Underwater Digital Exploration of Poompuhar using 3D Reconstruction of Submerged Features/Artifacts

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ABSTRACT

Poompuhar, also known as Kaveri Poompattinam, which is situated in Mayiladuthurai district of Tamilnadu, is an ancient old port city, which got submerged in the sea around 300 A.D. This paper endeavors to contribute to the recreation and preservation of submerged artifacts and objects within Poompuhar, a significant archaeological site submerged underwater. Leveraging cutting-edge imaging technology and sophisticated processing techniques, the paper embarks on a comprehensive reconstruction journey. Using a remotely operated vehicle (ROV) equipped with specialized underwater cameras, it meticulously captures high-resolution images of the submerged environment, including artifacts and structures. These images undergo rigorous preprocessing, including denoising and dehazing, to enhance their quality and clarity, ensuring optimal input for subsequent analysis. Subsequently, employing feature extraction techniques and point cloud generation algorithms, this creates a comprehensive 3D model of the underwater scene. Utilizing the capabilities of 3D modelling, this model is refined through the generation of dense point clouds, mesh creation, and texture mapping. Each stage of the reconstruction process is meticulously executed, ensuring a detailed and accurate representation of the submerged artifacts and structures. Through the collaborative efforts, the aim is to shed light on the historical significance of Poompuhar and contribute to the ongoing efforts in uncovering and preserving its cultural heritage. By recreating submerged artifacts and objects with precision and fidelity, the understanding of ancient civilizations is enriched and pave the way for further exploration and research in underwater archaeology. In summary, this paper stands as a testament to the power of interdisciplinary collaboration and technological innovation in unlocking the mysteries of the past and preserving our cultural heritage for future generations.

KEYWORDS :

3D reconstruction; Denoising; Dehazing; Artifacts; Ocean Archaeology; Submarine Research

1.INTRODUCTION:

This paper is an implementation funded by the Department of Science and Technology (DST) of India. The underwater exploration was first started at the "Dwaraka's" submerged city by the DST. Then it was followed by underwater exploration at the "Poompuhar" submerged city. This paper helps in 3D reconstructing the submerged artifacts with the help of the underwater images that have been obtained from the site after pre-processing the images for better quality. Human imaginations have long been drawn to the investigation and study of underwater settings, yet the difficulties associated with underwater photography have frequently distorted our perception of these fascinating worlds. Our ability to see beneath the waves with more clarity and accuracy is advancing along with technology. By using advanced imaging technology and complex processing techniques to reconstruct submerged items and produce accurate three-dimensional (3D) models of underwater areas, this paper aims to push the boundaries of underwater research. Light attenuation, colour distortion, and image noise are merely some of the special difficulties that come with documenting the underwater world. These issues may mask details and deform how submerged situations appear visually. It takes a combination of sophisticated process, using advanced algorithms, and in-depth knowledge to overcome these obstacles.

This paper seeks to take high-resolution photos of underwater scenes and process them to remove distortions and improve clarity using advanced underwater cameras and sophisticated methods. Submerged structures, artifacts, and ecosystems can be better understood by researchers and scientist’s part to the rich 3D models of the underwater environment that will be built using these processed photographs as a base of operations.

The paper's goals are highlighted in this introduction, which include building realistic 3D models employing advanced image processing and reconstruction methods, improving underwater images, and reconstructing submerged items. The paper's importance is also emphasized in a number of different fields, including environmental monitoring, underwater exploration, and marine archaeology, and how it might enhance our knowledge of the oceanic ecosystem and its inhabitants. This paper aims to uncover the mysteries beneath the ocean's surface by combining imaging technologies, image processing, and 3D reconstruction. This could unlock the way to further exploration and understanding of the underwater world.

2.RELATED WORKS:

According to [1], This presents an innovative approach to addressing the challenges associated with enhancing visibility and clarity in underwater imagery affected by haze and turbidity. The proposed method introduces a novel technique that utilizes a color space dimensionality reduction prior to estimate the transmission map, a crucial element in the dehazing process for underwater images. By reducing the dimensionality of the color space, the method effectively captures the underlying structure of underwater scenes, enabling more accurate transmission map estimation. This approach improves upon traditional dehazing methods by specifically accounting for the unique characteristics of underwater environments, including color distortion and light attenuation. Experimental results showcased the effectiveness of the proposed method in enhancing the quality of underwater images across a variety of underwater scenes and conditions. The paper represents a significant contribution to the field of underwater imaging and holds promise for applications in marine research, underwater exploration, and related domains.

