Drone Photogrammetry for Underwater Cutural Heritage Documentation

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Underwater cultural heritage (UCH) is an irreplaceable resource with intrinsic value that requires preservation, documentation, and safeguarding. Documentation is fundamental to increasing UCH resilience, providing a basis for monitoring, conservation, and management. Advanced UCH documentation and virtualization technologies are increasingly important for dissemination and visualization purposes, domain expert study, replica reproduction, degradation monitoring, and all other outcomes after a metric survey of cultural heritage (CH). Among the different metric documentation techniques, underwater photogrammetry is the most widely used for UCH documentation. It is a non-destructive and relatively inexpensive method that can produce high-resolution 3D models and 2D orthomosaics of underwater sites and artifacts. However, underwater photogrammetry is challenged by the different optical properties of water, light penetration, visibility and suspension, radiometric issues, and environmental drawbacks that make underwater documentation difficult.

Keywords: underwater photogrammetry ; geomatics

1. Introduction

Underwater exploration is inherently interdisciplinary, requiring collaboration between researchers in diverse fields such as geology, biology, archaeology, engineering, and geomatics. Due to the remoteness and limited accessibility of underwater archaeological sites, it is essential to use 3D metric techniques to record these sites and their elements accurately and comprehensively [1]. Geomatics techniques offer many tools and solutions for monitoring and documenting marine assets [2].

The importance of modern technologies and innovative methods used today for the documentation of heritage [3][4][5][6] is not only linked to the ease with which they allow for dissemination among groups of scholars and researchers but is also fundamental to the involvement of the general public. In particular, the study of submerged heritage contributes to the formation of cultural identity both locally and internationally [7]. Most wrecks and loads carried are located in international contexts, deriving directly from ancient trade routes; for this reason, ships and their contents can often be located today at a great distance from their context of origin or destination [8][9].

Recent advancements in archaeological research have witnessed the integration of photogrammetry as a powerful scientific tool, bridging terrestrial and marine environments to unravel historical mysteries. Marín-Buzón et al. [10] highlights the burgeoning worldwide trends in utilizing photogrammetry within archaeology, showcasing its potential for comprehensive documentation and analysis. However, amidst this enthusiasm, McAllister [11] raises pertinent concerns regarding the application of ‘Digital Realism’ in underwater archaeology, particularly emphasizing the complexities of photogrammetric digital 3D visualization and interpretation. At the same time, Skarlatos et al. [12] emphasizes critical steps and considerations for image-based underwater 3D reconstruction in cultural heritage contexts.

The scientific community has fully addressed the increasing demand for high-resolution products with metric and colorimetric content for terrestrial applications; therefore, several commercial and non-commercial solutions and standard procedures are already available [13][14][15]. Conversely, high-resolution 3D reconstruction, radiometric correction capability, and positioning in an underwater context are ongoing issues. From a geomatics point of view, the presence of a water medium and the related additional drawbacks complicate scientific work as compared to the terrestrial field. Yet, Pulido Mantas et al. [16] advocates for a unified approach, transcending land and sea boundaries, demonstrating the versatility of photogrammetry in studying diverse environments.

Following conventional photogrammetry and computer-vision-based algorithms (the Structure from Motion approach), image collection and processing still represent a significant ongoing issue in underwater contexts [17]. Photogrammetric methods allow for the precise mapping of the underwater landscape and a detailed three-dimensional reconstruction of archaeological remains and evidence, which is useful for evaluating the health state of these findings [18]. Another aspect is the correction of color variation incurred by light propagating in water, which can be addressed through image enhancement [19].

2. The Use of Drones in Underwater Photogrammetry

2.1. UAS Photogrammetry in Very Shallow Water

To plan an effective archaeological survey campaign, it is essential to understand the topographic situation of a site, both to obtain an overview of the area and to comprehend the relationships between the surrounding territory and the underwater heritage itself. A hybrid approach integrating total stations and GNSS equipment for land surveys remains fundamental [20].

