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Optimizing underwater visual records for crime scene investigations in water with clear to reduced visibility

A "crime scene" can be defined as a place where a crime has been committed and forensic evidence may be gathered. However, at some scenes, the "crime scene do not cross" tape cannot be placed, forensic experts cannot attend as direct responders, and evidence can be washed away: when the crime scene happens to occur in a body of water, the investigation process can be extremely complex and the outcome of it highly affected by the limitation of equipment and procedures available. However, with an estimated 236,000 annual drowning deaths worldwide (World Health Organization data 2021) [1], several mass disasters occurring in or caused by bodies of water (i.e., boat sinking, tsunami, flooding), a large number of dangerous water-related sports and the never-ending opportunity to conceal body remains in wells, rivers, lakes, cisterns, aquatic environments are common crime scene scenarios [2].

When human remains are suspected to be in a particular water body or are found floating, underwater, or beached, law enforcement experts – police divers especially – are called to the scene. Such teams will perform a complete investigation, from the planning of the operations based on the available personnel and environmental conditions, to the (search and) recovery of the body, the documentation and the collection of small objects and other helpful evidence field [3,4]. However, despite best efforts, some pieces of evidence may be missed, and in certain circumstances, evidence observed underwater are not retrieved due to a lack of equipment, funds, or to safeguard the safety of the divers. In such cases, the correct scene documentation becomes pivotal for the course of the investigation. In most underwater cases, forensic pathologists and investigators will not experience the actual scene, but will see the human remains and the items connected with the body or the crime only when retrieved by the diving personnel. To complete crime scene reconstruction, forensic pathologists and investigators rely on images, documentation and memories provided by the divers. In these cases, accurate underwater crime scene photography and video become essential for capturing visual records of the scene, which can be analysed or examined later.

Photography has been considered a powerful forensic investigative tool since the middle of 1800, and the development of new technologies has expanded its use ever since [5]. In recent years, photography, videography, remote sensing, and artificial intelligence have evolved and are now commonly used in various environments to provide testimony of a wide range of investigations. Notorious historical examples on how photographic, video, and remote sensing images have been used in underwater investigations are the discovery of the Titanic wreck (1985), the Russian submarine Kursk (2011) and USS Monitor (2003); however, underwater video footage also used to investigate suspicious deaths, as was the case with the famous singer Whitney Houston, who was found unresponsive in a bathtub in 2012.

During underwater operations, the safety of the divers is of primary importance, with priority consideration taken regarding any hazard that could affect them. However, at the same time, the opportunity for divers to conduct systematic search and produce different type of scene documentation (e.g. sketching, photo, video) which can be used in Court can make the difference between closing a case or a miscarriage of justice.

Similarly to human remain recovery and excavation performed in a terrestrial environment, in a forensic investigation carried out in bodies of water, both classical tools and new technologies typically used in archaeology – underwater archaeology in this case – may assist law enforcement in such operations. However, it is essential to remember that divers can operate only for a certain period in an underwater scenario.

Divers' working time is determined by various factors such as the depth of the scene, water temperature, environmental conditions (e.g., visibility, currents, waves), and other stress-related factors that can affect the breathing pattern and, as a consequence, the time to reach the limit of a safe reserve of air in the tank. It's important to note that as the depth of the intervention increases, dive time and image/document acquisition time become shorter, due to the higher requirement of air supply during the bottom time, alongside the need of longer ascent times to accommodate decompression requirements [6]. Furthermore, it is necessary to consider that several factors affect the collection of video and still photography in underwater crime scenes. A degradation in the visibility of underwater images and video is caused by wavelength-dependent light absorption and scattering. This can affect pattern recognition accuracy and perception. Light absorption and scattering (particles suspended in the water column that cause turbidity) hinder the performance of underwater scene recognition and inspection. Color also degrades as longer wavelengths of light are filtered, with depth being a great contributing factor. Over the last few years, the focus has been on underwater image enhancement and restoration as the two techniques to improve underwater images. These processes have come a long way in enhancing underwater images through dehazing and color correction. However, in certain circumstances, an underwater crime scene has zero visibility, making the investigation much more challenging and dangerous for the divers involved [7]. In such cases, it may be difficult or impossible to capture clear and accurate visual records of the scene, and evidence may be gathered using other methods such as metal detectors or sonar equipment to detect any metallic objects or potential obstacles in the water, or special lighting or flares may be used to illuminate the area.