According to [4], The light attenuation, and underwater photography pose unique challenges that lead to low contrast and colour distortion. Current approaches focus on improving a single underwater image. However, an innovative technique takes into account several spectral characteristics of different kinds of water. Assuming similar attenuation coefficients across all colouring channels, the problem is reduced to single image dehazing by adding two additional global parameters: the attenuation ratios of the blue-red and blue-green colouring channels. An assessment across multiple water types is carried out since parameter estimation is made harder by water type variability. The technique of colour distribution analysis is used for figuring out the ideal parameters. A dataset involving 57 photos taken in different underwater environments is also demonstrated. By blending colouring charts into scenes and using stereoscopic imagery for determining 3D structure, ground truth is established. This dataset enables it easier to conduct a thorough quantitative evaluation of rehabilitation algorithms on images of underwater environment. This survey provides an extensive overview of the modern facilities in spectral profile-based underwater image enhancement, emphasising methods, obstacles, and future possibilities.

In [5], The issues like Light scattering and absorption cause haze, blur, low contrast, and colour distortion, are the additional difficulties for underwater imaging. This paper explores an innovative method for reconstructing underwater images that is based on the whole underwater image formation model (UIFM). In contradiction to standard methods that focus only on backward scattering and direct transmission, this new algorithm incorporates forward scattering into the UIFM. The discovery that the geodesic colour distance fr-om background light is inversely proportional to scene distance is employed in the transmission map estimated value. Furthermore, forward scattering's approximation of the point spread function improves the accuracy of scene radiance estimation. The most effective UIFM parameters necessary for both scene radiance restoration and transmission estimation are obtained by optimising a composite cost function that includes dark background prior, information loss, and sharpness. Significant enhancements in estimated transmission maps and scene radiance have been demonstrated experimentally, outperforming present contemporary methods. The paper offers a thorough examination of developments in underwater image restoration methods, clarifying methods, performance indicators, and possible application.

According to [8], An overview of contemporary techniques for enhancing and recovering underwater images is provided in this paper. These techniques address issues like low contrast, colour distortion, detail blurring, and anomalies in tone resulting from light scattering and absorption. Physically based models for picture restoration and non-physically based algorithms for image enhancement are the two basic categories into which the techniques belong. The classification and elaboration of these approaches are provided, followed by a detailed discussion of typical methods for underwater image restoration and enhancement. A comprehensive evaluation, encompassing qualitative and quantitative aspects, is conducted to assess the effectiveness of these techniques. The survey concludes with a summary of the research progress in underwater image restoration and enhancement, along with suggestions for future directions in this field.

In [9], The research focuses at methods for improving and repairing pictures that have been damaged by light absorption and dispersion, like those from cloudy, sandstorm, and underwater scenes. The suggested approach starts by exploiting depth-dependent colour changes to estimate ambient light. The variation between observed intensity and ambient light—referred to as the scene ambient light differential—is then used for evaluating scene transmission. The image formation model (IFM) integrates adaptive colour correction that eliminates colour casts and improve contrast. Generally, and without prejudice, experimental results over a range of degraded images show better performance than other IFM-based approaches. This technique can be considered as a generalisation of the dark channel prior (DCP) approach to image restoration, whereby ranging ambient lighting and turbid medium conditions need to be taken into account to reduce the technique to multiple DCP versions.

3.Proposed Work:

The proposed work has been divided into multiple 3D modelling steps. This work helps the underwater archaeologists to retrieve the authentic information of the object of concern, which helps to expose the trade, tradition, and culture veiled beneath it.

