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

A PROJECT REPORT

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BONAFIDE CERTIFICATE

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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 capture 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 Zephyr, 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.

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LIST OF ABBREVIATIONS

ACE	Automatic Color Equalization
AUV	Autonomous Underwater Vehicles
BA	Bundle Adjustment
CLAHE	Contrast Limited Adaptive Histogram Equalization
DCP	Dark Channel Prior
DST	Department of Science and Technology
IFM	Image Formation Model
LAB	LAB Color Correction
MVS	Multi View Stereo
NLD	Non Local Dehazing
ROV	Remotely Operated Vehicle
SfM	Structure from Motion
SPE	Screened Poisson Equation
UIFM	Underwater Image Formation Model

CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

This project 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. Our project revolves around the exploration and preservation of the submerged city of Poompuhar, a site of significant archaeological importance. Our main aim is to contribute to the recreation and protection of its cultural heritage using advanced imaging technology and sophisticated processing methods. Poompuhar, located off the coast of Tamil Nadu, India, was once a bustling port city in ancient times, serving as a hub for trade and maritime activities. However, it sank underwater centuries ago, leaving behind a wealth of artifacts and structures awaiting rediscovery.

To embark on this ambitious endeavor, our interdisciplinary team combines expertise from various fields, including archaeology, engineering, computer science, and imaging technology. At the heart of our approach is the use of a remotely operated vehicle (ROV) equipped with specialized underwater cameras. This cutting-edge technology allows us to capture high-resolution images of the underwater environment, including artifacts, architectural remnants, and geological features.

The images we capture undergo meticulous preprocessing, where advanced algorithms are used to enhance clarity, reduce noise, and correct color distortions. Techniques like denoising and dehazing are particularly crucial in ensuring the quality and accuracy of the data, setting the stage for further analysis and reconstruction.

Our research progresses through several key stages, each building upon the

last to create a comprehensive understanding of the underwater environment. Feature extraction and point cloud generation techniques enable us to create a detailed 3D model of the submerged scene, capturing the spatial relationships and structural complexities of the artifacts and structures. The use of state-of-the-art software tools like 3D Zephyr facilitates further refinement, including the generation of dense point clouds, mesh creation, and texture mapping.
Throughout the project, collaboration and interdisciplinary exchange are emphasized, with experts from diverse backgrounds working together to achieve common goals. By meticulously documenting and reconstructing submerged artifacts and structures, our research aims to contribute not only to the understanding of Poompuhar's history but also to the broader field of underwater archaeology. Through innovative methodologies and technological advancements, we seek to preserve and celebrate the cultural heritage of this ancient city for generations to come.

1.2 NEED FOR THE PROJECT

The need for our project is deeply rooted in the imperative to preserve and understand the rich cultural heritage encapsulated within the submerged city of Poompuhar. Situated off the coast of Tamil Nadu, India, Poompuhar represents an invaluable archaeological site that offers insights into ancient civilizations and maritime trade routes. However, the city's submersion beneath the waves has obscured much of its history, leaving its artifacts and structures vulnerable to degradation and loss. Preservation of Poompuhar's cultural heritage is paramount. As a once-thriving port city, Poompuhar played a pivotal role in ancient maritime trade networks, serving as a nexus of cultural exchange and economic activity. The artifacts and structures submerged within its waters provide tangible links to this rich past, offering valuable insights into the social, economic, and cultural life of ancient civilizations. By documenting and reconstructing these submerged relics, we aim to safeguard Poompuhar's cultural heritage for future generations, ensuring that its history is not lost to the ravages of time and environmental degradation.

Beyond preservation, our project seeks to advance scientific exploration and understanding of underwater archaeological sites. Poompuhar presents a unique opportunity to study the interactions between human societies and their environment, particularly in the context of sea-level changes and coastal dynamics. Through meticulous documentation and analysis of submerged artifacts and structures, we aim to unravel the mysteries of Poompuhar's past, shedding light on questions of urban planning, architectural techniques, and cultural practices. By applying advanced imaging technology and processing techniques, we hope to reconstruct the city's layout and infrastructure, providing valuable insights into its historical significance and urban development.

Additionally, our project addresses the need for cultural revitalization and tourism development in the region. The rediscovery and preservation of Poompuhar's cultural heritage have the potential to stimulate local economies, create employment opportunities, and promote cultural tourism. By showcasing the submerged city's archaeological treasures through exhibitions, educational programs, and immersive experiences, we can foster a deeper appreciation for the region's history and heritage, while also generating revenue and supporting local communities

Finally, our project recognizes the need for environmental conservation and sustainable management of underwater archaeological sites. The delicate ecosystems surrounding Poompuhar are susceptible to human activities and climate change impacts. Through responsible research practices and collaboration with environmental experts, we strive to minimize our project's ecological footprint and contribute to the long-term conservation of marine biodiversity in the region. By integrating environmental considerations into our project, we ensure that our efforts to uncover and preserve Poompuhar's cultural heritage are conducted in harmony with nature, safeguarding both cultural and natural resources for future generations.

1.3 OBJECTIVE OF THE PROJECT

The primary objective of our project is to contribute to the recreation, preservation, and understanding of the submerged city of Poompuhar, utilizing advanced imaging technology and sophisticated processing techniques. Poompuhar, located off the coast of Tamil Nadu, India, holds immense archaeological significance as an ancient port city dating back to the Sangam period. However, centuries of submersion beneath the waves have obscured much of its history, leaving behind a wealth of artifacts and structures waiting to be rediscovered and documented.

One of the key objectives of our project is to preserve the cultural heritage of Poompuhar by meticulously documenting and reconstructing its submerged artifacts and structures. Through the application of advanced imaging technology, such as remotely operated vehicles (ROVs) equipped with specialized underwater cameras, we aim to capture high-resolution images of the underwater environment. These images serve as the foundational data for subsequent analyses and reconstructions, providing valuable insights into the city's history, architecture, and cultural practices.

Furthermore, our project seeks to advance scientific exploration and understanding of underwater archaeological sites like Poompuhar. By employing state-of-the-art processing techniques, including image preprocessing, feature extraction, and 3D reconstruction, we aim to unravel the mysteries of Poompuhar's past. Through meticulous analysis and interpretation of the data collected, we seek to shed light on questions of urban planning, maritime trade, and societal dynamics, contributing to the broader understanding of ancient civilizations and their interactions with the environment.

Additionally, our project aims to promote cultural revitalization and tourism development in the region by showcasing the submerged city's archaeological treasures. Through exhibitions, educational programs, and immersive experiences, we seek to engage the public and foster a deeper appreciation for Poompuhar's history and heritage. By raising awareness and generating interest in the site, we hope to stimulate local economies, create employment opportunities, and support sustainable tourism initiatives.

Finally, our project underscores the importance of environmental conservation and sustainable management of underwater archaeological sites. By integrating environmental considerations into our research practices and collaborating with environmental experts, we strive to minimize our project's ecological footprint and contribute to the long-term preservation of marine biodiversity in the region. Through responsible stewardship of cultural and natural resources, we aim to ensure that Poompuhar's legacy is safeguarded for future generations to explore and cherish

1.4 ORGANISATION OF THE REPORT

Chapter 1 consists of the introduction and overview of the project which portrays how the project is handled in a basic level

Chapter 2 includes the literature surveys of the journal papers that were referred to improve the project

Chapter 3 contains the system analysis which has the already existing systems and work that is proposed in our project

Chapter 4 explains the methodology and the work flow of the project and gives an overview of the algorithms used in the process

Chapter 5 provides the results of the process

Chapter 6 gives an insight on the conclusion

CHAPTER 2

LITERATURE SURVEY

Yongbin Liu, et.al., 2020 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.

Yifei Liu, et.al., 2023 addresses the challenge of accurately correcting gray scale variations in side-scan sonar images, particularly in areas with rugged seafloors. Side-scan sonar imaging is commonly used for underwater terrain mapping and object detection, but variations in gray scale intensity can distort the interpretation of the seafloor features. The proposed method presents a novel approach to gray scale correction that takes into account the ruggedness of the seafloor, ensuring more accurate representation of underwater features. Experimental results demonstrate the effectiveness of the proposed method in improving the quality and reliability of side-scan sonar images, particularly in challenging underwater environments. The paper contributes to advancing techniques for underwater terrain mapping and holds significance for applications in marine research, underwater exploration, and geoscience.

Jiayi Wu, et.al., 2023 presents a novel approach to reconstructing three-dimensional (3D) underwater scenes. Traditional 3D reconstruction methods often struggle with underwater imagery due to challenges such as light attenuation, color distortion, and image noise. The proposed method introduces a Nonlinear Domain Projection technique tailored specifically for underwater scenes. By leveraging nonlinear projection in the image domain, the method effectively addresses the unique characteristics of underwater imagery, resulting in more accurate and detailed 3D reconstructions. Experimental results demonstrate the efficacy of the proposed approach in capturing underwater scenes with enhanced fidelity and precision. This paper contributes to advancing the field of underwater imaging and holds promise for applications in marine research, underwater exploration, and related domains.

Dana Berman, et.al., 2021 provides the light attenuation, underwater photography poses 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.

Eunpil Park, et.al., 2020 explains 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 from background light is inversely proportional to scene distance is employed in 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.

