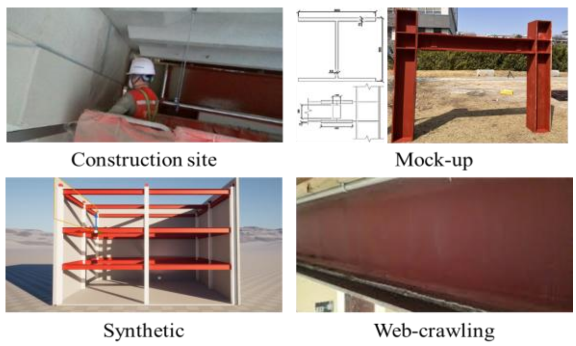

Figure 2: Four types of train dataset

For data preparation, RGB-D videos are recorded during fireproofing spray using an RGB-D camera, and RGB images and depth maps are extracted at 30 fps. Also, a YOLOv11 segmentation model is trained for steel structure beam segmentation using four types of train dataset, with a total of 480 images(Figure 2).

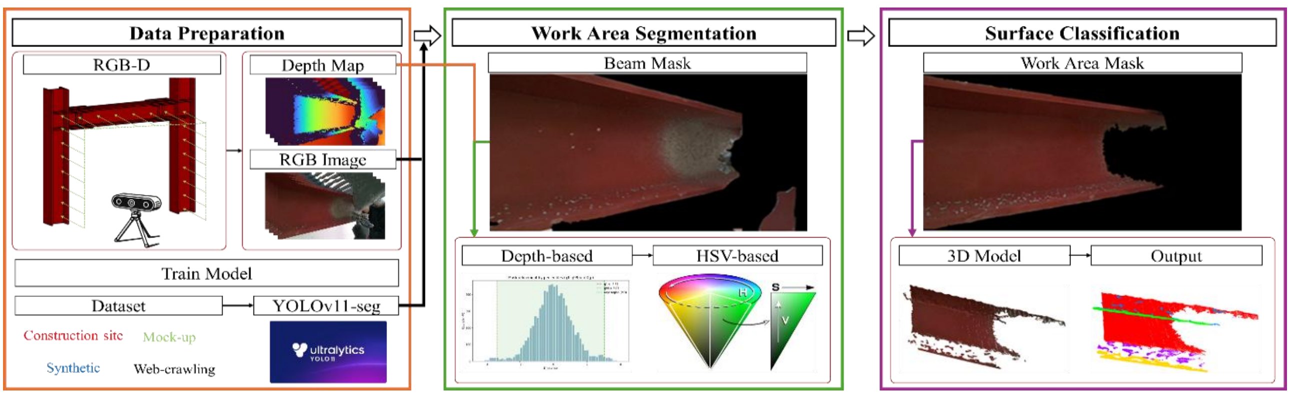

Figure 1: RGB-D work area recognition model framework

Work Area Segmentation

A trained YOLOv11 segmentation model generates an initial mask of the steel structure beam from the RGB image. The mask is refined using the depth map by expanding the boundary and keeping only pixels within the 1st–99th percentile depth range inside the mask. Within the refined region, HSV-based rules separate unworked and worked areas: unworked area is selected by red Hue ranges (0–20 or 160–180) with sufficient saturation and value, while worked area is excluded using low saturation and high value without constraining Hue. The final work area mask is obtained by removing worked area pixels.

Surface Classification

A 3D point cloud is reconstructed from the final work area mask and the depth map. RANdom Sample Consensus(RANSAC; web: thresh = 0.01 m, minPoints = 5000, maxIteration = 4000; flange: thresh = 0.008 m, minPoints = 1500, maxIteration = 3000) iteratively extracts planar surfaces by selecting the plane with the largest inlier set, removing its inliers, and repeating on the remaining points. Density-based spatial clustering of applications with noise(DBSCAN; eps = 0.02, min_points = 10) then clusters inliers on each plane into spatially consistent groups, yielding five classified work area surfaces on the steel structure beam.

Experiment

Experiment was conducted using the setup shown in Table 1, with 51 pairs of RGB image and depth map separately collected for evaluation.

Table 1: Experimental setup

Subject	Medium-density fibreboard((MDF) mock-up beam(H-300×300×10×15)	
Data Acquisition	Sensor	Intel RealSense D455
	View Direction	Same as the spray direction
	Distance	300~600mm
Time of Recording	During fireproofing spray operation	
Data	Resolution	RGB Image 1280×720, Depth map 848×480
	Quantity	51 Pairs of RGB Image&Depth map

Result Analysis

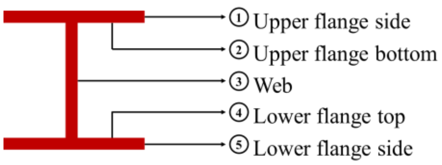

Figure 3: Steel structure beam surfaces

We defined five work surface classes on the steel structure beam, as illustrated in Figure 3. The five surface classification performance was evaluated using precision, recall, and F1-score computed on the 3D point cloud by aggregating outcomes for each class. Overall performance was summarized using the macro average across the five surfaces. Each surface results are reported in Table 2.

Table 2. Experiment results

Surface	Precision	Recall	F1-score	Macro Average
①	0.9992	0.9958	0.9771	0.8682
②	0.8398	0.4995	0.6264	
③	0.9794	0.9238	0.9508	
④	0.9469	0.7385	0.8298	
⑤	0.9758	0.9385	0.9567	

Surface ② showed the lowest recall, likely because one inner flange surface was captured at an unfavorable viewing angle under the current setup. As the camera was positioned approximately perpendicular to the web, the opposite inner flange surface was less visible, resulting in sparse depth points and more difficult surface separation.

Conclusion

This study proposed RGB-D based work area recognition model for a fireproofing spray robot that classifies five work area surfaces on a steel structure beam. It outputs surface level work areas and achieved a macro average of 0.8682 during spraying. Therefore, the proposed model provided surface level work area information for fireproofing spray robot.

However, the experiment was conducted in a controlled environment and did not fully reflect varying site conditions such as illumination changes, dust, and occlusions. Future work will include an ablation study to evaluate the contribution of each pipeline component, improve the model, and validate robot integration for progress monitoring and spray path generation.

Acknowledgments

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