Image Acquisition: A remotely operated vehicle (ROV) is used to take high-resolution pictures of the underwater environment during the image acquisition phase. Utilizing thrusters to travel underwater, the remotely operated vehicle (ROV) is outfitted with cameras specifically designed for underwater imaging and is managed from the surface. By operating at varying depths and capturing photographs from many perspectives, the ROV guarantees thorough coverage of the undersea landscape. With its outstanding maneuverability and real-time monitoring capabilities, the acquisition of images is precisely managed, providing unparalleled detail and precision for the exploration and documentation of underwater structures, artifacts, and ecosystems.

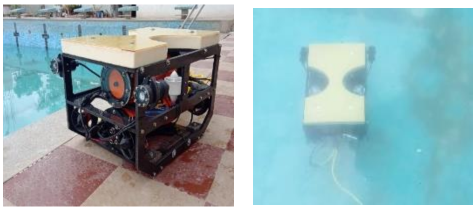

FIG 1: Remotely Operated Vehicle

Image Pre-processing: High-resolution photos taken by the remotely operated vehicle (ROV) are carefully enhanced throughout the Image Preprocessing step. By using dedicated cameras designed for underwater photography, the ROV makes sure the entire scene is covered. Algorithms for denoising, minimize the noise in the images of the collected dataset and methods for dehazing bring visibility back. For an accurate portrayal, colour balance is adjusted by colour correction. This crucial preprocessing, made possible by the ROV's mobility and imaging powers, maximizes input data for later 3D reconstruction and analysis.

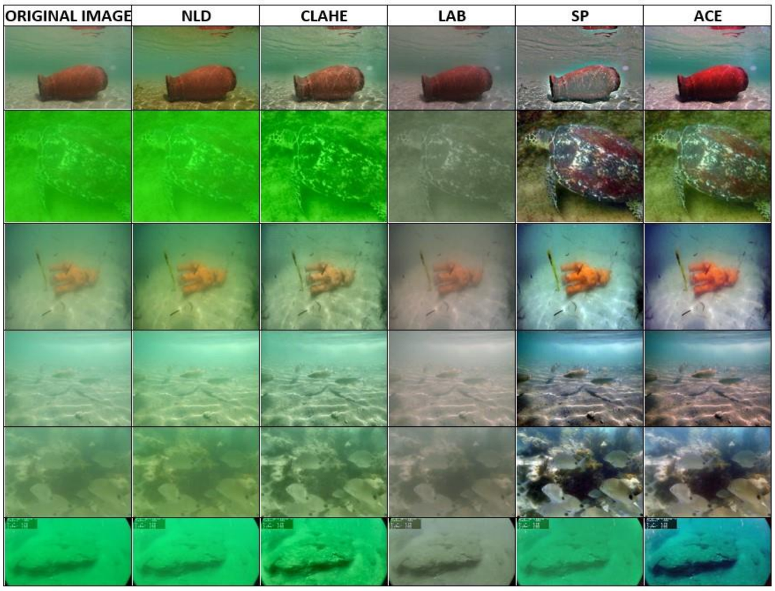

FIG 2: Image Pre-processing of several underwater samples

In the underwater image reconstruction process, five advanced algorithms have been utilized which are - Automatic Colour Equalization (ACE), Contrast Limited Adaptive Histogram Equalization (CLAHE), LAB Colour Correction, Non-Local Dehazing (NLD), and Screened Poisson Equation (SPE). These algorithms serve as a critical component of the image pre-processing pipeline, enhancing the quality and clarity of underwater images before further processing. Figure 2 demonstrates the significant improvements achieved through the application of these algorithms, contributing to more accurate and detailed reconstruction of underwater scenes.

Feature Extraction: Feature extraction finds important features and structures in the underwater images after image improvement. These distinguishing characteristics act as benchmarks for reconstruction and alignment, which are necessary for precise 3D Reconstruction. This process leverages the accuracy of ROV - captured imagery to optimize data for analysis by identifying critical components. Feature extraction is a crucial step in the reconstruction process since it helps to extract important information from the dataset, sets the foundation for other steps, and guarantees the accuracy of the final 3D model of the underwater environment. Though the underwater noises are varying water to water, the proposed algorithm extracts the maximum feature from the image dataset.