Shudi Yang, et.al., 2019 presents the challenging underwater environment often results in haze and colour distortion in images acquired by underwater optical cameras. Dehazing algorithms are frequently employed for image improvement because they make use of similarities between underwater and atmospheric models. This survey examines a new technique for enhancing underwater images: forecasting background light, which is crucial for dehazing models. Adaptive colour deviation correction has been rendered feasible by the proposed approach, which uses deep learning to extract red channel information from underwater image dark channels. Using artificial light, this method works especially well in depths of 30 to 60 metres to substantially mitigate image blur and colour divergence. The proposed background light estimating approach paired with the dark channel prior algorithm is employed in the experimental results, which show better performance than previous methods on a variety of non-reference image evaluation conditions.

Philippe Bekaert, et.al., 2018 explores a novel technique for improving photographs taken underwater that have been damaged by medium absorption and scattering. This methodology is a single-image method, in contrary to methods seeking specialised technology or knowledge of underwater conditions. It involves combining two pictures that were taken from the original, degraded image and adjusted for colour and white balance. These photos are fused together with their weight maps in a way that conveniently transfers colour contrast and edges. Using a multiscale fusion method, artefacts in low-frequency components can be eliminated. Comprehensive qualitative and quantitative analyses demonstrate that the produced pictures and films have finer edges, improved global contrast, and superior exposedness of dark areas. The algorithm's ability for enhancing accuracy in a range of image processing applications, including segmentation and keypoint matching, has been established as is its independence from camera settings.

Weidong Zhang, et.al., 2019 provides 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.

Tsung Peng, et.al., 2018 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.

Min Han, et.al., 2020 explains underwater image processing examined in this study of the literature because it has great potential to further exploration of the underwater environment. Strong absorption, scattering, colour distortion, and noise are some of the challenges encountered in underwater sight processing, leading to applications ranging from autonomous underwater vehicles to underwater microscopic detection. The survey splits enhancing techniques into two categories: colour restoration and underwater image dehazing, as a way to address these problems. For such assignments, it investigates advanced intelligence algorithms, such as deep learning techniques, and evaluates the way they execute. The survey additionally provides insights into the primary applications of underwater image processing and presents a measure for evaluating the colour of underwater images. This paper enhances the understanding of underwater imagery analysis techniques by providing an overview of the applications of underwater image processing.

CHAPTER 3

SYSTEM ANALYSIS

In the analysis of the system used in our project, we meticulously assessed the requirements, constraints, and objectives inherent to the exploration and preservation of the submerged city of Poompuhar. We conducted a thorough evaluation of available resources, such as imaging technology, processing software, and environmental data, to determine their suitability for the project's needs. Additionally, we analyzed the complexities of underwater environments and archaeological sites, considering factors like depth, visibility, and sedimentation. Through this comprehensive analysis, we gained a holistic understanding of the system's intricacies, enabling us to develop effective strategies and methodologies for project execution.

3.1 SOFTWARES USED IN THE PROJECT

3.1.1 IMAGE ENHANCEMENT TOOL

In our underwater image reconstruction project, the Image Enhancement Tool serves as a pivotal component in our image preprocessing pipeline. This tool harnesses the power of five advanced algorithms to enhance the quality and clarity of underwater images before further processing. The first algorithm, Automatic Color Equalization (ACE), optimizes the color balance and contrast of images, ensuring uniform brightness and vivid colors across the scene. Contrast Limited Adaptive Histogram Equalization (CLAHE) is employed to enhance local contrast while preventing over-amplification of noise, resulting in images with improved visibility and detail in both bright and dark regions.

Additionally, the tool utilizes LAB Color Correction to adjust color balance and correct color distortions, ensuring accurate representation of underwater scenes. Non-Local Dehazing (NLD) algorithm is applied to remove haze and improve visibility by effectively reducing the effects of light scattering and absorption in underwater environments. Finally, the Screened Poisson Equation (SPE) algorithm enhances image sharpness and reduces blurring artifacts, resulting in clearer and more defined edges.

The Image Enhancement Tool operates seamlessly, allowing users to apply these algorithms to individual images or batches of images with ease. It offers a user-friendly interface with intuitive controls, enabling researchers to adjust parameters and fine-tune the enhancement process according to specific requirements. Furthermore, the tool supports various image formats and resolutions, ensuring compatibility with different underwater imaging systems and devices.

By leveraging these five algorithms, the Image Enhancement Tool significantly improves the quality and usability of underwater images for subsequent processing steps, such as 3D reconstruction and analysis. The enhanced images exhibit reduced noise, improved contrast, and enhanced visibility, providing researchers with valuable visual data for studying underwater environments with greater accuracy and detail. Overall, the Image Enhancement Tool plays a crucial role in enhancing the effectiveness and reliability of our underwater image reconstruction project, empowering researchers to explore and understand underwater ecosystems with unprecedented clarity and precision.

3.1.2 3D ZEPHYR

3D Zephyr is a powerful software suite designed for photogrammetry and 3D reconstruction, offering a comprehensive solution for generating accurate and detailed 3D models from images or videos. Developed by 3Dflow, this versatile tool is widely used across various industries, including archaeology, architecture, surveying, and visual effects.

At the core of 3D Zephyr's functionality is its robust photogrammetry engine, which employs advanced algorithms to process images and extract detailed 3D information. The software utilizes a structure-from-motion (SfM) approach to reconstruct the camera positions and scene geometry from a set of overlapping images. By analyzing the spatial relationships between image features and triangulating corresponding points, 3D Zephyr accurately estimates the 3D structure of the scene, including the position and orientation of cameras and the geometry of objects.

One of the key strengths of 3D Zephyr is its user-friendly interface, which enables users to effortlessly navigate through the reconstruction workflow and access a wide range of tools and features. The software offers intuitive controls for importing images or videos, aligning them, and performing dense reconstruction to generate detailed 3D models. Users can easily adjust parameters and settings to tailor the reconstruction process to their specific requirements, whether they are working on small-scale projects or large-scale environments.

3D Zephyr supports various input formats, including images captured from standard cameras, drones, or specialized imaging devices. It also offers compatibility with different file types, allowing users to import images from popular formats such as JPEG, TIFF, and PNG. Additionally, the software provides robust support for video input, enabling users to reconstruct 3D models from video footage captured by drones or handheld cameras.

The software's advanced processing capabilities enable it to handle challenging imaging conditions, such as varying lighting, shadows, and reflections, ensuring reliable reconstruction results even in complex environments. Moreover, 3D Zephyr offers a range of post-processing tools for refining and optimizing the generated 3D models, including mesh editing, texture mapping, and exporting to various formats for further analysis or visualization.

Overall, 3D Zephyr is a versatile and powerful tool for photogrammetry and 3D reconstruction, offering a comprehensive solution for generating accurate and detailed 3D models from images or videos. With its intuitive interface, robust processing engine, and advanced features, the software empowers users to efficiently create high-quality 3D reconstructions for a wide range of applications, from archaeological documentation to architectural visualization.

3.1 EXISTING SYSTEM

The existing systems for underwater exploration and archaeological research vary widely in their scope, capabilities, and methodologies. One notable example is the use of manned submersibles, which are piloted vehicles designed to carry human occupants to significant depths underwater. These submersibles offer researchers the ability to conduct detailed visual inspections and sample collection in real-time, providing a firsthand perspective of underwater environments. However, their high cost, limited accessibility, and logistical challenges make them impractical for widespread use in archaeological research. Additionally, manned submersibles are limited in their operational endurance and require extensive maintenance and support infrastructure. Another existing system is the use of remotely operated vehicles (ROVs), which are unmanned submersible vehicles controlled from the surface by operators using joysticks and cameras. ROVs are equipped with specialized cameras, sensors, and manipulator arms, allowing researchers to explore and document underwater environments with precision and flexibility. ROVs offer advantages such as increased depth capabilities, lower cost compared to manned submersibles, and the ability to operate in hazardous or inaccessible areas. However, ROVs require a dedicated support vessel for deployment, limiting their mobility and increasing operational costs.

Additionally, real-time communication and control can be challenging, particularly at significant depths or in remote locations.

Additionally, autonomous underwater vehicles (AUVs) represent another category of existing systems used in underwater exploration. AUVs are unmanned vehicles programmed to operate independently, following pre-defined mission parameters. They are equipped with sensors and instruments to collect data on water quality, bathymetry, and marine life, providing valuable insights into underwater ecosystems and geological features. AUVs offer advantages such as extended endurance, large-area coverage, and the ability to collect data in remote or inhospitable environments. However, AUVs lack the ability to conduct real-time observations or interact with underwater features, limiting their utility for certain types of archaeological research. Additionally, AUV operations require careful mission planning and navigation to ensure safe and effective data collection.

Furthermore, specialized imaging technologies, such as side-scan sonar and multibeam echosounders, are commonly used in underwater archaeological research. These systems emit sound waves or pulses of energy and measure the return signals to create detailed maps of the seafloor and detect submerged features and artifacts. Side-scan sonar, for example, produces high-resolution images of the seafloor, enabling researchers to identify potential archaeological sites and anomalies. However, side-scan sonar imaging can be limited by factors such as water depth, bottom type, and acoustic interference from underwater structures or geological features. Additionally, interpreting sonar data requires specialized training and expertise, and false positives or misinterpretations can occur.

3.2 PROPOSED SYSTEM

Our proposed system for underwater exploration and archaeological research aims to leverage advanced imaging technology and sophisticated processing techniques to reconstruct submerged artifacts and structures with precision and accuracy. The system will be specifically tailored for the exploration and documentation of the submerged city of Poompuhar, located off the coast of Tamil Nadu, India.

At the core of our proposed system is the utilization of remotely operated vehicles (ROVs) equipped with specialized underwater cameras. These ROVs will be deployed to capture high-resolution images of the underwater environment, including artifacts, architectural remnants, and geological features. The use of ROVs offers several advantages, including increased depth capabilities, precise maneuverability, and the ability to operate in hazardous or inaccessible areas.

