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Three-Dimensional Modeling of an Object Using Underwater Photogrammetry

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ABSTRACT

Since the use of cameras in the underwater environment, underwater photogrammetry (UP), a sub-science of photogrammetry, has emerged. Methods and software that can produce three-dimensional (3D) data from moving recordings of objects known as Structure from Motion-SfM, which are used in the same photogrammetry, are also used in underwater photogrammetry. It can be used to create 3D models of shipwrecks, marine ecosystems and archaeological remains with UP. In this article, an object was placed in a 1.5-meter deep pool and it was aimed to create a (3D) model of the object by underwater photogrammetry using the obtained data set. The 3D visual of the model was created by combining the images taken under water in the software.

1. INTRODUCTION

With the developing technology, the present and future generations are provided with opportunities to collect and evaluate environmental information in various ways. One of these fields is photogrammetric studies. Photogrammetry is a branch of technology, science and art in which reliable information is obtained because of recording, measuring and interpreting the images shaped by physical objects and the rays reflected from the environment they form and the electromagnetic energies they emit (Yakar et al., 2009; Ulvi et al., 2020). The photogrammetry process, which aims to collect three-dimensional information about the geometry, color and texture of an object, is a technique that allows the creation of a 3D virtual model by obtaining digital images (Yakar et al., 2016). In this way, 3D models are frequently used in many areas such as documentation studies, smart city applications and the production of city models, modeling of organs for medical purposes, modeling of architectural designs, and archaeological studies, since they contain many details of the building (Yiğit et al., 2020).

With the production of cameras that can photograph underwater, underwater has also been added to these areas. In this way, 3D modeling has begun to be used in different areas such as modeling the underwater topography, marine ecosystem, archaeological remains and shipwrecks (Alyılmaz et al., 2010; Van Damme, 2015). Experiments in water alto photogrammetry can be performed both in laboratory conditions and in pools a few meters deep or in natural waters.

The usage areas of underwater photogrammetry are very wide. Of these, it is now widely used in marine biology and archeology to study sunken objects (such as shipwrecks and prehistoric settlements). Additionally, hydrographic measurements and bathymetric surveying include the maintenance of underwater cables and pipelines (Yılmaz et al., 200; Kanki et al., 2021; Hamal and Ulvi, 2020).

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Underwater photogrammetry is the creation of a 3D model with the help of 2D photographs taken underwater without contact with the object (Drap, 2012; Drap et al., 2015). Digital cameras are used in underwater photogrammetry. However, most digital cameras require a special underwater housing with a lens port suitable for the underwater environment to be suitable for underwater inspections. (Capra et al., 2015; Skarlatos et al., 2021). For this reason, it is obtaining popularity by supplying comparatively high resolution in relation to low-cost devices such as the GoPro camera and its maintenance costs. Requires professional divers during underwater expeditions to use either expensive digital cameras or inexpensive GoPro cameras. Due to the dangerous features of the measurements (divers being under water for a long time, difficult measurement conditions, etc.), unmanned underwater vehicles such as unmanned aerial vehicles or underwater drones are increasingly needed. They can be controlled entirely remotely or with little diver intervention. (Raoult et al., 2016; Kujawa, 2021).

There are many factors that affect the quality and accuracy of measurements taken in underwater photogrammetry (Korumaz et al., 2011). The first of these; The blowing from the wind causes the sun's rays on the water surface to vibrate, which creates shiny textures called caustics on the water floor or on the objects on the bottom. When light comes to still water, the water acts as a reflective mirror, while the light coming into wavy water is more absorbed by the water. Light rays are refracted by forming caustics on wavy surfaces, which is undesirable for photogrammetric applications. This is because it affects the extraction of two-dimensional content data from the photo as well as creating poor quality object texture. The intensity of the light caustics depends on the slope of the sun angle, the water turbidity and the depth, but after a few meters the effect gradually decreases. In underwater environments, especially in deep places, it is necessary to use artificial light sources such as electronic flashes. Because it is argued that both the colors can be reflected as they are and the clarity caused by the limited viewing angle can be compensated (Menna et al., 2016; Menna et al., 2016). Various particles such as phytoplankton, organic substances, and pollution suspended in the water cause the water to become cloudy, and light is scattered in the water for these reasons. Scattering, or diffuse reflection, occurs due to the random deflection of light from its direction. Scattering; it limits the view quality, lowers the contrast and causes blurry images.

The second factor affecting underwater photogrammetry is the clarity of the water (Köseoğlu and Kocaman, 2018). It is advised to measure in the early morning or late afternoon to avoid reflection of sunlight from the water surface and the research object (in areas with shallower depths) (Agrafiotis et al., 2018). Shooting distance also varies depending on viewing conditions. Insufficient water transparency decrease the contrast of the image. This need the camera to be closer to the subject when taking pictures (Drap et al., 2007; Gambin et al., 2021).