Point Cloud Generation: The features that have been detected from the dataset are used in the point cloud generation stage to produce a point cloud representation of the underwater scene. By using multi-view stereo techniques, these features' positions are triangulated over a number of photos, making it easier to create an extensive point cloud. In later phases of the reconstruction process, additional densification and refinement are built upon this initial depiction.

The target artifact is shown in eight directions from various points of view. The camera's parameters determine the image quality. On the radius sphere, the location of a specific point is evenly sampled. A convolutional neural network called VGG16 is used to extract each image's vector. The cosine distance, which is defined as the similarity between the two vectors, is calculated by comparing the attributes of the nearest object model that is acquired and saved in a database.

$$Similarity(x, y) = \frac{xy}{\| x\| \|y\|}$$

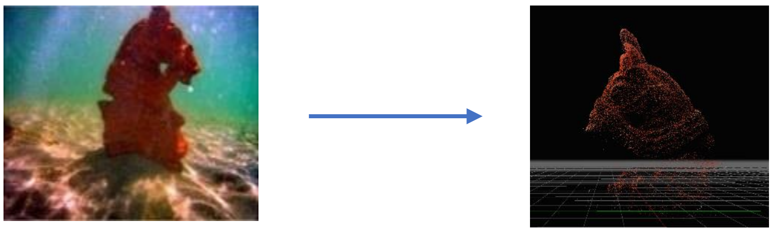

FIG 3: Point Cloud Generation

Sparse point cloud generation: During the Sparse Point Cloud Generation phase, more feature information is added from the images to the basic point cloud, making it even more refined. This procedure ensures a complete yet lightweight structure by improving the point cloud representation's density and detail. Sophisticated algorithms are used to triangulate important features from several angles, producing a finely tuned sparse point cloud that captures all of the important details of the underwater environment. This fine-tuned point cloud provides the fundamental framework for next stages of reconstruction, enabling precise 3D modelling while preserving computational effectiveness.

Dense point cloud generation: During the Dense Point Cloud Generation phase, more information is added from the images to improve the point cloud representation. The program triangulates pixel correspondences across several perspectives using sophisticated multi-view stereo algorithms to produce a densely populated point cloud with excellent spatial resolution. This finely detailed point cloud provides a thorough representation for further investigation and reconstruction by capturing the intricate surface textures and structural complexity of the underwater scene. The dense point cloud produced by sophisticated algorithms is an essential first step towards the creation of intricate surface meshes or textured 3D models. This make it possible to understand the underwater world more thoroughly.

Mesh Generation: Using the dense point cloud, a polygonal mesh representation of the underwater environment is generated during the Mesh Generation stage. By joining the heavily packed points into a continuous mesh structure, this procedure precisely captures the geometry and contour of the underwater environment. The final mesh gives a thorough foundation for further research and visualization, making it possible for them to efficiently examine and comprehend the 3D data. The mesh is a set of faces, vertices and edges defined as ṿ, ḝ, ḟ respectively, ḿ = {ṿ, ḝ, ḟ}. The creation of a mesh network comes after the creation of a point cloud. The algorithm creates points that are joined to neighboring vertices by edges, forming a mesh network that creates the structure of a three-dimensional object. The preceding vertices influence the edge prediction of the network of vertexes.

$$p(\epsilon) = \prod_{i=2}^{n} P(\overrightarrow{e_\iota} \,|\vartheta_1, \ldots \vartheta_i, \overrightarrow{e_1} \ldots . \overrightarrow{e_{\iota-1}})$$

FIG 4: Mesh Generation

Texture Mapping: The process of applying colour and texture information to the mesh surfaces during the Texture Mapping step is crucial. The pixel values are projected from the original input images onto the vertices or faces of the mesh by using the associated 3D geometry and the original input photographs. The reconstructed 3D model of the underwater world now has more visual realism and detail thanks to this collective effort, which guarantees proper data representation and interpretation. The method chosen, known as visual masking, smoothens the hard surface by breaking down the relevant plane on the 3D model's surface. A customized filter is employed to filter the various spatial frequencies measured in the plane before the decomposition process begins. The filter can be represented as,

$$\mathcal{F} = Xi \left[\!\left[e^{-a^2/\sigma^2_{a_{1i}}} - Yie^{-a^2/\sigma^2_{a_{2i}}} + Zie^{-a^2/\sigma^2_{a_{3i}}} \right]\!\right] e^{-b^2/\sigma^2_{b_{1i}}}$$

Where a and b are spatial indexes or positions, Xi is the maximum gain and different scaling of Gaussian adopted to filter different spatial frequencies. This is the most important step which gives the clear view of the structure of the artifact.

