Integrating the Technologies of Image Processing and Virtual Reality for the Digital Preservation of Disappeared Archaeological Sites

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Abstract: Tangible historical and cultural assets refer to physical artifacts that can be touched and intergenerationally transferred. This kind of asset is considered the past that the next generations should memorize. One of the issues that archaeologists frequently face is the methods used in digitally restoring disappeared archaeological assets. This is due to their low quality, noisy texture, or uncolored images. On the other hand, the advent of new technologies such as digital image processing (DIP) and virtual reality (VR) makes it palatable to digitalize and sustain tangible historical assets. These technologies are recognized as efficient tools insofar as they can contribute to preserving the heritage of civilizations. Hence, this study suggests an approach that integrates DIP and VR techniques to restore historical assets that have disappeared from low-quality images. The findings show that the proposed methodology is successful in restoring archaeological sites or objects, as demonstrated by the results obtained.

Keywords: Cultural Heritage, Tangible Cultural Assets, Image Processing, Image Enhancement, Virtual Reality, Disappearing Heritage

1 Introduction

The emergence of sophisticated technologies has had a significant impact on addressing life challenges. These technologies have made many previously daunting issues much more manageable. One such technology that has gained widespread use in recent times is VR. It is an up-and-coming technology that is expected to become increasingly prevalent in our society [Cr24]. It allows individuals to immerse themselves in and explore new virtual worlds. The versatility of VR technology allows for the creation of virtual environments that can include any real-world object. This unique feature enables developers to design immersive virtual worlds that showcase historical or cultural landmarks [BB24]. They also provide people with the opportunity to explore these landmarks as if they were physically present remotely. One of the exciting and promising applications of VR is cultural and historical heritage preservation since it makes it easy to explore any historical site without even visiting it.

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Cultural heritage preservation using digital approaches is an essential aspect of protecting our history and culture. However, preserving cultural heritage is not only about capturing the beauty and grandeur of historical artifacts and landmarks. It is also about documenting historical and cultural objects, especially objects that were damaged or physically disappeared due to natural disasters, wars, and human negligence [XR23]. In this regard, the use of destructed, old, low-quality images in digital cultural heritage preservation has become increasingly important. It can contribute to building VR models for objects that no longer physically exist. Low-quality, old, or destructed images refer to photographs that may not be visually appealing or of high resolution but still provide valuable information about an archeological or historical object [Su23].

These images may have been taken many years ago or during times of destruction, but they serve as a record of the past. Yet, they also help researchers and historians understand the evolution and transformation of cultural heritage over time. Moreover, building VR models for historical objects needs to have images of acceptable quality that aim to show the texture and the details of the surface of these objects. The particulars may reflect facts of interest for the researchers, historians, or archeologists. Therefore, it is crucial to enhance this kind of image for cultural heritage preservation. Image processing methods may be performed through digital restoration. This approach involves software to remove scratches, dust, and other imperfections from old images. Digital restoration can improve the clarity and detail of the images, making them more helpful for research and documentation purposes [SS21].

It is essential to mention that these image-processing methods should also be used responsibly and respectfully. They should not be used to alter the historical accuracy or authenticity of the images but rather to improve their usefulness for cultural heritage preservation. Moreover, it is crucial to obtain consent from relevant stakeholders before using such quality-improved images. Furthermore, DIP plays a vital role in enhancing and restoring images of historical sites, offering a vivid and invaluable window into the past [Pi20]. Historical sites have a rich cultural and architectural significance, but over time, these sites can deteriorate or vanish due to some real-world factors. DIP techniques come to the rescue by enabling the restoration and enhancement of old site images.

One of the critical advantages of DIP is the competence to correct imperfections caused by diverse factors by bringing out subtle features and details that might have been overlooked in the original images. Using advanced algorithms, it is feasible to increase the resolution, balance the illumination, increase the sharpness, and even correct the colors [Ca23]. This not only preserves the historical record but also makes sure that upcoming generations can value the architectural nuances and beauty of these sites. This makes the images of historical sites more appealing to a broader audience, adopting a deeper understanding of the valuable heritage. Improving the quality of images using DIP enables different types of people to visually explore these sites incredibly, enhancing the cultural and educational experience. Using DIP not only protects the cultural heritage but also enriches the appreciation and understanding of the past. As technology continues to thrive, the chances for enhancing and restoring these historical

images are boundless, ensuring that the historical monuments remain lucid and available for generations to come.