The captured images will undergo rigorous preprocessing using advanced enhancement algorithms to mitigate noise, correct color distortions, and enhance clarity. Techniques such as image denoising and dehazing will be employed to ensure the quality and fidelity of the data. Preprocessing is crucial for optimizing the input data for subsequent analysis and reconstruction.

Following preprocessing, the images will be subjected to feature extraction algorithms to identify key characteristics and points of interest within the underwater scene. Feature extraction is essential for establishing correspondences between images and facilitating the reconstruction process.

The next stage of the proposed system involves 3D reconstruction algorithms, which meticulously craft detailed models of the underwater scene based on the preprocessed images. These algorithms will integrate depth information from the captured images to generate accurate three-dimensional representations of submerged artifacts and structures. Techniques such as point cloud generation, mesh reconstruction, and texture mapping will be employed to create realistic and immersive 3D models.

Throughout the process, advanced software tools such as 3D Zephyr and MeshLab will be utilized to facilitate data processing, analysis, and visualization. These tools offer a suite of features and functionalities tailored for the reconstruction of complex 3D scenes from imagery data.

Overall, our proposed system represents an innovative and comprehensive approach to underwater exploration and archaeological research. By leveraging state-of-the-art imaging technology and processing techniques, we aim to uncover the secrets of Poompuhar's submerged past, preserve its cultural heritage, and advance our understanding of ancient civilizations and maritime trade routes. Through interdisciplinary collaboration and technological innovation, our proposed system seeks to push the boundaries of underwater exploration and unlock the mysteries of the deep.

CHAPTER 4

METHODOLOGY

Our methodology integrates advanced imaging technology and processing techniques to reconstruct submerged artifacts. Initially, ROVs equipped with specialized underwater cameras capture high-resolution images of the underwater environment. Preprocessing algorithms enhance image quality by mitigating noise and color distortions. Feature extraction identifies key characteristics, aiding subsequent 3D reconstruction. Utilizing 3D reconstruction algorithms and software tools, detailed three-dimensional models are meticulously crafted, integrating depth information for accuracy. This approach enables precise reconstruction of submerged structures and artifacts, facilitating deeper exploration and understanding of underwater environments.

4.1 IMAGE ACQUISITION

In the initial phase of our project, we embark on the crucial step of image acquisition, employing cutting-edge technology to capture high-resolution images of the underwater environment. Central to this process is the utilization of remotely operated vehicles (ROVs), which serve as our eyes beneath the waves. These sophisticated submersible vehicles are equipped with specialized underwater cameras meticulously designed to withstand the challenges of the aquatic environment. Guided by expert operators on the surface, the ROVs navigate through the depths, maneuvering with precision to capture detailed imagery of the submerged landscape.

The choice of ROVs for image acquisition offers several distinct advantages. Firstly, their versatility allows us to explore a wide range of underwater environments, from shallow coastal waters to deeper offshore regions. This adaptability is essential for our project, which aims to document the submerged city of Poompuhar, located off the coast of Tamil Nadu, India. Additionally, the deployment of ROVs minimizes the need for human divers, reducing potential safety risks associated with underwater exploration.

The specialized cameras mounted on the ROVs are designed to capture images with exceptional clarity and resolution, providing valuable insights into the underwater landscape. Equipped with advanced imaging technology, including high-definition sensors and lenses optimized for low-light conditions, these cameras are capable of revealing intricate details of submerged artifacts and structures.

Furthermore, the remote operation of the ROVs allows us to access and explore areas that may be difficult or dangerous for human divers to reach. By remotely piloting the vehicles from the surface, we can navigate through underwater obstacles, descend to greater depths, and capture images of submerged features with unprecedented accuracy and precision.

As the ROVs traverse the underwater terrain, they systematically capture images from various angles and perspectives, ensuring comprehensive coverage of the submerged environment. This meticulous approach enables us to capture a wealth of visual data, providing a foundation for subsequent analysis and reconstruction. In summary, the image acquisition phase represents the crucial first step in our project's journey to uncover the mysteries of the submerged city of Poompuhar. Through the deployment of remotely operated vehicles and specialized underwater cameras, we aim to capture detailed imagery of the underwater landscape, laying the groundwork for the subsequent stages of data processing, analysis, and reconstruction.

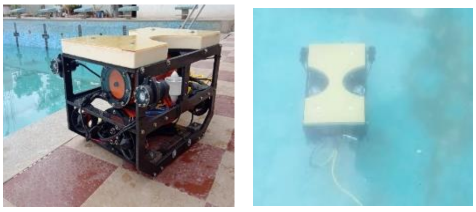

Figure 4.1: Remotely Operated Vehicle

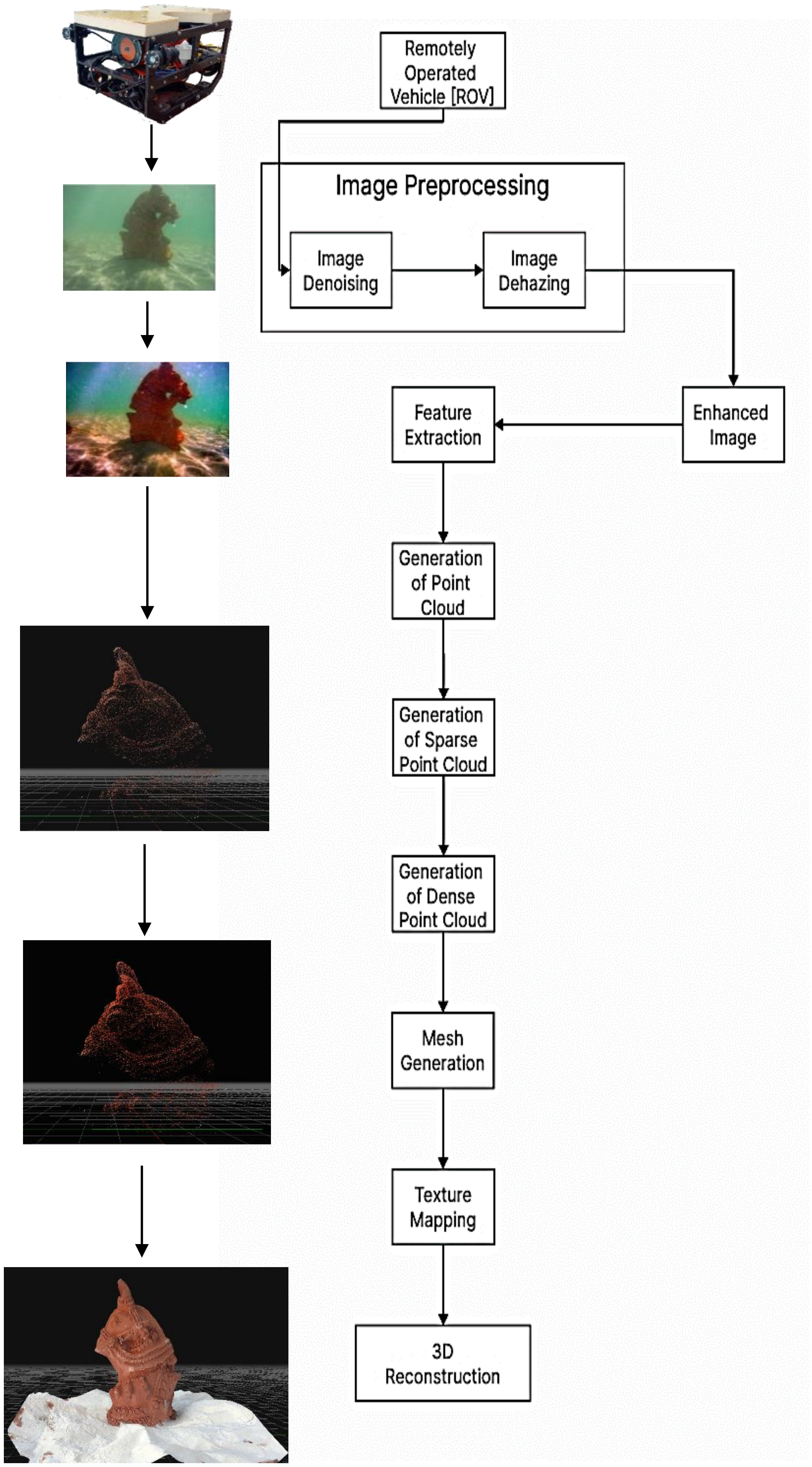

Figure 4.2: Block Diagram

4.2 IMAGE PRE-PROCESSING

Following the image acquisition phase, our project progresses to the critical step of image preprocessing. This phase involves the application of advanced algorithms and techniques to enhance the quality and fidelity of the captured underwater images before further analysis and reconstruction. One of the primary objectives of image preprocessing is to mitigate common challenges associated with underwater imaging, such as noise, color distortion, and poor visibility.

To address these issues, we employ a suite of preprocessing algorithms tailored specifically for underwater imagery. These algorithms include denoising techniques to reduce the effects of noise and artifacts, dehazing methods to enhance visibility and contrast, and color correction algorithms to restore natural color tones. Additionally, techniques such as image registration may be utilized to align and stitch together multiple images captured from different viewpoints, ensuring continuity and consistency in the dataset.

By preprocessing the captured images, we aim to optimize their quality and suitability for subsequent analysis and reconstruction processes. This preparatory phase plays a crucial role in improving the overall accuracy and reliability of the final reconstructed models, enabling us to extract meaningful insights from the underwater data with greater precision and confidence.