Aerial photography is an important tool for this purpose, as it can be used for both land surveys and the shallow water mapping of archaeological evidence. This is important not only to identify the presence of archaeological sites but also to better understand the layout of structures. Aerial photogrammetry, including legacy data, represents a cartographic basis for drafting an overall plan for the site.

For sites with assets halfway between water and land or with emerged and submerged portions, it is particularly important to study the relationship between the coast and the land to identify elements that may suggest continuity, or continuation. Here again, aerial photogrammetry plays an important role in understanding the limits of archaeological structures on land and underwater, which is essential for better planning subsequent surveys.

UAS (Unmanned Aerial System) photogrammetry has emerged as a powerful tool for archaeological surveys in very shallow water, offering a cost-effective and efficient way to perform bathymetric surveys [21]. However, the unique characteristics of shallow water environments pose several challenges for UAS photogrammetry, particularly the effects of refraction and waves [22].

In the case of UAS photogrammetry in shallow water, the difference in refractive index between air and water causes light rays to bend towards the water’s surface, leading to distortion in the captured images. This distortion can result in errors in the reconstructed 3D models, affecting the accuracy of archaeological interpretations.

Waves on the water surface introduce additional challenges for UAS photogrammetry. The movement of waves can cause blurry or distorted images. Additionally, the rippling effect of waves can create artifacts in the reconstructed 3D models, affecting the visual interpretation of the archaeological site.

To mitigate the effects of refraction and waves, Partama [23] developed geometric modeling techniques specifically tailored for UAS photogrammetry in shallow water. These techniques involve incorporating the refractive index of water and wave characteristics into the photogrammetry software. This allows the software to compensate for the distortion caused by refraction and waves, resulting in more accurate 3D reconstructions [24]. Other solutions are represented by bathymetric mapping from UAS imagery based on machine learning [25] to automatically compensate for water refraction and wave motion.

Overall, these studies have demonstrated the effectiveness of geometric modeling in mitigating the effects of refraction and waves, leading to more accurate and reliable 3D reconstructions of underwater archaeological sites in very shallow waters.

2.2. Remotely Operated Vehicles (ROVs) in Underwater Photogrammetry

Remotely operated vehicles (ROVs) have emerged as powerful tools for underwater exploration and surveying, particularly in the context of underwater photogrammetry. Their ability to navigate underwater environments and acquire high-resolution imagery has transformed our ability to study underwater structures, habitats, and ecosystems. Unlike human divers, ROVs can operate in hazardous or inaccessible environments, providing a safer and more efficient means of data collection.

ROVs come in various sizes and configurations, catering to specific applications and depths. Smaller ROVs, known as mini ROVs, are typically used for shallow-water operations, while larger ROVs can venture into deeper waters. Some ROVs are designed for specific tasks, such as inspecting and maintaining underwater infrastructure, while others are more versatile for a wider range of applications.

ROVs offer several advantages over traditional underwater photogrammetry methods such as scuba diving and towed cameras:

- Enhanced safety: ROVs eliminate the risks associated with human divers, such as decompression sickness, entanglement, and hazardous marine life encounters.
- Deeper reach: ROVs can operate at depths beyond the reach of human divers, providing access to a wider range of underwater environments.
- Increased flexibility: ROVs can navigate complex underwater structures and environments with greater maneuverability than towed cameras.
- Automated data acquisition: ROVs can be programmed to follow predetermined paths and capture images autonomously, reducing operator fatigue and increasing efficiency.

ROVs have found widespread applications in underwater photogrammetry for various purposes, including documenting underwater shipwrecks, submerged settlements, and archaeological sites [26]; assessing coral reef health, studying marine habitats, and monitoring the impact of human activities [27]; and examining pipelines, dams, and other underwater structures for cracks, corrosion, or other damage [28].

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