One of the DIP techniques is image super-resolution. It has a significant impact on image quality by enhancing the resolution, level of detail, and clarity of an image. It is beneficial when dealing with low-resolution or pixelated images, and they play a crucial role in various applications, including old low-resolution images of historical sites. It increases spatial resolution, allowing for better details to be perceived. This improvement leads to more detailed and visually better images. One crucial feature is improving the zooming capabilities so that the processed images can be zoomed in without significant loss of quality. Fig. 1(a) demonstrates a sample of a 4x zoomed image using super-resolution [C019]. Another DIP technique is color correction, which can be used for images of historical sites. It is a vital post-processing step to ensure that the colors precisely represent the authentic look of the site or, at the very least, keep historical accuracy and visual consistency.

This can neutralize any color casts caused by camera settings or lighting conditions [Da19]. Fig. 1(b) depicts a sample of a color-corrected image. Another important DIP technique is sharpness enhancement, which is a common image processing task that can help bring out better details and improve the overall quality of the images [Ma21]. Fig. 1(c) shows a sample of a sharpness-enhanced image. Finally, illumination balancing is another significant DIP technique that aids in correcting illumination inconsistencies and improving the visible quality. Lighting differences can be initiated by issues such as shadows, improper natural lighting, and incorrect artificial lighting, and they can affect the accuracy and clarity of the image details [Pe21]. Fig. 1(d) describes a sample of an illumination-balanced image.

The utilization of DIP in enhancing and restoring images of historical sites is a vital endeavor with solid implications for heritage preservation, public appreciation, and research. Through advanced algorithms, DIP breathes new life into low-quality images, bringing out significant details that might have been lost in time. This imaging revitalization serves as a portal to the past to allow the exploration and connection with the historical heritage in unimaginable ways [RA23]. The impact of DIP goes beyond mere aesthetics. It empowers many people to acquire more profound insights into the historical significance of these sites.

The clarity and fidelity of the processed images contribute significantly to the advancement of knowledge, education, and public engagement. In this digital era, the effective utilization of DIP tools continues to progress, offering even more advanced approaches to restore and enhance images of historical sites [RM20]. Accordingly, it is ensured that the stories embedded in these images remain vivid and enduring, enriching the understanding of the past and the legacy left for the coming generations [Tr21].

The thesis statement of this work is that disappeared archeological assets can be efficiently restored from low-quality information. Hence, the contribution of this work is to validate this statement by utilizing DIP techniques in converting low-quality images

of disappearing archeological assets and generating high-quality 3D models that can be explored using VR technology and metaverse. This study is organized as follows: The next section presents the description of the dataset and the detailed procedures of the proposed method. Section 3 demonstrates the results of the proposed method and their related discussions. Finally, this work is concluded in Section 4; the section also provides recommendations for future works and potential research directions.

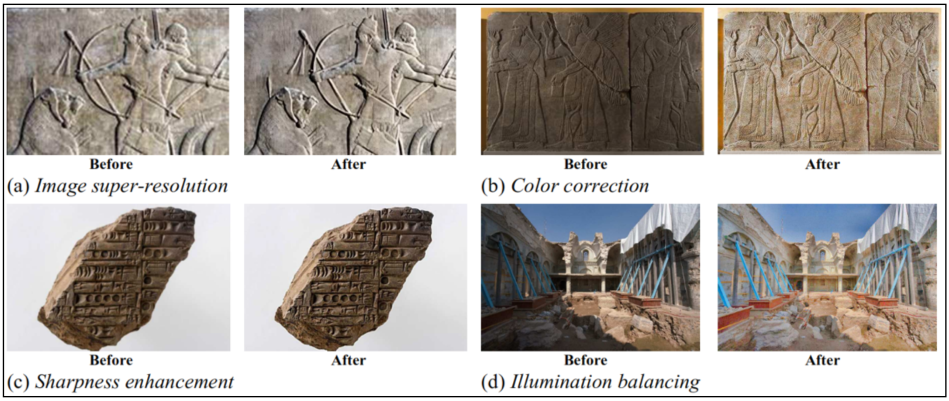

Fig. 1: Examples of using DIP with archeology-related images

2 Research Methodology

The dataset used in this work consists of 255 low-quality gray-scale images with an average size of 70KB. These images represent a Roman stone sarcophagus that was found at the Jadara archeological site in Jordan. The general diagram of the proposed approach is shown in Fig. 2, which starts with the use of image processing techniques to process low-quality images. Then, the processed images are used in Metashape to generate the 3D model.