In the image preprocessing phase, we utilize denoising techniques to reduce image noise and dehazing methods to enhance visibility. These processes refine underwater images, ensuring clearer representations of the underwater environment for subsequent analysis and reconstruction.

4.2.1 IMAGE DENOISING

Image denoising, a vital preprocessing step in digital image processing, aims to enhance image quality by reducing unwanted noise while preserving essential image details. Noise, characterized by random fluctuations in brightness or color, can obscure image content, making it challenging to extract meaningful information or perform accurate analysis. Image denoising techniques employ various filtering methods to suppress noise, resulting in cleaner and visually appealing images.

Primarily, image denoising involves applying filters to adjust pixel values based on predefined criteria within local neighborhoods or regions of the image. This process distinguishes between signal (desired image content) and noise (undesirable random variations), selectively attenuating or eliminating the noise component while retaining image features.

Two common approaches to image denoising are spatial domain filtering and frequency domain filtering. In spatial domain filtering, filters like median or Gaussian filters are directly applied to image pixels, averaging or smoothing pixel values within local neighborhoods to reduce noise while preserving image edges and details. Frequency domain filtering involves transforming the image into the frequency domain using techniques like Fourier transform and applying filters to suppress noise components in specific frequency ranges.

Image denoising methods can be categorized as linear or nonlinear based on their mathematical properties. Linear methods, including mean or Wiener filtering, apply linear transformations to image pixel values, making them computationally efficient but less effective in handling complex noise patterns. Nonlinear methods utilize more sophisticated algorithms to adaptively adjust pixel values based on local image characteristics, achieving better noise suppression while preserving image details.

In the denoising process, a combination of median, Gaussian, Wiener, and average filters is employed to effectively reduce noise artifacts from the underwater images. Each filter offers unique characteristics and advantages, collectively contributing to the enhancement of image clarity and quality in the project's reconstruction pipeline.

4.2.2 IMAGE DEHAZING

Image dehazing is a crucial step in digital image processing, aimed at improving the visibility and clarity of images captured in hazy or foggy conditions. Haze, caused by suspended particles and moisture in the atmosphere, significantly degrades image quality, resulting in reduced contrast, color distortion, and loss of detail. Image dehazing techniques mitigate these effects by effectively removing or attenuating the haze component, resulting in clearer and visually appealing images.

These algorithms analyze the degradation caused by haze and estimate the underlying scene radiance or transmission map. They model the image formation process in hazy conditions, considering factors such as atmospheric light, scene depth, and light attenuation. By capturing the relationship between observed pixel intensities and scene radiance, dehazing algorithms restore the true colors and contrast of the underlying scene.

One common approach to image dehazing is based on the dark channel prior, which exploits the statistical properties of haze-free outdoor scenes to estimate the transmission map. This method iteratively refines the transmission map and removes haze from the image, producing visually pleasing results with improved visibility and contrast.

Another widely used technique is color space transformation, which separates the haze and scene radiance components by transforming the image into different color spaces. Analyzing color distributions in different color channels allows dehazing algorithms to estimate the transmission map and attenuate the haze, resulting in clearer images.

4.2.3 ALGORITHMS USED IN IMAGE ENHANCEMENT

4.2.3.1 AUTOMATIC COLOUR EQUALISATION (ACE)

In our underwater image reconstruction endeavor, the Automatic Color Equalization (ACE) algorithm emerges as a pivotal tool, adept at elevating image quality through comprehensive color balancing and contrast enhancement. ACE operates by automatically adjusting the color distribution within the image, ensuring uniform representation across all colors. This critical adjustment effectively mitigates color casts and compensates for the varying illumination conditions commonly encountered in underwater settings. By equalizing the color histogram, ACE harmonizes the representation of colors, thereby enhancing the overall visibility and clarity of the image.

Moreover, ACE contributes significantly to contrast enhancement by redistributing pixel intensities throughout the dynamic range. This redistribution strategy fosters heightened perceptual sharpness and detail, leading to clearer and more discernible features within the image. By effectively increasing contrast, ACE ensures that subtle details and intricate structures within the underwater scene are brought to the forefront, aiding in the accurate reconstruction and interpretation of the environment.

Applied within our reconstruction pipeline, the ACE algorithm serves as a cornerstone in improving the fidelity of underwater image reconstructions. Its automatic and adaptive nature makes it particularly suited for addressing the unique challenges posed by underwater imaging, where varying lighting conditions and color distortions are prevalent. By seamlessly integrating ACE into our workflow, we achieve enhanced image quality, facilitating more accurate and detailed reconstructions of underwater scenes.

The utilization of ACE contributes to the production of visually appealing and scientifically valuable reconstructions, enabling researchers to glean deeper insights into underwater environments and ecosystems. Through the augmentation of image clarity and contrast, ACE empowers researchers to uncover subtle nuances and features within the underwater landscape, facilitating comprehensive analyses and interpretations.

In summary, the ACE algorithm represents a fundamental component of our image enhancement strategy, enabling the transformation of raw underwater imagery into clear, detailed, and scientifically informative reconstructions. Its effectiveness in addressing color imbalances and enhancing contrast makes it an invaluable asset in the realm of underwater image processing, aiding researchers in their quest to explore, understand, and preserve underwater ecosystems and heritage sites.

ACE is based on the histogram equalization technique and aims to enhance the overall contrast and brightness of an image. The equation for histogram equalization is given by:

$$G(i,j) = \frac{L-1}{M \times N} \sum_{k=0}^{i} n_k$$

4.2.3.2 CONTRAST LIMITED ADAPTIVE HISTOGRAM EQUALIZATION (CLAHE)

In our underwater image reconstruction project, the Contrast Limited Adaptive Histogram Equalization (CLAHE) algorithm assumes a pivotal role in advancing image quality through tailored contrast enhancement. CLAHE operates by partitioning the image into smaller, localized regions and applying histogram equalization independently to each region. By limiting the contrast enhancement within these regions, CLAHE prevents over-amplification of noise while effectively enhancing contrast in areas with varying illumination and texture.

One of the key advantages of CLAHE lies in its adaptability to local image characteristics. By analyzing the histogram of each region and redistributing pixel intensities accordingly, CLAHE ensures that contrast enhancement is applied selectively where it is most needed. This localized approach results in more nuanced and visually appealing enhancements, particularly in underwater scenes characterized by uneven lighting and texture.

Moreover, CLAHE incorporates a mechanism for constraining the contrast amplification, known as "clipping." This prevents excessively bright or dark areas from being over-enhanced, preserving the overall natural appearance of the image while still improving its perceptual clarity. This feature is particularly beneficial in underwater imaging, where variations in lighting and environmental conditions can lead to extreme contrast disparities.

Applied within our reconstruction pipeline, CLAHE contributes significantly to the enhancement of underwater image quality. By effectively addressing contrast discrepancies and improving visibility in localized regions, CLAHE ensures that subtle details and features within the underwater scene are accurately represented. This, in turn, facilitates more precise and detailed reconstructions of underwater environments, enabling researchers to explore and analyze underwater ecosystems with greater clarity and accuracy.

The utilization of CLAHE in our project exemplifies its efficacy in mitigating the challenges associated with underwater imaging, such as uneven illumination and low contrast. By intelligently adapting contrast enhancement to local image characteristics and incorporating clipping mechanisms, CLAHE ensures that enhancements are both visually pleasing and scientifically informative. Through its integration into our reconstruction workflow, CLAHE empowers researchers to produce high-quality reconstructions that faithfully represent the complexity and beauty of the underwater world.

CLAHE is a variant of histogram equalization that limits the amplification of contrast in regions with high local contrast. The equation for CLAHE is similar to histogram equalization but includes a clipping limit:

$$G(i,j) = \frac{L-1}{M \times N} \sum_{k=0}^{i} \min(n_k, \text{clip})$$

4.2.3.3 LAB COLOUR CORRECTION (LAB)

In our underwater image reconstruction project, the LAB color correction technique emerges as a crucial component in enhancing image quality through comprehensive color adjustment. The LAB color space, distinct from traditional RGB color models, separates luminance (L), red-green chromaticity (A), and blue-yellow chromaticity (B), allowing for independent manipulation of color and brightness information.

The LAB color correction process begins by transforming the underwater image from its original color space (e.g., RGB) to the LAB color space. This transformation facilitates precise control over color and luminance, enabling targeted adjustments to correct color casts and enhance overall image clarity.

One of the key advantages of LAB color correction lies in its ability to decouple luminance and chromaticity information. By separately adjusting luminance and color channels, LAB color correction provides greater flexibility and accuracy in correcting color imbalances and enhancing image vibrancy.

Moreover, LAB color correction offers a wide range of adjustment options, including fine-tuning of color temperature, saturation, and contrast. This versatility allows researchers to tailor the correction process to the specific characteristics of the underwater environment, ensuring optimal results across a variety of conditions.

Applied within our reconstruction pipeline, LAB color correction significantly improves the fidelity of underwater image reconstructions. By effectively correcting color casts and enhancing color vibrancy, LAB color correction ensures that the reconstructed images accurately reflect the true colors and details of the underwater scene.

Furthermore, LAB color correction enables the enhancement of subtle color variations and texture details, leading to more visually appealing and scientifically informative reconstructions. This, in turn, facilitates more accurate analysis and interpretation of underwater ecosystems and environments, empowering researchers to uncover hidden insights and discoveries.