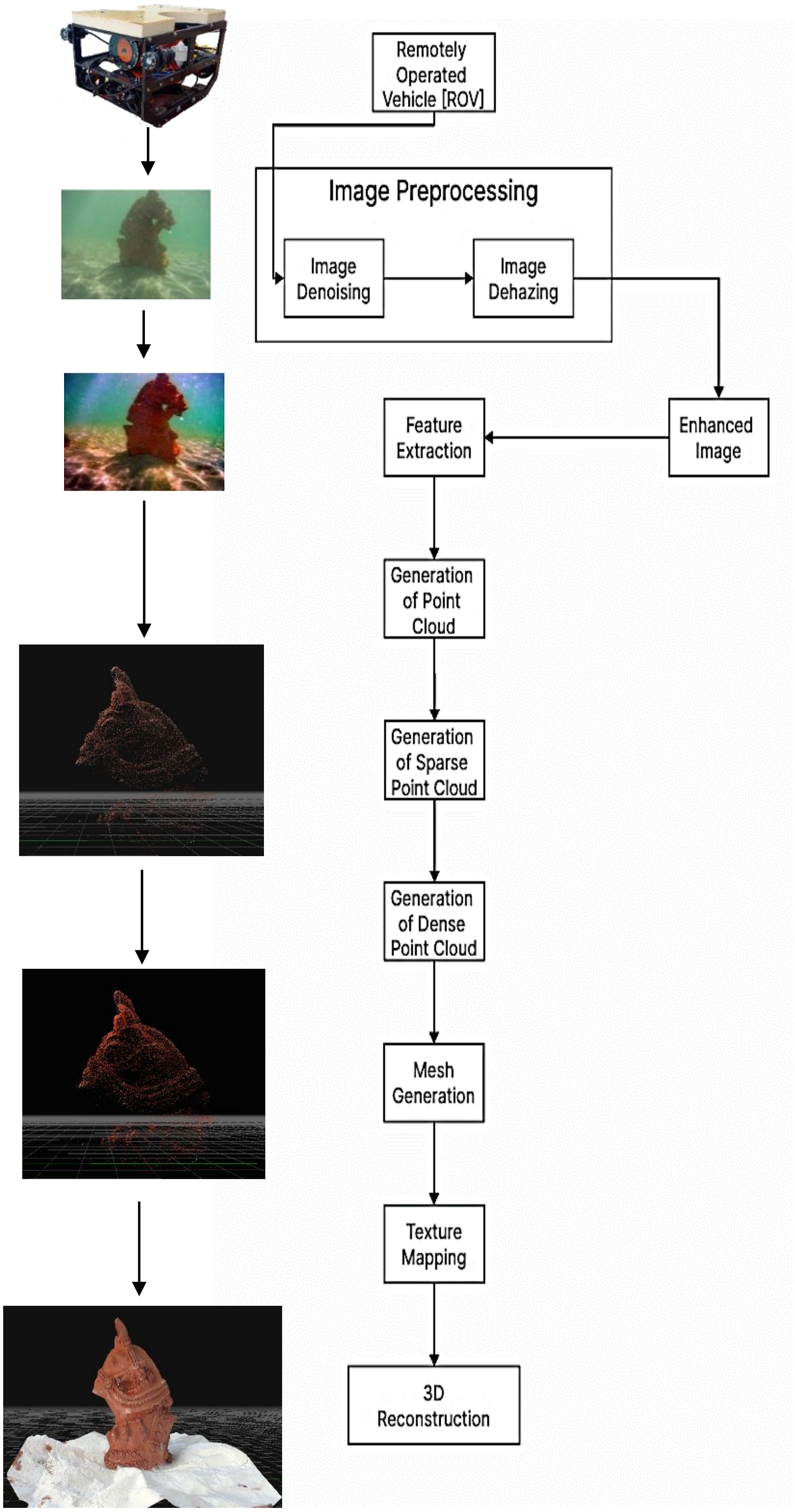

FIG 5: Block Diagram

4. RESULT AND DISCUSSION:

The study of reconstruction of underwater artifacts and objects in Poompuhar has produced important new understandings and advances in the field of underwater archaeology. The 3D Reconstructed model which was obtained as the output is compared with the real time artifacts and proves that the output is 90% accurate to the artifact.

By employing a remotely operated vehicle (ROV) fitted with specialized underwater cameras, precise images of the submerged environment, encompassing buildings and artefacts, with great precision were obtained. The quality and clarity of these photos were improved by the use of preprocessing techniques including denoising and dehazing, which guaranteed the best possible input for the analysis that followed.

With the help of point cloud generation algorithms and feature extraction techniques, an accurate 3D model of the underwater scene was produced. Sophisticated algorithms were used to create meshes, map textures, and generate dense point clouds, all of which helped to improve this model. The resulting three-dimensional (3D) models offer exact, accurate, and detailed representations of the submerged structures and artefacts, facilitating investigation and interpretation.

This initiative has brought to the ongoing efforts to identify and preserve Poompuhar's cultural history through joint efforts and interdisciplinary approaches. The rebuilt artifacts and objects provide important insights into past civilizations and their interactions with the environment, making them invaluable tools for archaeological research and teaching.