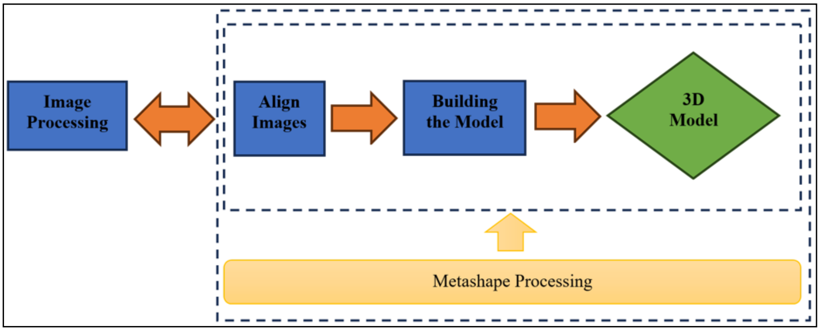

Fig. 2: Diagram of the proposed approach

2.1 Image Processing Phase

The applied preprocessing includes three key steps: the first one is normalization, which regularizes the contrast; the second one is illumination adjustment, which uniforms the illumination; the third one is denoising, which reduces the noise to produce better quality images. The preprocessing step begins by applying a simple normalization method to redistribute the intensity values of the input image to the full range, making the image appear better with improved contrast. The utilized normalization method can be expressed using the following equation [AYA21]:

$$N = \frac{I - \min(I)}{\max(I) - \min(I)} \tag{1}$$

where I is the input image, and N is the normalized image. The second step involves the utilization of an adaptive image enhancement method to equalize the illumination [Wa19]. Although the input images are grayscale, they, in fact, contain three gray layers and are displayed as RGB. Thus, the proposed algorithm in [Wa19] is utilized to equalize the non-uniform illumination. This algorithm begins by transforming the image to the hue, saturation, and value (HSV) domain. Next, the reflectance of the V channel is determined and then enhanced adaptively. After that, the weights are computed, and a specialized fusion method is applied to produce the final enhanced V channel. The phase of this step involves transforming the image back to the RGB domain. The output of step two is then sent to a coefficients-based total variation denoising algorithm [AS14] to reduce the noise of the image and produce more explicit results. This algorithm is designed for medical image denoising but has been used in this study because the method has excellent abilities in reducing different types of noise. The denoising step begins by converting the image (w) to grayscale, then setting and initializing parameters as explained in [AS14] with $\lambda = 2500$. The iteration starts, and an estimation of the input image with better edges is determined using the following equation:

$$\ddot{u}^{q}_{j,k} = \left(0.5 \cdot div\, f^{q-1}_{j,k}\right) - u^{q-1}_{j,k} \cdot \lambda \tag{2}$$

where ($\ddot{u}$) is the approximated image; (λ) is a scalar responsible for the denoising strength, in that a lower value leads to more denoising; (q) is the iteration count; ($\cdot$) is a multiplication operator; (u) is initialized as ($u = w$) and w is the output image of step two; (j and k) are image coordinates; the divergence ($div\ f_{j,k}$) is initialized as a zero matrix having the same size as w. Next, based on the afore-estimated image, four difference operators are calculated to detect the variations in four different directions using the following equations:

$$\left(\nabla \ddot{u}^{q}\right)^{1}_{j,k} = \ddot{u}^{q}_{j+1,k} - \ddot{u}^{q}_{j,k} \tag{3}$$

$$\left(\nabla \ddot{u}^{q}\right)^{2}_{j,k} = \ddot{u}^{q}_{j,k+1} - \ddot{u}^{q}_{j,k} \tag{4}$$

$$\left(\nabla \ddot{u}^{q}\right)^{3}_{j,k} = \ddot{u}^{q}_{j-1,k} - \ddot{u}^{q}_{j,k} \tag{5}$$

$$\left(\nabla \ddot{u}^{q}\right)^{4}_{j,k} = \ddot{u}^{q}_{j,k-1} - \ddot{u}^{q}_{j,k} \tag{6}$$

Using the detected variations in Eq. (3) to Eq. (6), four distinguishing coefficients are implemented to detect the noise information from the variations using the following equations:

$$\left(f^{q}_{j,k}\right)^{1} = \frac{\left(f^{q-1}_{j,k}\right)^{1} + \beta \cdot \left(\nabla \ddot{u}^{q}\right)^{1}_{j,k}}{1 + \beta \cdot \sqrt{\left(\left(\nabla \ddot{u}^{q}\right)^{1}_{j,k}\right)^{2} + \left(\left(\nabla \ddot{u}^{q}\right)^{2}_{j,k}\right)^{2} + \left(\left(\nabla \ddot{u}^{q}\right)^{3}_{j,k}\right)^{2} + \left(\left(\nabla \ddot{u}^{q}\right)^{4}_{j,k}\right)^{2}}} \tag{7}$$