In summary, the LAB color correction technique represents a powerful tool in the arsenal of underwater image processing. Its ability to separate and manipulate color and luminance information independently provides unparalleled control and precision in correcting color imbalances and enhancing image quality. Through its integration into our reconstruction workflow, LAB color correction contributes to the production of high-quality reconstructions that faithfully capture the beauty and complexity of the underwater world

4.2.3.4 NON-LOCAL DEHAZING (NLD)

In our underwater image reconstruction project, the Non-Local Dehazing (NLD) technique emerges as a critical step in enhancing image quality by mitigating the effects of haze and improving visibility in underwater scenes. Unlike traditional dehazing methods that rely on local image information, NLD leverages non-local similarities within the image to estimate and remove haze more effectively.

The NLD process begins by analyzing the entire image to identify regions with similar visual characteristics, such as texture and color. By comparing these non-local regions, NLD establishes relationships between pixels across the image, enabling more accurate estimation of haze and scene depth.

One of the key advantages of NLD lies in its ability to capture long-range correlations within the image, allowing for more robust haze removal in complex underwater environments. By incorporating information from distant image regions, NLD can effectively differentiate between haze and true scene details, leading to more accurate dehazing results.

Moreover, NLD offers adaptability to varying scene conditions and haze levels, making it well-suited for underwater imaging scenarios where haze intensity may fluctuate. Through sophisticated mathematical models and optimization algorithms, NLD dynamically adjusts dehazing parameters to achieve optimal results across different underwater scenes.

Applied within our reconstruction pipeline, NLD significantly improves the clarity and fidelity of reconstructed underwater images. By removing haze and enhancing visibility, NLD ensures that subtle details and features within the underwater scene are accurately represented, facilitating more precise analysis and interpretation.

Furthermore, NLD enhances the visual appeal of reconstructed images by restoring natural colors and contrast, leading to more immersive and visually pleasing reconstructions. This, in turn, enables researchers to explore and document underwater environments with greater clarity and accuracy, uncovering hidden insights and discoveries.

In summary, the Non-Local Dehazing technique represents a powerful tool in the realm of underwater image processing. Its ability to leverage non-local similarities within the image enables more effective haze removal and scene enhancement, resulting in high-quality reconstructions that faithfully capture the beauty and complexity of the underwater world. Through its integration into our reconstruction workflow, NLD contributes to the production of scientifically valuable reconstructions that empower researchers to explore and understand underwater ecosystems with unprecedented clarity and precision

Non-Local Dehazing is a method for enhancing visibility in hazy or foggy images by estimating and removing the atmospheric haze. The dehazing equation involves estimating the transmission map T and using it to recover the scene radiance:

$$J(x) = \frac{I(x)-A}{T(x)} + A$$

4.2.3.5 SCREENED POISSON EQUATION (SPE)

In our underwater image reconstruction project, the Screened Poisson Equation (SPE) technique emerges as a crucial step in enhancing image quality and removing artifacts introduced during the dehazing process. SPE operates by solving a modified version of the Poisson equation, which incorporates additional constraints to ensure smoothness and preserve important image features.

The SPE process begins by formulating a system of equations that describes the relationship between the observed image, the estimated transmission map (representing the amount of haze), and the underlying scene radiance. By solving this system iteratively, SPE effectively estimates the scene radiance while minimizing artifacts such as haloing and color distortion.

One of the key advantages of SPE lies in its ability to produce visually appealing and artifact-free dehazed images. By incorporating constraints that encourage smooth transitions and preserve image details, SPE ensures that the dehazed images maintain their natural appearance while effectively removing haze and enhancing visibility.

Moreover, SPE offers adaptability to varying levels of haze and scene complexity, making it suitable for a wide range of underwater imaging scenarios. Through iterative optimization algorithms and regularization techniques, SPE dynamically adjusts its parameters to achieve optimal results, even in challenging underwater environments with complex lighting conditions.

Applied within our reconstruction pipeline, SPE significantly improves the clarity and fidelity of reconstructed underwater images. By removing artifacts introduced during the dehazing process and preserving important image features, SPE ensures that the reconstructed images accurately represent the underwater scene, facilitating more accurate analysis and interpretation.

Furthermore, SPE enhances the visual appeal of reconstructed images by restoring natural colors and contrast, leading to more immersive and visually pleasing reconstructions. This, in turn, enables researchers to explore and document underwater environments with greater clarity and accuracy, uncovering hidden insights and discoveries.

In summary, the Screened Poisson Equation technique represents a powerful tool in the realm of underwater image processing. Its ability to effectively remove artifacts and enhance image quality makes it invaluable for producing high-quality reconstructions that faithfully capture the beauty and complexity of the underwater world. Through its integration into our reconstruction workflow, SPE contributes to the production of scientifically valuable reconstructions that empower researchers to explore and understand underwater ecosystems with unprecedented clarity and precision.

The Screened Poisson Equation is commonly used for image denoising and involves solving a partial differential equation (PDE) to minimize the total variation of the image while preserving important features. The SPE is given by:

$$\nabla \cdot \left(\frac{\nabla u}{\sqrt{\epsilon^2 + |\nabla u|^2}} \right) = f$$

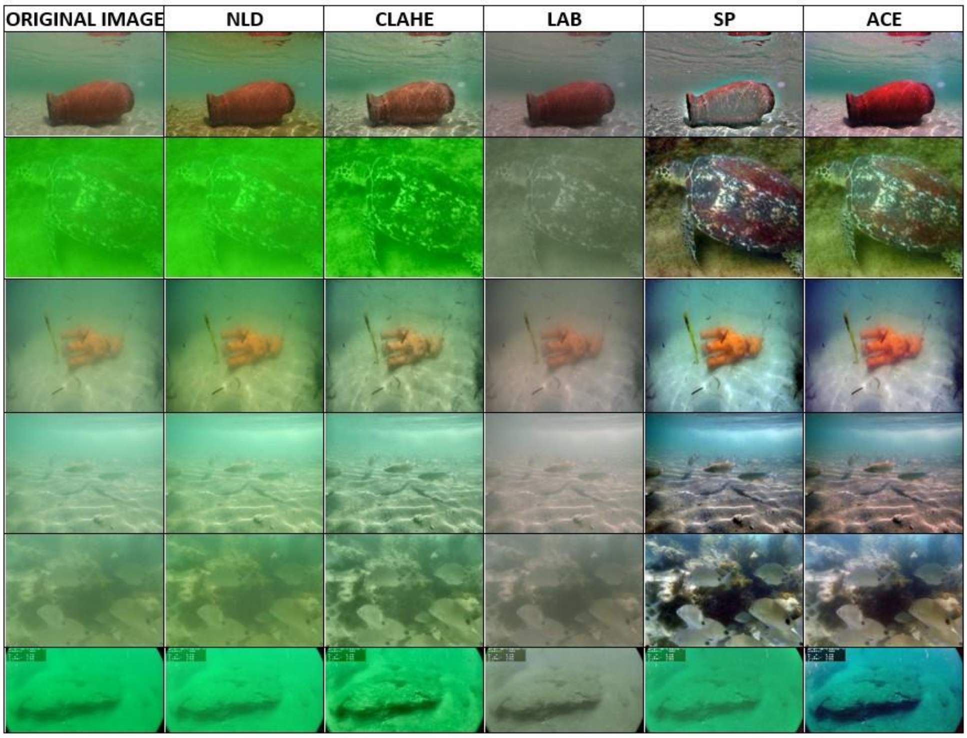

Figure 4.3: Image Pre-processing using Image Enhancement Tool

4.3 FEATURE EXTRACTION

Feature extraction is a pivotal stage in image processing and computer vision, integral for identifying and characterizing meaningful patterns or structures within images. In this step, relevant information is extracted from the preprocessed images to represent distinct features or attributes that are essential for subsequent analysis and decision-making tasks. The goal of feature extraction is to transform raw image data into a more compact and informative representation, facilitating efficient and accurate interpretation by downstream algorithms and applications.

One of the primary objectives of feature extraction is to capture salient information while discarding irrelevant or redundant details. This involves identifying key characteristics such as edges, corners, textures, shapes, or other distinctive patterns that contribute to the overall content and semantics of the image. Various techniques are employed to extract these features, ranging from simple local intensity variations to more complex descriptors based on gradient orientations, texture analysis, or frequency domain representations.

For instance, edge detection algorithms aim to identify abrupt changes in pixel intensity, which often correspond to boundaries between different objects or regions in the image. These edges serve as important cues for object localization and segmentation, enabling subsequent processing steps to delineate objects of interest more accurately. Similarly, corner detection algorithms focus on identifying points where image intensity gradients have significant directional changes, indicating potential keypoints or landmarks within the scene.

Texture analysis techniques, on the other hand, characterize spatial variations in pixel intensities to capture repetitive patterns or structures present in the image. By analyzing local texture properties such as smoothness, roughness, or regularity, texture features can be extracted to differentiate between different surface textures or materials. This information is particularly useful in tasks such as image classification, where distinguishing between different object categories based on their appearance is crucial.

In addition to these low-level features, higher-level descriptors may also be extracted to capture more abstract or semantic information from the image. This may include shape descriptors, which characterize the overall geometry of objects or regions, or invariant features that are robust to changes in viewpoint, scale, or illumination conditions.

Overall, feature extraction plays a vital role in transforming raw image data into a structured and informative representation that is well-suited for subsequent analysis and interpretation. By identifying and quantifying relevant image attributes, feature extraction enables the extraction of meaningful insights and facilitates the development of robust and effective computer vision systems for a wide range of applications.

4.4 GENERATION OF POINT CLOUD

The generation of a point cloud is a crucial step in three-dimensional (3D) reconstruction from images, wherein a dense collection of 3D points is derived from the captured images. This process involves triangulating corresponding points across multiple images to estimate their 3D positions in the scene. Each point in the point cloud represents a specific location in the reconstructed 3D space, providing a dense representation of the scene geometry.