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This perspective piece aims to present a brief summary of the fundamental physics of light that impact underwater photography in situations of clear or limited visibility (excluding zero visibility), as well as an overview of the current equipment available for underwater photo and video capture, its suitability for various underwater conditions, and its affordability and cost-effectiveness. The intended audience for this perspective piece is individuals involved in underwater investigations with varying levels of expertise, capability and backgrounds. Additionally, this piece aims to open up critical discussions about what equipment should be included in the toolkit of investigators dealing with underwater crimes, providing a foundation for understanding the limitations and potential solutions in underwater investigations.

The right equipment needs to be set around three principal facts: lights, visibility, and depth [8]. Crossing these parameters could create multiple settings that need different technology to allow safe and suitable acquisitions. Understanding the lighting fundamentals and color temperature underwater is essential for correctly choosing equipment.

The fundamental physics of light shows that the underwater environment gets darker in proportion to the distance from the surface [9]. This is the effect of the surface of the water reflecting off the light, resulting in a reduction of the light able to penetrate the surface. This reduction is affected by the water surface conditions, the weather, and the time of the day. Furthermore, the loss of color is due to the water-absorbing different wavelengths of light at different degrees [9]. The order in which colors are absorbed is the order in which they appear in a rainbow: red goes first, generally absorbed within the first 5 m from the surface, followed by orange within 7 m, yellow within 10–15 m, and green within 20–25 m, leaving behind only colors in the blue part of the light spectrum, until complete darkness from 35 m underwater.

In addition to the loss of color at depth, there is also the cumulative loss of color in the horizontal distance. For example, if a is diver 7 m underwater observing an object 5 m away, the light has traveled a total of 12 m. This results in the filtering out of all the reds, oranges and some of the yellows. Furthermore, when light enters water from air, it changes direction due to refraction. In water, the index of refraction (degree to which the light is refracted in water) is more significant than in air, and as a consequence, the target object will appear up to 25% closer and 33% larger underwater than it actually is. Therefore, all photographed evidence should be shot in situ with a reference photo scale, waterproof, and weighted to ensure accuracy [10]. However, when the combination of water turbidity, lighting conditions, and the angle of observation impede the observation of the standard scale, it is suggested to use as alternative object of standard dimensions and with negative buoyancy, such for example a coin.

When taking underwater photos, the changing/loss of colors is significant. Shooting in ambient light is possible, and the pictures could be improved with a manual or custom white balance, underwater or later, using computer software. However, even when the colors seem to be there, filters, strobes, photo and video lights, and special settings should be used to improve the colors of the images, as the human brain tends to compensate for the loss of colors underwater [9].

To obtain good images at depths between 5 and 25 m, images could be captured through higher ISO values (values that determine the sensor's light sensitivity in the camera) and – despite losing some quality – increasing the exposure time. Furthermore, strobes can be optionally used to restore the partial loss of color, but at depths beyond 30–40 m, their use becomes essential, as blue light will be the only visible one [11]. However, it is essential to remember that also the strobe light can be lost because of the distance traveled in the water: for example, when a strobe lights up something 5 m away, its light has to travel 5 m towards the object plus 5 m back to the camera, for a total of 10 m, resulting in a loss of red, orange and possibly yellow.

Color-correcting filters can be added to the camera (at the front or the rear of the lens) to improve the quality of the pictures. Such filters do not restore the reds but reduce the amount of blue light to balance it with the amount of red-orange-yellow light available. Since the filters reduce the amount of light getting to the camera, they are only recommended for daylight dives and reasonably shallow waters. To note, filters will also filter the strobe light; therefore, no artificial light should be used when using any colors correcting filter.

Besides light, visibility underwater can also be affected by the particulate matter in the water between the diver/photographer and the object. Debris in the water can cause a backscatter effect, illuminating the particulate matter while taking a picture of the object of interest. To minimize the backscatter, the diver/photographer should maintain a neutral buoyancy or remain still on the bottom to avoid stirring up more particulate. Furthermore, the object to be photographed should be as close as possible, and the strobes far from the camera, positioned to the side, not parallel to the matter.