$$\left(f^{q}_{j,k}\right)^{2} = \frac{\left(f^{q-1}_{j,k}\right)^{2} + \beta \cdot \left(\nabla \ddot{u}^{q}\right)^{2}_{j,k}}{1 + \beta \cdot \sqrt{\left(\left(\nabla \ddot{u}^{q}\right)^{1}_{j,k}\right)^{2} + \left(\left(\nabla \ddot{u}^{q}\right)^{2}_{j,k}\right)^{2} + \left(\left(\nabla \ddot{u}^{q}\right)^{3}_{j,k}\right)^{2} + \left(\left(\nabla \ddot{u}^{q}\right)^{4}_{j,k}\right)^{2}}} \tag{8}$$

$$\left(f^{q}_{j,k}\right)^{3} = \frac{\left(f^{q-1}_{j,k}\right)^{3} + \beta \cdot \left(\nabla \ddot{u}^{q}\right)^{3}_{j,k}}{1 + \beta \cdot \sqrt{\left(\left(\nabla \ddot{u}^{q}\right)^{1}_{j,k}\right)^{2} + \left(\left(\nabla \ddot{u}^{q}\right)^{2}_{j,k}\right)^{2} + \left(\left(\nabla \ddot{u}^{q}\right)^{3}_{j,k}\right)^{2} + \left(\left(\nabla \ddot{u}^{q}\right)^{4}_{j,k}\right)^{2}}} \tag{9}$$

$$\left(f^{q}_{j,k}\right)^{4} = \frac{\left(f^{q-1}_{j,k}\right)^{4} + \beta \cdot \left(\nabla \ddot{u}^{q}\right)^{4}_{j,k}}{1 + \beta \cdot \sqrt{\left(\left(\nabla \ddot{u}^{q}\right)^{1}_{j,k}\right)^{2} + \left(\left(\nabla \ddot{u}^{q}\right)^{2}_{j,k}\right)^{2} + \left(\left(\nabla \ddot{u}^{q}\right)^{3}_{j,k}\right)^{2} + \left(\left(\nabla \ddot{u}^{q}\right)^{4}_{j,k}\right)^{2}}} \tag{10}$$

where (β = 0.2) is the time step; $(f_{j,k})^1$, $(f_{j,k})^2$, $(f_{j,k})^3$, and $(f_{j,k})^4$ are initialized as a zero matrix having the same size as *w*. After that, the divergence is determined, which signifies the noise in the overall image and then reduced using a non-complex minimization function as follows:

$$div\, f^{q}_{j,k} = \frac{\left(f^{q}_{j,k}\right)^{1} - \left(f^{q}_{j-1,k}\right)^{1} + \left(f^{q}_{j,k}\right)^{2} - \left(f^{q}_{j,k-1}\right)^{2} + \left(f^{q}_{j,k}\right)^{3} - \left(f^{q}_{j+1,k}\right)^{3} + \left(f^{q}_{j,k}\right)^{4} - \left(f^{q}_{j,k+1}\right)^{4}}{2} \tag{11}$$

$$u^{q}_{j,k} = \left(u^{q-1}_{j,k} + \frac{\beta}{2} \cdot u^{q-1}_{j,k}\right) - \frac{div\, f^{q}_{j,k}}{\lambda} \tag{12}$$

The output is then regularized to adjust the intensity using the following equation:

$$u_{j,k}^{q} = \frac{u_{j,k}^{q} - \min\left(u_{j,k}^{q}\right)}{\max\left(u_{j,k}^{q}\right)} \tag{13}$$

These processes are repeated a number of times depending on a predetermined number of iterations, which is set as 50 for this study. After the iterations end, the output is a denoised image that is ready to be sent to Metashape software to create the 3D model.

2.2 3D Model Construction

In this phase, the 3D model is constructed using Agisoft Metashape. The input for this phase is the enhanced images. The steps of this phase are dataset preparation, image alignment, mesh generation, mask generation, chunk alignment and merging, building mesh and texture, and finally, generating the 3D model.

3 Results and Discussion

Before using the enhanced images for generating the 3D model, the row images are used instead. The purpose of this step is to see the quality of the 3D model before using the enhanced images. To this end, the row images are imported to Agisoft Metashape software. Then, these images are aligned to build the 3D model (see Fig. 3). The resulting model is depicted in Fig. 4. Obviously, the generated model could be better since it severely lacks accuracy and clarity. Therefore, it is clear that low-quality images cannot be used to create a precise model, and thus, the enhanced images are used instead.