These results also demonstrate the potential of modern imaging equipment and processing techniques in underwater archaeology, with implications that go beyond the particular situation of Poompuhar. Through the utilization of these instruments, scholars can investigate and record submerged locations with unparalleled accuracy and comprehensiveness, enhancing our comprehension of human chronicles and cultural legacy.

To sum up, these findings highlight how crucial interdisciplinary cooperation and technological innovation are to solving historical mysteries and safeguarding our cultural legacy for coming generations. This gives a hope to learn more about submerged archaeological sites and their significance in the larger context of human history through ongoing research and investigation.

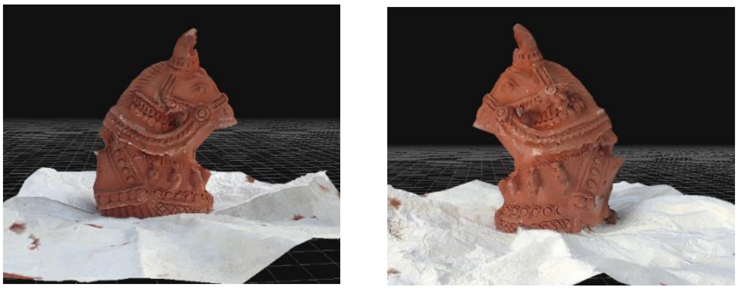

FIG 6: 3D Reconstructed Output of Head of a Terracotta Horse

For field research, a terracotta horse was used. At first, the entire terracotta construction was submerged in the ocean, and a number of photos were taken with a remotely operated vehicle. Afterwards, the terracotta was divided into several pieces, and each piece's 3D modelling was taken into account. We only looked at the terracotta horse's head, and we got between 80 and 90 pictures of it. When it comes to clear water, the features are easily retrieved, and creating a 3D model may just require 40 to 50 photos. If the water is turbid, we might need to take additional 2D pictures to extract the target object's features.