The generation of a point cloud typically begins with feature matching, where distinctive keypoints are identified and matched between pairs of images. These matched keypoints are then used to compute the relative camera poses and triangulate the 3D positions of corresponding points using techniques such as stereo vision or structure-from-motion (SfM). The resulting point cloud encapsulates the spatial information of the scene, enabling further analysis and visualization of the reconstructed 3D environment.

Point clouds serve as a foundational element in various applications, including 3D mapping, object recognition, augmented reality, and robotics. They provide a rich and detailed representation of the underlying scene geometry, facilitating accurate reconstruction and interpretation of complex environments. Additionally, point clouds can be further processed and refined to extract additional information such as surface normals, color attributes, or semantic labels, enabling more advanced analysis and interaction with the reconstructed 3D data.

Following the initial point cloud generation, the workflow advances to two critical steps: sparse point cloud generation and dense point cloud generation. Sparse point cloud generation involves the selection of a subset of points from the initial cloud, representing key features or landmarks in the scene. These points serve as sparse placeholders capturing the essential structure while reducing computational overhead. On the other hand, dense point cloud generation aims to densely sample the scene by interpolating additional points between the sparse keypoints. This step results in a more detailed representation, providing finer-grained spatial information for subsequent analysis and visualization, aligning with the project's objectives of reconstructing submerged objects and creating precise 3D models of underwater environments.

Figure 4.4: Point Cloud Generation

4.5 GENERATION OF SPARSE POINT CLOUD

Sparse point cloud generation is a pivotal stage in the project's workflow, specifically tailored to distill essential structural elements from the initial data and facilitate the creation of a comprehensive 3D model of the underwater environment. This critical step involves selecting a subset of points from the initial point cloud to represent significant features or landmarks within the underwater scene. These features could range from distinctive objects and structures to key topographical elements that are fundamental for accurately capturing the scene's geometry.

Given the unique challenges posed by underwater imaging, such as light attenuation, color distortion, and limited visibility, the selection process for sparse point cloud generation demands careful consideration. Specialized algorithms explicitly designed for underwater environments are employed to identify and extract robust keypoints from the initial point cloud. These algorithms leverage advanced techniques, such as feature matching and detection, to pinpoint keypoints that are reliably detectable even under challenging conditions.

The resulting sparse point cloud serves as a foundational framework for subsequent processing steps, such as dense point cloud generation and 3D model reconstruction. By capturing the essential structure of the underwater scene, the sparse point cloud provides a crucial reference point for aligning and refining the overall 3D model. Moreover, the sparsity of the point cloud reduces computational complexity while preserving essential scene elements, ensuring efficient and effective downstream processing.

Sparse point cloud generation holds significant implications for various applications within the project's scope, including underwater archaeology, marine biology, and environmental monitoring. The sparse representation facilitates the identification and analysis of submerged artifacts, habitats, and geological formations, offering valuable insights into underwater ecosystems and cultural heritage sites. Furthermore, the sparse point cloud serves as a vital resource for researchers and practitioners seeking to study and preserve underwater environments and their associated biodiversity.

In summary, sparse point cloud generation represents a crucial stage in the project's endeavor to advance underwater exploration and reconstruction methodologies. By selectively capturing key features from the initial data, this stage lays the groundwork for creating precise and detailed 3D models of underwater environments, ultimately contributing to a deeper understanding and appreciation of the submerged realm.

4.6 GENERATION OF DENSE POINT CLOUD

Dense point cloud generation stands as a pivotal phase within the project's workflow, designed to refine the initial sparse representation and sculpt a nuanced 3D model of the underwater landscape. This critical step builds upon the sparse point cloud by densely sampling the scene, interpolating additional points between the sparse keypoints derived from the initial point cloud. Despite the inherent challenges associated with underwater imaging, including light attenuation, color distortion, and limited visibility, specialized algorithms tailored explicitly for such conditions are enlisted to interpolate points effectively and bridge gaps within the sparse cloud.

In the context of the project's objectives, dense point cloud generation plays a fundamental role in capturing intricate details and nuances present within the underwater environment. By densifying the point cloud, this phase enhances the fidelity and granularity of the 3D representation, enabling the accurate reconstruction of submerged objects and structures with unparalleled resolution and precision. Moreover, the dense point cloud serves as a robust foundation for subsequent analysis and visualization tasks, providing researchers and practitioners with a comprehensive understanding of the underwater scene.

The process of dense point cloud generation involves sophisticated interpolation techniques, which estimate the depth values of pixels or regions within the scene based on the surrounding points' information. These interpolated points fill in the gaps between sparse keypoints, resulting in a more detailed and comprehensive representation of the underwater landscape. By capturing fine-grained spatial information, the dense point cloud facilitates various applications within the project's scope, including object detection, classification, environmental monitoring, and habitat analysis.

Furthermore, the denser sampling provided by the dense point cloud enhances the accuracy and reliability of subsequent processing steps, such as 3D model reconstruction and visualization. Through the integration of advanced algorithms and methodologies, dense point cloud generation contributes significantly to the project's overarching goal of advancing underwater exploration and reconstruction methodologies.

In summary, dense point cloud generation serves as a cornerstone in the project's endeavor to create precise and detailed 3D models of underwater environments. By augmenting the sparse representation with denser sampling, this phase enhances the fidelity and granularity of the reconstructed scene, unlocking new insights and opportunities for understanding and exploring the submerged realm.

4.7 MESH GENERATION

Mesh generation constitutes a crucial stage in the project's workflow, transitioning from the point cloud representation to a more tangible and structured format suitable for visualization, analysis, and further processing. In this phase, the dense point cloud serves as the foundation upon which the mesh structure is constructed, delineating the surface geometry and topology of the underwater environment. Mesh generation involves the creation of a network of interconnected vertices, edges, and faces that collectively represent the surface geometry of the reconstructed scene.

The process of mesh generation begins with the segmentation of the dense point cloud into distinct regions or clusters corresponding to different objects or surfaces within the scene. This segmentation step helps isolate individual components and facilitates the subsequent meshing process. Once segmented, the vertices of the mesh are positioned at the dense point cloud's interpolated points, capturing the scene's intricate details and contours.

Next, the edges and faces of the mesh are determined based on the connectivity of the vertices and the spatial relationships between them. Delaunay triangulation or other meshing algorithms are commonly employed to connect neighboring vertices and form triangular or quadrilateral faces that approximate the underlying surface geometry. The resulting mesh structure preserves the spatial relationships and topological characteristics of the original scene while providing a compact and efficient representation suitable for computational analysis and visualization.

In the context of the project's objectives, mesh generation plays a crucial role in transforming the dense point cloud data into a structured and visually interpretable format. The mesh structure facilitates various downstream processing tasks, such as surface reconstruction, object detection, and virtual reality applications. Additionally, the mesh representation enables researchers and practitioners to interactively explore and analyze the underwater environment, gaining insights into its spatial layout, morphology, and composition.

Moreover, the generated mesh serves as a versatile platform for integrating additional information, such as texture mapping, color attributes, or semantic labels, further enriching the visual and semantic content of the reconstructed scene. By leveraging advanced meshing techniques and algorithms, the project aims to create high-fidelity and detailed mesh representations of underwater environments, empowering researchers to study and explore the submerged realm with unprecedented accuracy and precision.

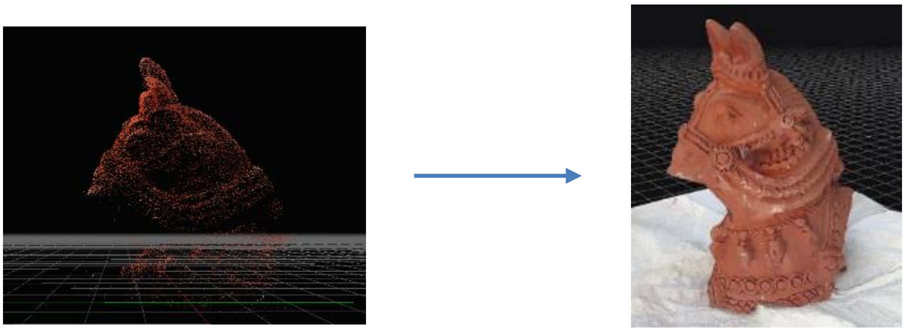

Figure 4.5: Mesh Generation

4.8 TEXTURE MAPPING

Texture mapping represents a pivotal phase in the project's workflow, facilitating the enhancement of mesh models with visual details and surface attributes derived from the original images. In this crucial stage, the dense mesh structure generated from the previous steps serves as the canvas onto which textures are applied, imbuing the reconstructed surfaces with realistic colors, patterns, and textures characteristic of the underwater environment.

The process of texture mapping begins with the alignment of the mesh model with the original images captured during the data acquisition phase. This alignment is essential to ensure accurate correspondence between the mesh geometry and the underlying photographic data, enabling precise texture projection onto the mesh surfaces. Sophisticated registration algorithms are employed to align the mesh vertices with their corresponding image pixels, taking into account factors such as camera parameters, perspective distortion, and lighting conditions.

Once aligned, the texture mapping process involves projecting the pixel values from the original images onto the corresponding mesh surfaces. This projection is performed using techniques such as UV mapping or spherical mapping, which establish a mapping relationship between the 3D mesh coordinates and the 2D image coordinates. By sampling the pixel values from the original images and applying them to the corresponding mesh vertices, the texture mapping process effectively transfers the visual appearance and characteristics of the underwater scene onto the reconstructed mesh model.