The third factor affecting underwater photogrammetry is the refraction of light. In most underwater imaging systems, a beam of light travels through water, housing (glass or plastic), and air. Light rays are refracted twice at the air and water interfaces (Taşdemir et al., 2009; Treibitz et al., 2012; Song et al., 2019). The principle of refraction is given in the following equation (1) according to Snell's law:

$$\frac{sin\theta_i}{sin\theta_t} = \frac{n_2}{n_1} \quad (1)$$

Snell's law states that for a light ray, the ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant (Bhattacharjee, 2021). Here n_1 is the scale of refraction of the medium from which the light comes, and n_2 is the scale of refraction of the medium in which the light is refracted. In addition, $\theta_i$and θ_t are the angles of the incident and refracted ray with the normal, respectively.

The light beam is refracted as it passes through various mediums (water, glass, air). This causes a refractive error that must be taken into account in the calibration process. Two solutions have been proposed for this problem. The first solution is to use a modified linearity model with geometric interpretation of light in multimedia (camera housing - water). The second solution requires the use of standard system calibration software, including a camera and a waterproof housing device. (Telem and Filin, 2010; Elnashef and Filin, 2019; Kujawa, 2021).

The process of geo-referencing photographs in underwater photogrammetry is a problematic issue because of the more complex logistics underwater than in the air (Yilmaz et al., 2004). Several techniques are used in the literature in the geo-referencing process. In the measurement of small objects, grids made of scaled iron rods are made before the measurement to make the measurement easier and faster. For large areas, depending on the topography of the measured place, grid-shaped strips are drawn in the area to be measured underwater and placed with iron bars at the control points. In order to measure these points accurately and precisely (fixed), these buoys were measured with the help of GPS before placing buoys with varying weights on the surface and starting the measurement. The lengths of the iron rods are subtracted for the depth calculation of the measured points.

2. METHOD

2.1. Data acquisition

In the study, overlay photographs covering the entire study area were taken to create a 3D model with the underwater photogrammetry technique. The photos are in similar weather conditions, the sky is cloudy, the temperature is around 23 °C and the height of the pool is 1.5 meters. For this purpose, the go pro black hero 9 camera was used to collect the photographic data of the underwater location (Figure 1). The technical information of the camera used in the study is shown in table 1.

Figure 1. Go Pro Hero Black 9 camera and housing

Table 1. Technical specifications of the Go Pro Hero Black 9 camera

Technicial Specifications	Value
Sensor	CMOS Sensor
Sensor Resolution	23,6 MP
Media Recording	1 x microSD / HC / XC (256 GB Maksimum)
Still Image Support	JPEG - 20 MP
Audio format	WAV
Display type	LCD
Dimension	5.7 cm / 2.27 inç
Secondary Display	Front: Live View Monitor
Shutter speed	1/25 - 1/2000 second (photografy)
Photo ISO Range	100 - 6400
Video ISO Range	100 - 6400
Burst Photo	30 Photos / 3 Seconds
Image stabilization	Digital
Waterproof Depth	33.0 '/ 10.0 m (camera)
White Balance Modes	Oto
Built-in Microphone	Yes
Built-in speaker	Yes
Wireless Internet	Yes
Battery	Rechargeable Battery Pack, 1720 mAh
Charging Method	USB
Weight	5,6 oz / 158 g

Care has been taken to take the photographs with an overlay so that they can see the object from different angles.

During the photo shoot, attention was paid to ensure that each control point marked around the object in the appropriate number and angle for the production of the 3D model of the work with high resolution and accuracy is visible and selectable in three photographs. The number of photos varies according to the size of the model to be made 3D model. In the study, 80 overlay photographs were taken.

2.2. Data processing

Context Capture software was preferred for photogrammetric evaluation and creating the 3D model of the object.

The intersection points of the ceramics around the placed object were used for the detail points in the photographs taken (Figure 2).

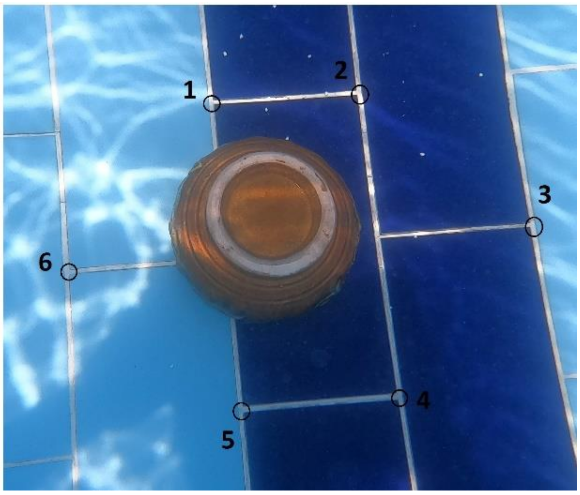

Figure 2. Tie point

3. RESULTS

First, the photographs were loaded into the software and the alignment process was performed. Then, the detail points are marked in the photos to create an accurate and precise model. Finally, dense point cloud and mesh were produced (Figure 3 and Figure 4).