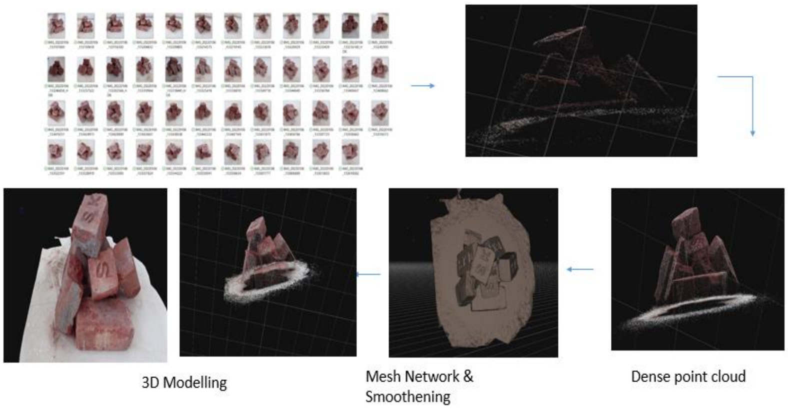

FIG 7: 3D Reconstructed Output of a Bricks

Using 3D reconstruction methods, over seventy pictures of a brick building inside a landform were collected. The ROV was maneuvered on a spiral trajectory to get these 4:3 aspect ratio photographs. Thirty photos were taken from the top of the brick construction, and forty from the bottom. By applying 3D reconstruction methods, an intricate 3D model of the brick building was created. More images were included to improve accuracy and to help with the calibration and improvement of the reconstruction process.

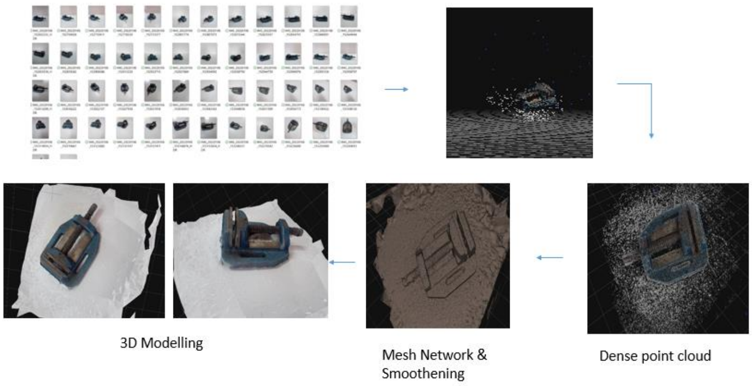

FIG 8: 3D Reconstructed Output of Bench vice

The bench vice's consistent detailing throughout its parts made reconstruction easier, requiring only a few 2D images for feature matching. This effectiveness simplified processes, cutting down on the number of images and making the reconstruction of complex features easier. The leg of the vice was uniform, so it was easy to line and match precisely, which reduced the amount of effort involved. As an outcome, the reconstruction went without any difficulties and made use of the fewest possible photos to accurately effectively replicate the bench vice's structure.

5. CONCLUSION:

To summarize up, this study has successfully shown how to use modern imaging technology and complex processing methods to address the difficulties involved in 3D reconstruction and underwater exploration. A precise 3D model was designed with underwater settings and rebuilt submerged things by utilizing advanced software methodologies and sophisticated underwater cameras. Overcoming challenges which includes light attenuation and colour distortion, the addition of image dehazing and denoising algorithms has greatly enhanced the quality and clarity of underwater imagery.

This capacity to provide precise depth data and capture pictures with high resolution has facilitated the creation of complex 3D models that have provided crucial information about underlying structures and artefacts. Several disciplines, including ocean archaeology, submarine research, and environmental monitoring, will be greatly influenced by these results. This work has not only achieved its objectives but also added to the library of knowledge in these domains.

The advancement of modern imaging and processing techniques through additional research and development is crucial for the future of underwater 3D reconstruction. It would be easier for us to study and preserve the biodiversity and underwater heritage provided future technical advancements result in even deeper insights into underwater habitats.

With everything taken into account, this project is evidence of how well multidisciplinary teamwork and resourcefulness can solve difficult obstacles. It also highlights the importance of pushing technological boundaries to unlock the mysteries of the underwater environment and lays the groundwork for future research in this captivating field.

Image Courtesy: National Institute of Ocean Technology [NIOT]

Acknowledgement: The project has been funded by Department of Science and Technology (DST) for the project, “Image Pre-Processing, Enhancement, 2D Mosaicing and 3D Reconstruction of Submerged Features / Objects for Digital Reconstruction of Poompuhar City Puhar-UW Photo” under the scheme Interdisciplinary Cyber Physical Systems (ICPS) and it’s gratefully acknowledged.

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