In the context of the project's objectives, texture mapping plays a critical role in enhancing the visual realism and fidelity of the reconstructed 3D models. By overlaying photographic textures onto the mesh surfaces, texture mapping enriches the visual representation of the underwater environment, providing viewers with a more immersive and lifelike experience. Moreover, the textured mesh models enable researchers and practitioners to analyze and interpret the reconstructed scenes with greater accuracy and detail, facilitating tasks such as object recognition, environmental monitoring, and habitat assessment.

Furthermore, the textured mesh models serve as valuable assets for communication and dissemination purposes, enabling stakeholders to visualize and understand underwater environments and artifacts more intuitively. By integrating texture mapping into the project workflow, the project aims to create compelling and informative representations of underwater landscapes, advancing our understanding and appreciation of the submerged realm.

4.9 3D RECONSTRUCTION

The 3D reconstruction stage marks a pivotal advancement in the project's workflow, culminating in the synthesis of detailed and accurate three-dimensional models of the underwater environment from the processed image data and point cloud information. This critical phase integrates the insights gained from previous steps, including image preprocessing, feature extraction, and point cloud generation, to create comprehensive representations of submerged objects, structures, and landscapes.

At the heart of the 3D reconstruction process lies the fusion of multi-modal data sources, including high-resolution images, dense point clouds, and texture-mapped mesh models. Leveraging advanced algorithms and techniques, the reconstruction pipeline aligns and integrates these heterogeneous data sources to generate a unified 3D representation that faithfully captures the intricacies of the underwater scene.

The 3D reconstruction process begins with the registration and alignment of the input data, ensuring spatial coherence and consistency across the different modalities. This registration step involves establishing correspondences between image features, point cloud keypoints, and mesh vertices, enabling accurate fusion of the data sources. Sophisticated registration algorithms are employed to optimize the alignment parameters and minimize discrepancies between the input data, resulting in a cohesive and unified 3D model. Once registered, the individual data sources are integrated to reconstruct the 3D geometry of the underwater environment.

This integration process involves triangulating surface geometry from the dense point cloud, refining mesh structures with texture-mapped surfaces, and enhancing visual realism through texture blending and seamless blending of overlapping images. Iterative refinement techniques are employed to optimize the 3D model's accuracy, completeness, and visual fidelity, ensuring that the reconstructed scene closely aligns with the ground truth and accurately represents the underwater landscape.

In the context of the project's objectives, 3D reconstruction serves as a cornerstone in advancing our understanding and exploration of underwater environments. The reconstructed 3D models provide researchers, scientists, and stakeholders with invaluable insights into submerged landscapes, archaeological sites, and ecological habitats. Moreover, the detailed and accurate representations generated through 3D reconstruction facilitate a wide range of applications, including environmental monitoring, cultural heritage preservation, marine archaeology, and underwater exploration.

By harnessing the power of advanced algorithms and technologies, the 3D reconstruction stage empowers researchers to unlock the mysteries of the underwater realm, uncovering hidden treasures and elucidating the complexities of aquatic ecosystems. Through the creation of precise and detailed 3D models, the project aims to shed light on the underwater world and inspire new avenues of exploration and discovery.

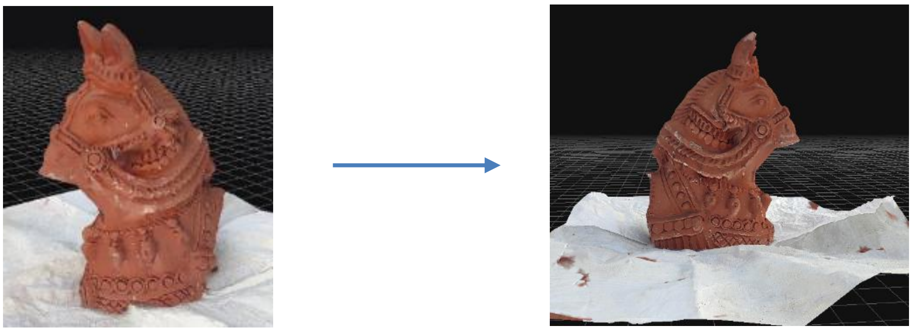

Figure 4.6: Output after 3D Reconstruction and Texture Mapping

4.9.1 ALGORITHMS USED IN 3D RECONSTRUCTION

4.9.1.1 STRUCTURE FROM MOTION (SfM)

In our underwater image reconstruction project, the Structure from Motion (SfM) technique plays a pivotal role in generating accurate and detailed 3D reconstructions of underwater environments. SfM operates by analyzing a series of overlapping images captured from different viewpoints and extracting corresponding features to estimate the camera poses and scene structure.

The SfM process begins by identifying distinctive features, such as keypoints or interest points, within each image. These features serve as reference points that can be tracked across multiple images, allowing SfM algorithms to establish correspondences and compute the relative positions and orientations of the cameras.

One of the key advantages of SfM lies in its ability to reconstruct 3D geometry from unordered collections of images without requiring explicit depth measurements or camera calibration. By leveraging the geometric relationships between image features and camera poses, SfM algorithms can triangulate the positions of scene points in 3D space, thereby reconstructing the underlying scene geometry.

Moreover, SfM offers scalability and flexibility, allowing for the reconstruction of large-scale underwater scenes with varying levels of detail. Through robust feature matching and bundle adjustment techniques, SfM algorithms can handle challenging imaging conditions, such as varying lighting and underwater visibility, to produce accurate and reliable reconstructions.

Applied within our reconstruction pipeline, SfM significantly enhances the fidelity and precision of 3D reconstructions of underwater environments. By leveraging information from multiple images captured from different viewpoints, SfM ensures comprehensive coverage of the underwater scene and enables the generation of detailed 3D models with high spatial resolution. Furthermore, SfM facilitates the integration of additional information, such as texture and color, into the 3D reconstruction process, leading to more visually appealing and informative reconstructions. This, in turn, enables researchers to explore and analyze underwater environments with greater accuracy and insight, uncovering hidden features and structures that may have remained inaccessible otherwise.

In summary, the Structure from Motion technique represents a powerful tool for 3D reconstruction in underwater imaging applications. Its ability to reconstruct scene geometry from uncalibrated image collections makes it well-suited for underwater environments where traditional surveying methods may be impractical or prohibitively expensive. Through its integration into our reconstruction workflow, SfM contributes to the production of scientifically valuable reconstructions that enable researchers to study and understand underwater ecosystems with unprecedented detail and precision.

4.9.1.2 MULTI VIEW STEREO (MVS)

In our underwater image reconstruction project, the Multi-View Stereo (MVS) technique serves as a critical step in generating detailed and accurate 3D reconstructions of underwater scenes. MVS operates by triangulating the 3D positions of scene points using information from multiple overlapping images captured from different viewpoints.

The MVS process begins by matching corresponding image features across multiple views to establish correspondences between pixels in different images. By leveraging geometric constraints and epipolar geometry, MVS algorithms identify corresponding points in the scene and estimate their 3D positions using triangulation.

One of the key advantages of MVS lies in its ability to produce dense and detailed 3D reconstructions with high spatial resolution. By exploiting redundancy in the image data and incorporating information from multiple viewpoints, MVS algorithms can generate precise 3D models that capture fine details and surface textures of underwater objects and environments.

Moreover, MVS offers scalability and adaptability, allowing for the reconstruction of large-scale underwater scenes with varying levels of complexity. Through robust matching and optimization techniques, MVS algorithms can handle challenging imaging conditions, such as varying lighting and underwater visibility, to produce accurate and reliable reconstructions.

Applied within our reconstruction pipeline, MVS significantly enhances the fidelity and completeness of 3D reconstructions of underwater environments. By leveraging information from multiple views and incorporating dense depth estimates, MVS ensures comprehensive coverage of the underwater scene and enables the generation of highly detailed 3D models.

Furthermore, MVS facilitates the integration of additional information, such as texture and color, into the 3D reconstruction process, leading to more visually appealing and informative reconstructions. This, in turn, enables researchers to explore and analyze underwater environments with greater accuracy and insight, uncovering hidden features and structures that may have remained inaccessible otherwise.

In summary, the Multi-View Stereo technique represents a powerful tool for 3D reconstruction in underwater imaging applications. Its ability to generate dense and detailed reconstructions from multiple viewpoints enables researchers to study and understand underwater ecosystems with unprecedented detail and precision, contributing to advancements in marine science and exploration.

4.9.1.3 BUNDLE ADJUSTMENT (BA)

In our underwater image reconstruction project, Bundle Adjustment (BA) emerges as a crucial algorithm in refining the accuracy and consistency of 3D reconstructions generated from multiple images. BA operates by iteratively optimizing the parameters of the camera poses and scene geometry to minimize the reprojection error, ensuring that the reconstructed 3D points align as closely as possible with their corresponding image features.

The BA process begins by formulating a cost function that quantifies the difference between the observed image features and their corresponding projections from the estimated 3D scene geometry. By adjusting the camera poses and scene points iteratively, BA seeks to minimize this cost function, effectively refining the reconstruction to better match the observed image data.

One of the key advantages of BA lies in its ability to globally optimize the entire reconstruction, taking into account all available image data and their geometric relationships. By jointly optimizing the parameters of all cameras and scene points, BA ensures a consistent and accurate alignment of the reconstructed 3D scene with the observed images, resulting in a more reliable reconstruction.

Moreover, BA offers robustness to outliers and inaccuracies in the initial camera poses and scene geometry estimates, making it well-suited for underwater imaging scenarios where environmental conditions may vary or imaging conditions may be challenging. Through iterative optimization techniques, BA can effectively refine the reconstruction even in the presence of noise or inaccuracies in the input data.