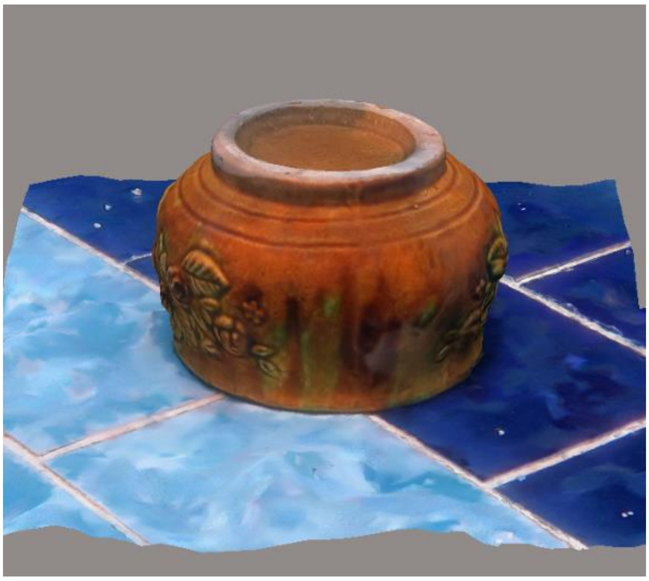

Figure 3. The resulting dense point clouds.

Figure 4. The resulting mesh.

The mean square error of the created model is ±1 cm.

However, when the positions of the point clouds are examined, even though the shape and details of the model provide a meaningful unification, there are fluctuations in the ceramics around the model. As can be seen in Figure 5, while the junction values of the model were 0.00097 cm, its circumference increased up to 0.14157 cm values. There are two reasons for this situation. The positions of the ceramics may be deviated due to the object-oriented shooting during the first photo shoot. Secondly, due to taking underwater photos, it was concluded that the waves were effective even if they were mild.

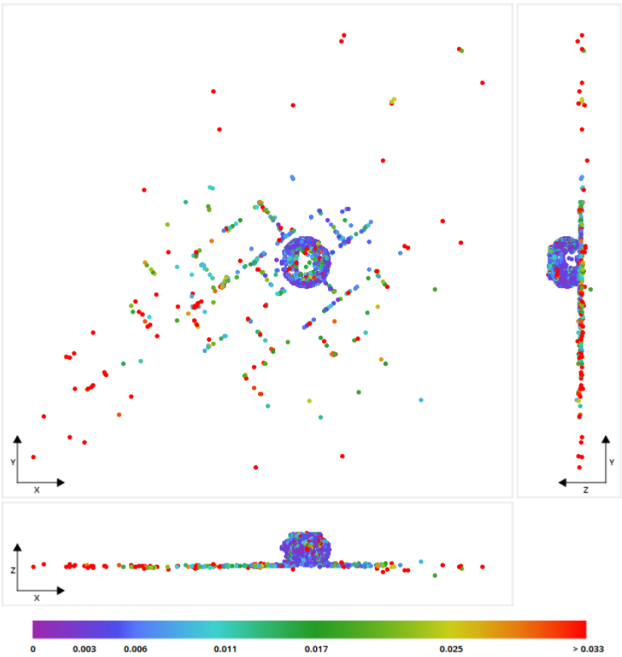

Figure 5. Top view (XY plane), side view (ZY plane) and front view (XZ plane) displays of all tie points

4. DISCUSSION and CONCLUSION

In this article, the processing stages of the photographs obtained in the underwater environment are presented. Photograph taken at shallow depth and under good environmental conditions (no water turbidity and good lighting conditions). However, in 10 of the photographs taken, caustics occurred in the images due to fluctuations. These photos were not used in merging.

The mean square error of the research model was ±1 cm, and it was seen that it provided convenience in terms of obtaining the data. The software used was quite effective in giving a detailed and realistic image. When the 3D point cloud and mesh model of the research model are examined, the details of the patterns on the model are given clearly.

This shows that underwater photogrammetry can be used in cultural heritage documentation. The presented research model validates the use of underwater cameras in photogrammetry. It can be seen as a new beginning for more professional research in the context of underwater photogrammetry.

Author contributions

The contributions of the authors to this article are equal.

Conflicts of interest

The authors declare no conflicts of interest.

Statement of Research and Publication Ethics

The authors declare that this study complies with Research and Publication Ethics

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