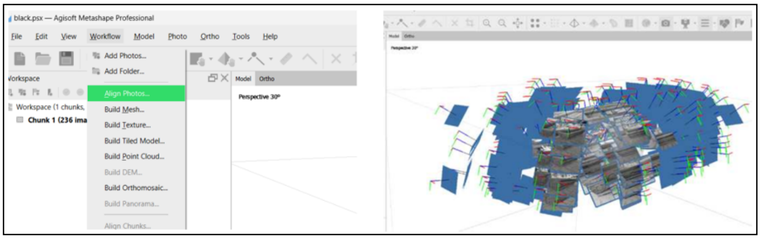

Fig. 3: Aligning images entered into Agisoft Metashape Software (prepared by the researchers)

This step is performed by importing the enhanced images to Metashape. Then, the steps mentioned in Section 2.2 are applied. According to Fig. 5, the generated model is accurate and precise. Fig. 6 demonstrates the 3D model after using the enhanced images. This result means that the proposal and the statement of this work are successful. In other words, disappeared archeological assets can be efficiently restored from low-quality images.

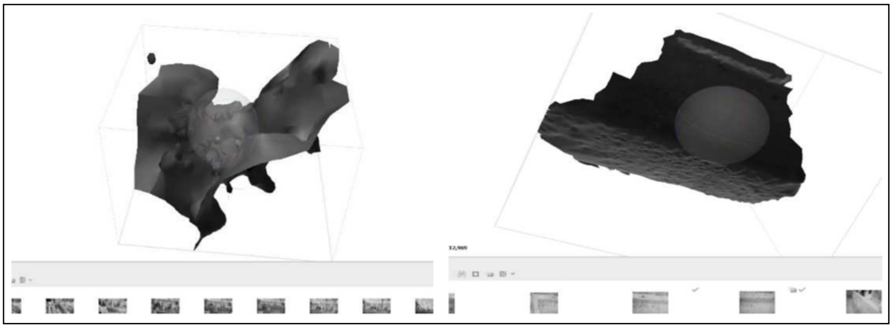

Fig. 4: 3D model before applying image processing techniques

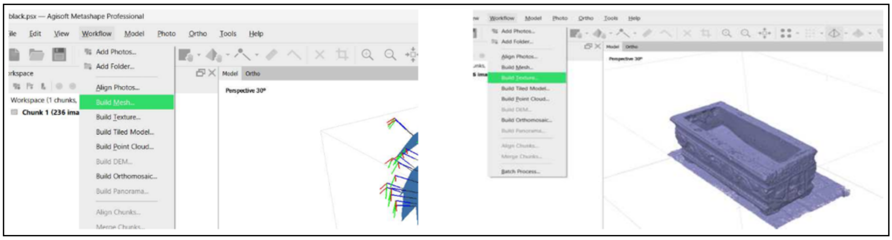

Fig. 5: Building the 3D model using the enhanced images

Fig. 6: The final generated 3D model using the enhanced images

This is important for various cultural heritage preservation applications. Moreover, cultural heritage assets are often subject to degradation over time, which results in low-quality visual data that may need to be improved for accurate 3D reconstruction.

According to the obtained results, the DIP methods have played a crucial role in enhancing low-quality images for generating 3D models. Therefore, DIP algorithms and techniques are utilized as invaluable tools for improving the quality and fidelity of input images before they are used to create 3D models. Image denoising, in particular, helps to remove undesired noise from images, resulting in cleaner and more accurate representations of the underlying scene or object. Hence, by enhancing low-quality images through denoising and other DIP methods, archeologists can produce higher-quality input data for 3D reconstruction. This, eventually, leads to more accurate and realistic virtual representations of archeological assets. These enhanced 3D models can then be utilized in VR applications to provide immersive experiences that allow users to explore and interact with their heritage in ways that would otherwise be impractical. Finally, the integration of DIP techniques and 3D modeling holds great promise for the preservation, documentation, and dissemination of cultural heritage in the digital age.

4 Conclusion

This study utilized DIP techniques for generating VR-based 3D models of archeological assets. Low-quality images of disappearing assets were enhanced and used to create 3D models. The results showed that generating 3D models using low-quality information is insufficient in terms of the accuracy and clarity of the generated objects. However, involving DIP techniques in enhancing low-quality images is highly sufficient for generating high-quality 3D models. The proposed approach has proved efficient in developing 3D models for disappearing archeological assets. However, the limitation of the proposed approach is other datasets may be needed for better model generation. Thus, future work can extend to include more datasets that have different types of noise. Also, more image processing techniques can be used to generate 3D models efficiently.

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