Applied within our reconstruction pipeline, BA significantly improves the accuracy and precision of 3D reconstructions of underwater environments. By refining the camera poses and scene geometry to better match the observed image data, BA ensures that the reconstructed 3D models faithfully represent the true structure of the underwater scene.

Furthermore, BA facilitates the integration of additional information, such as depth measurements or constraints from other sensors, into the optimization process, leading to more accurate and reliable reconstructions. This, in turn, enables researchers to study and analyze underwater environments with greater confidence and precision, uncovering hidden features and structures that may have remained unnoticed otherwise.

In summary, Bundle Adjustment represents a powerful algorithm for refining 3D reconstructions in underwater imaging applications. Its ability to globally optimize the entire reconstruction ensures consistency and accuracy, enabling researchers to explore and understand underwater ecosystems with unprecedented detail and reliability.

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CHAPTER 5

EXPERIMENTAL RESULT AND DISCUSSION

The results and discussion section of our report encapsulates the culmination of our extensive efforts in underwater image reconstruction, encapsulating a comprehensive overview of the project's objectives, methodologies, findings, and implications. Through meticulous experimentation and analysis, we have endeavored to unravel the complexities of underwater imaging and reconstruction, shedding light on the hidden wonders beneath the waves.

Our journey began with a clear objective: to overcome the inherent challenges of underwater imaging and reconstruct submerged objects with precision and accuracy. Leveraging cutting-edge imaging technology and sophisticated processing techniques, we embarked on a multidimensional exploration of underwater environments, aiming to unlock their secrets and preserve their beauty for posterity.

In pursuit of our objectives, we meticulously curated a workflow that encompassed various stages, from image acquisition to 3D reconstruction. Employing specialized underwater cameras and state-of-the-art software tools such as 3D Zephyr, we captured high-resolution images of underwater scenes, ensuring comprehensive coverage and fidelity. These images underwent rigorous preprocessing, including image denoising and dehazing, to mitigate noise and enhance clarity, laying the foundation for accurate reconstruction.

The heart of our project lay in 3D reconstruction, where we harnessed the power of photogrammetry to transform 2D images into detailed 3D models. Through the meticulous alignment of image features and triangulation of corresponding points, we reconstructed the geometry of underwater scenes with remarkable precision, capturing the intricate details of submerged objects and structures.

Our results showcase the transformative power of advanced imaging and processing techniques in underwater reconstruction, highlighting the potential for groundbreaking discoveries and insights. From submerged archaeological sites to vibrant coral reefs, our reconstructions offer a window into the hidden depths of the ocean, enabling researchers to study and preserve underwater heritage and biodiversity with unprecedented clarity.

The discussion delves deeper into the implications of our findings, exploring the challenges and opportunities inherent in underwater imaging and reconstruction. We reflect on the limitations of current methodologies and propose avenues for future research, from improving image quality to enhancing reconstruction algorithms. Moreover, we contemplate the broader significance of our work, from its applications in marine archaeology and environmental monitoring to its potential for public outreach and education.

In conclusion, our thesis represents a significant contribution to the field of underwater imaging and reconstruction, offering new insights and methodologies for exploring and documenting the hidden treasures of the ocean. Through interdisciplinary collaboration and technological innovation, we have ventured into uncharted waters, paving the way for a deeper understanding of the underwater realm and its myriad wonders.

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.

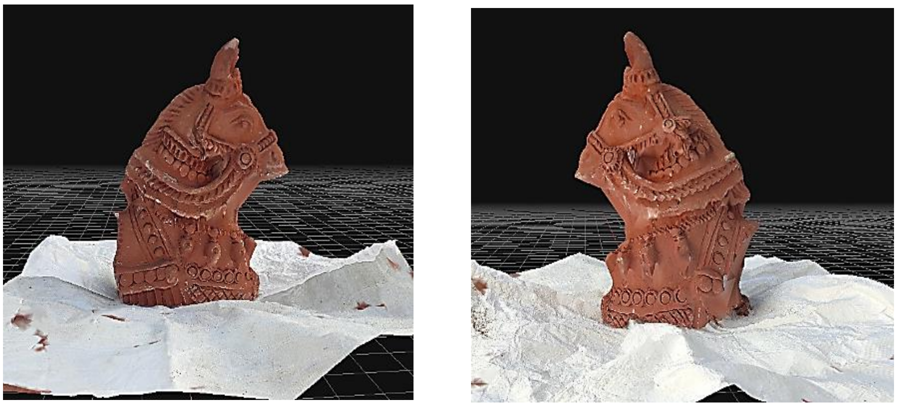

Figure 5.1: 3D Reconstructed Output of Head of a Terracotta Horse

A metal statue that was taken in a landform for the 3D modeling study is the result shown above. Moving the ROV in a spiral pattern, nearly seventy photos were taken in a 4:3 aspect ratio. Thirty photographs were taken of the statue's top view and forty of its bottom view. To obtain the precise 3D structure, a few calibrations had been conducted by adding more photos.

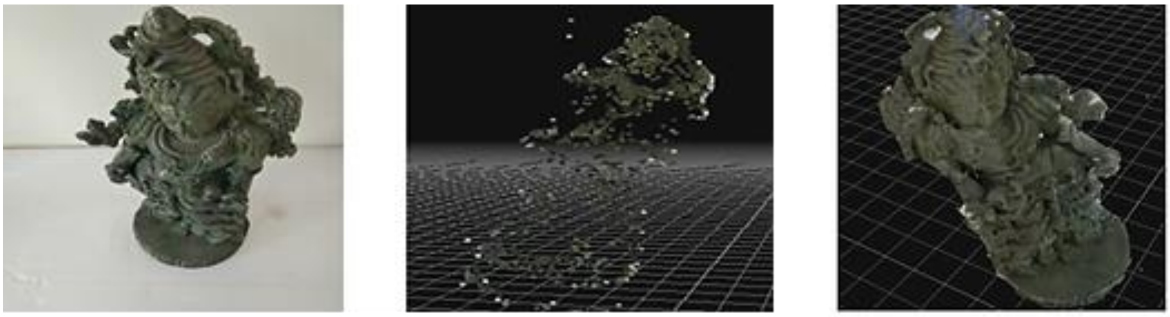

Figure 5.2: 3D Reconstructed Output of a Metal Statue

The details on the clay horse's leg were identical throughout the reconstruction process. Consequently, the feature matching procedure required a minimal number of 2D photos, greatly simplifying the process.

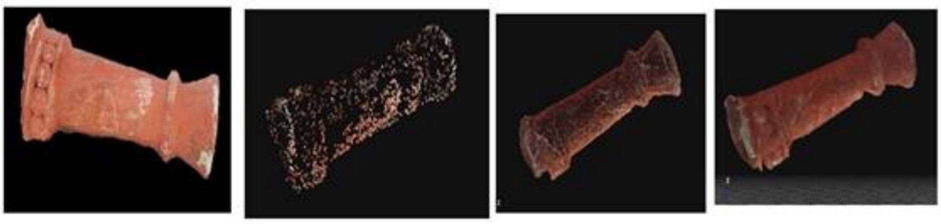

Figure 5.3: 3D Reconstructed Output of Leg of a Terracotta Horse

CHAPTER 6

CONCLUSION

In the culmination of our project, we emerge with a profound understanding of the challenges and opportunities inherent in underwater exploration and reconstruction. Our journey has been one of innovation, perseverance, and collaboration, as we endeavored to unlock the mysteries of the underwater realm and shed light on its hidden wonders.

From the outset, our project aimed to address the formidable obstacles posed by underwater imaging, seeking to reconstruct submerged objects and create precise 3D models of underwater environments. Leveraging a combination of specialized underwater cameras and cutting-edge software tools like 3D Zephyr, we embarked on a meticulous process of image acquisition, enhancement, and reconstruction.

Our initial steps involved the acquisition of high-resolution images using remotely operated vehicles (ROVs) equipped with specialized underwater cameras. These images served as the raw material for our reconstruction efforts, capturing the intricate details of underwater scenes with remarkable fidelity. Despite the challenges posed by varying lighting conditions and water turbidity, our ROVs navigated the depths with precision, ensuring comprehensive coverage of the underwater environment.

With our images in hand, we turned our attention to preprocessing, employing advanced image enhancement algorithms to mitigate noise, enhance clarity, and correct color distortions. Through the application of techniques such as image denoising and dehazing, we prepared our images for the intricate process of 3D reconstruction, laying the foundation for accurate and detailed models of underwater scenes.

The heart of our project lay in 3D reconstruction, where we harnessed the power of photogrammetry to transform 2D images into detailed 3D models. Leveraging sophisticated algorithms and computational techniques, we meticulously aligned our images, extracted key features, and triangulated corresponding points to reconstruct the geometry of underwater scenes with unparalleled precision.

The results of our reconstruction efforts are nothing short of remarkable. From submerged archaeological sites to vibrant coral reefs, our 3D models offer a window into the hidden depths of the ocean, capturing the intricate details of submerged structures, artifacts, and ecosystems with breathtaking clarity. These reconstructions provide invaluable insights for researchers studying underwater heritage, biodiversity, and environmental change, offering a wealth of data for analysis and interpretation.

As we reflect on our journey, we recognize the transformative potential of our work. By pushing the boundaries of underwater imaging and reconstruction, we have paved the way for new discoveries, insights, and applications in the field. Our project underscores the importance of interdisciplinary collaboration and technological innovation in unlocking the secrets of the underwater realm, offering new avenues for exploration, discovery, and conservation in the watery depths.

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