Considering the underwater situation and the available funding, the set of tools needed to obtain an optimal visual record for underwater crime scene investigation is reported in Table 1.

Despite the cost of the tools, images acquired in an underwater scenario will probably be highly distorted because of the challenging environment that degrades the quality of the images [9]. Underwater crime scene investigations require the use of specialized tools and software to acquire and process images. There are several photogrammetric software programs that are used for underwater crime scene analysis, including Agisoft®; AutoCad® for image acquisitions and post-production, as well as software programs such as RealityCapture, Pix4Dmapper, and PhotoModeler, that beside processing images, can create 3D models, maps, orthophotos, and point clouds from acquired images, which can be particularly useful in underwater crime scene reconstruction and detailed analysis, to help in identifying clues and reconstructing the crime scene in 3D space [12,13]. Specifically, RealityCapture allows to create high-resolution 3D models from photos and 3D scans and it can be used for underwater crime scene reconstruction and detailed analysis; Agisoft Metashape allows you to create 3D

Table 1
Set of tools required in different underwater situations to obtain an optimal visual record on an underwater crime scene.

Depth of the scene	Fund required	Tools	Result	Fund required
0–25 m	Up to 500 EUR (binary gas included)	Action camera	Photo - video information and testimony of the settings with enough light and low-quality images.	Up to 500 EUR (binary gas included)
0–60 m	Up to 15,000 EUR (binary and ternary gas included)	A compacted, reflex, or mirrorless camera with lens wet lens (macro and/or wide), lights (artificial and/or strobe), and dive suit kit (porthole, focus ferrule etc.) or underwater drone	Video testimony of the interested area and possibility to perform underwater photogrammetry and 360° imaging.	Up to 15,000 EUR (binary and ternary gas included)
60+ m	More than 15,000 EUR (ternary gas and oxygen included)	Camera and dive suit kit with proper lens, wet lens (macro and/or wide) and lights (artificial and/or strobe), underwater drone and ROV technics	Perform acquisition, photogrammetry and 360° imaging/tour of the underwater environment even in the toughest scenario.	More than 15,000 EUR (ternary gas and oxygen included)

models, orthophotos and point clouds from acquired images and can be used for underwater crime scene reconstruction and clue identification; Pix4Dmapper is designed to generate 3D models and maps from aerial and land images, providing great solutions for underwater crime scene analysis, for example for creating 3D models of the seabed; and PhotoModeler allows to create 3D models, maps and measurements from captured images.

Additionally, specific algorithms can be used to restore or enhance underwater images, such as the deconvolution algorithm for removing blurring caused by water and the color correction algorithm for correcting color distortion [14]. For example, it is possible to increase or decrease the temperature of an image, bringing up specific colors to disappear because of color distortion, poor visibility, scattering, or contrast reduction. These algorithms are designed and are used to improve image quality and reduce distortion caused by water, such as deconvolution algorithm which is used to enhance underwater image by removing blurring caused by water. The deconvolution algorithm uses knowledge of the diffusion function of the underwater image to restore the original image. The color correction algorithm can be used to correct the water color absorption effect on the underwater image [15,16]. This algorithm uses a physical model to correct the color distortion of the underwater image.

Furthermore, Artificial intelligence (AI) has become an indispensable tool in underwater crime scene investigation. It plays a fundamental role in the use of algorithms to improve underwater images and in the identification and classification of specific patterns. One of the many benefits of AI is the automation of underwater image analysis processes, resulting in faster and more accurate analysis. Investigators can use AI, even on board underwater ROVs, to automatically recognize specific patterns, objects, and details that are not easily identifiable or visible, or anomalies present in the underwater crime scene, such as foreign or unusual objects that could be indicators of criminal activity [17]. Convolutional neural networks (CNN) for machine learning are useful for improving sharpness, removing noise, and addressing other image quality issues that commonly occur in underwater images. These possibilities, complemented by the use of AI, are used for pattern recognition in underwater images, such as the identification of collision marks or the recognition of specific underwater objects or structures. AI can help investigators identify potential clues or evidence that might otherwise be overlooked, making it an important tool for underwater crime scene analysis.

