IDOL Reconstruction Using Deep Learning and Additive Manufacturing: A Framework for Cultural Heritage Restoration

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ABSTRACT

Often times, cultural heritage artifacts and idols are damaged by aging, environmental conditions, accidents and natural disasters. Traditional methods for the restoration are time consuming and need skilled artisans. The proposed approach an Idol reconstruction framework based on an AI-assisted additive manufacturing. A deep learning model is used to detect and reconstruct the damaged idol regions from the damaged images. The reconstructed geometry is turned into a 3D model and printed in fused deposition modelling (FDM) 3D printing technology. This proposed approach combines computer vision, deep learning, and additive manufacturing technologies to restore broken parts of the idol precisely while maintaining the artistic and cultural value.

KEYWORDS: Idol Reconstruction; Cultural Heritage; Fused Deposition Modelling; 3d Printing; Deep Learning; AI

1. INTRODUCTION

Sculptures and idols from the past symbolize priceless religious and cultural legacy. However, due to natural deterioration and unintentional damage, many artifacts include fractures, erosion, and missing parts. Traditional restoration techniques mainly rely on manual workmanship, which is time-consuming and frequently subjective. Recent developments in additive manufacturing and artificial intelligence provide new prospects for digital restoration. While 3D printing technologies allow for the quick manufacture of reconstructed components with great dimensional accuracy, deep learning-based image reconstruction approaches can predict missing geometrical characteristics. This paper presents an integrated framework combining convolutional neural networks (CNNs) and additive manufacturing for idol restoration. The proposed framework addresses reconstruction of missing idol portions digitally and fabricates replacement parts using 3D printing technology.
In recent years many researchers work on cultural artifact preservation. Y.Jo (2020) utilizes noncontact approach for restoring a damaged stone-seated Bodhisattva [1]. Bonora (2021) focuses on finding the most suitable material along with the ideal printing position [2]. Razo utilizes hybrid workflows are for conservator for finishing to correct joints, tune texture, or match colour to the original surface [3].

2. MATERIALS AND METHODS

The proposed idol reconstruction framework consists of two phases: computer vision-based damage detection and 3D model generation, followed by Fused Deposition Modelling (FDM)-based 3D printing. The dataset included 500 high-resolution images of 300 healthy and 200 damaged idol images collected from medieval Hemadpanti temples in Maharashtra with the pre-processing techniques were resizing, noise removal, contrast enhancement, illumination normalization, and background segmentation. ResNet-50 [4] was used to identify damaged areas and create damage masks, and a generative reconstruction model was used to reconstruct missing geometry, maintaining the symmetry and artistic characteristics of the idols. The reconstructed images were converted into point clouds, transformed into polygon meshes, and exported as STL files for printing. Finally, the reconstructed idol parts were sliced using Cura, with a nozzle diameter of 0.4 mm, a layer height of 0.2 mm, an infill density of 20% and a printing speed of 50 mm/s, allowing for accurate reproduction of the parts.

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3. RESULTS AND DISCUSSION

The proposed framework was realized with the help of Python 3.11, TensorFlow, OpenCV, Blender, and Cura for deep-learning, mesh generation and 3D printing. It was tested based on reconstruction accuracy, SSIM, PSNR and dimensional accuracy and compared with CNN, ResNet-50, U-Net models. As shown in Figure 1, the proposed method obtained the reconstruction accuracy of 98.4%, which not only has superior restoration performance, but also has high dimensional precision and short restoration time without destroying the cultural and artistic characteristics.



Model	Accuracy (%)	Precision (%)	Recall (%)	F1-Score (%)	PSNR (dB)	SSIM
CNN	91.5	90.8	89.7	90.2	28.7	0.892
ResNet50	94.8	93.9	94.2	94.0	31.2	0.915
U-Net	96.3	95.7	95.8	95.7	33.8	0.942
Proposed Model	**98.4**	**97.9**	**98.1**	**98.0**	**36.9**	**0.971**

Metric	Values
Printing Time	3.2 Hours
Material Consumption	68 g
Dimensional Accuracy	98.6%
Surface Roughness	5.4 µm

Figure 1. a) Graphical abstract of Proposed model of idol reconstruction b) Reconstruction Performance C) Quantitative Analysis of 3D Printer

4. DISCUSSION

The proposed deep learning–additive manufacturing framework demonstrates effective detection and reconstruction of damaged idol regions, achieving 98.4% reconstruction accuracy and 98.6% dimensional accuracy (Figure 1). The integration of ResNet-50, 3D mesh generation, and FDM printing provides a practical and scalable approach for digitally preserving cultural heritage while retaining the artistic characteristics of traditional sculptures.

5. CONCLUSION

The proposed deep learning and additive manufacturing-based idol reconstruction system aims to determine the damaged areas, reconstruct the missing idol parts, create 3D models of the idol and print the parts to be replaced, using 3D printing technologies. The proposed framework offers a cost-effective and scalable solution for preserving cultural heritage artefacts and heritage monuments

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