It is important un underline that when modifying an image that lacks a reference image, a no-reference image quality evaluation should be used to evaluate the results of restoration techniques as a quality assessment for using such images in Court [18]. The outputs will be used in court to understand and reconstruct a crime scene. The best practice in these cases is to create accessible data that can be opened and viewed on multiple platforms and run on a based-equipped laptop/desktop computer [18]. This will allow replicating the final event of an act of forensic authority.

While the documentation of crime scenes in terrestrial environments is highly standardized, and innovative techniques are becoming a reality in many countries, the underwater criminal scenario is still under/poorly investigated. The large number of cases happening in bodies of water required raising the profile of underwater documentation, taking advantage of the knowledge, techniques, and tools already developed in and for underwater archaeology and underwater photography. However, while it is possible to take advantage of considerable funds for the best tools, in this context, the availability of a good diver is priceless.

With the advances in underwater drone technology as platforms for multiple sensor suites, side scan sonar and other acoustic imaging technologies have become valuable tools for locating submerged targets, particularly for first responders and law enforcement.

With experienced operators, large areas can be covered to identify targets of potential interest allowing the recovery team to preserve the scene's integrity before the survey and recovery process.

Remotely Operate Vehicles (ROV) can play a significant role in processing images and data of a submerged crime scene [19]. Using remote sensing techniques can be advantageous, because data can be collected without the need for direct physical contact with the environment being studied. This means that researchers can gather information from areas that may be difficult or dangerous to access, such as deep or remote underwater locations, or sites with hazardous materials. Remote sensing can also provide a wider perspective of the area being studied, allowing for more comprehensive analysis and interpretation of the data collected. Additionally, remote sensing techniques can be used to monitor changes in the environment over time, providing valuable information for long-term studies and monitoring programs [20].

One of the current methods used in archaeology and the investigation of submerged archaeological sites is the use of photogrammetric surveys [12]. This technique extracts information from photo inputs by analysing overlapping images from various angles and is used to document submerged sites three-dimensionally.

Primarily developed for the demand for accurate underwater maps and models for environmental monitoring, subsea infrastructure, and marine archaeology, it can document and reconstruct a scene with the aid of advanced photogrammetry software. This technique addresses several challenges, including color correction, lighting, and focus. This technology has developed into a standard documentation tool for submerged archaeological sites and has allowed archaeologists to acquire great detail of underwater cultural heritage sites. Photogrammetry methods allow for greater reliability, accuracy, and detail. ROVs can also equipped with acoustic sensing containing various sonar devices for seafloor mapping, submersible navigation, and underwater object [21]. The most common type of sonars used in underwater investigation are side scan sonar, that produces high-resolution images of the seafloor and its features, including shipwrecks, debris, and other objects; multibeam sonar, that uses multiple beams to create a 3D image of the seafloor and its features, allowing for accurate mapping of the area; sub-bottom profiler, used to image layers beneath the seafloor and is particularly useful in geological and archaeological investigations; and scanning sonar, used for real-time imaging of underwater environments and objects, often used in search and rescue operations or for underwater surveys.

In conclusion, the investigation of underwater crime scenes presents unique challenges to forensic investigators, particularly in regards to visual documentation. This paper has provided valuable insights into the role of underwater photography in forensic investigations. By highlighting the key factors that affect underwater photography and summarizing the available equipment, this paper serves as a useful resource for forensic investigators and researchers interested in enhancing their ability to accurately document and analyze underwater crime scenes. Incorporating the insights presented in this paper can enable investigators to obtain an accurate visual record of the scene and improve the overall quality and effectiveness of forensic investigations. While the affordability and cost-effectiveness of advanced underwater photography equipment remain a concern, the potential benefits in forensic investigations cannot be overlooked. Overall, this paper highlights the importance of underwater photography in forensic investigations and provides a starting point for further research in this area. By continuing to explore and develop new techniques and technologies, forensic investigators can enhance their ability to solve crimes that occur in aquatic environments.

Disclaimer

The first author and the last author contributed equally to this work. The last author's position reflects their seniority and role as corresponding author.

Conflict of interest

None.

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