Underwater Image Mosaic of AUV System Using Photogrammetry

Kim C.W.[1], Ko H.W.[1], Lim P.C.[1], Yoon W.S.[1] and Kim T.J.[2*]

[1]Image Eng. Research Centre: Associate Research Engineer, 3DLabs Co. Ltd, Republic of Korea

[2*]Department of Geoinformatic Engineering: Professor, Inha University, Republic of Korea

*tezid@inha.ac.kr

1. INTRODUCTION

Most accidents that occur in the ocean are inaccessible to humans. In particular, strong currents often make underwater exploration impossible, which has led to an increasing use of unmanned vehicles. The most commonly used unmanned systems are unmanned aerial vehicles (UAVs), which are generally employed for surface exploration. Through previous research, we have studied various mosaic algorithms for remote exploration using photogrammetry-based sensor modeling of UAVs. Mosaic images captured by optical cameras can be effectively used for remote exploration. However, UAVs cannot operate in underwater environments, so autonomous underwater vehicles (AUVs) are typically used for underwater exploration. While AUVs have traditionally relied on side-scan sonar for exploration, recent studies indicate a growing interest in equipping them with optical cameras. In this study, we aim to generate an underwater mosaic using optical images and investigate whether our traditional photogrammetry methods can be applied to underwater environments.

2. MATERIALS AND METHODS

The video data used in study were captured along the coast of Spain at a rate of 15 frames per second. We extracted frame images at a rate of 1 frame per second to maintain an overlap ratio of 60 to 70 percent and matched exterior orientation parameters (EOPs) acquired from onboard sensors. An AUV~~s~~ explored the underwater at a depth of approximately 17 meters and provided position data using NED coordinates (North, East, Depth). This data was then converted from NED to UTM (Universal Transverse Mercator) 31N coordinates. The AUV's angles were provided in the formats for roll, pitch, and heading. These angles were then converted to omega, phi, and kappa for photogrammetric processing. We acquired a total of 305 images for 3 strips, excluding the intervals where the AUVs were rotating. Table 1 shows used dataset for image mosaic. We expected that the accuracy of the initial EOPs was quite low due to the underwater environment, so bundle adjustment was necessary to get rid of initial error in EOPs. We propose a method for performing traditional photogrammetry-based bundle adjustments.

Table 1: The used dataset for image mosaic.

Strips	Name of images	Number of images
1	Frame 00000 – 00095.jpg	96 images
2	Frame 00170 – 00273.jpg	104 images
3	Frame 00396 – 00500.jpg	105 images

2.1 Extraction of tie points

Corresponding points are extracted between adjacent frame images. We select only the tie points that correspond across three adjacent frame images. By using triple tie points, it is possible to eliminate mismatched points, thereby enhancing the effectiveness of the bundle adjustment. We can also estimate the X,Y, and Z positions of triple tie points through the bundle adjustment. The positions of all images in the same strip are used as input data for strip bundle adjustment. To achieve higher adjustment accuracy, a sampling method is applied by dividing the images at regular intervals, ensuring that each region contains a minimum number of tie points.

2.2 Strip bundle adjustment

Strip bundle adjustment is performed using the extracted triple tie points. A re-weighted least squares estimation method is used to adjust the initial EOPs. This method assigns higher weights to more reliable data and adjusts these weights based on the covariance calculated in each iteration. In our study, we consider that the accuracy of initial EOPs to be quite low, so we assign a low initial weight to EOPs to allow for more dramatic adjustments. The initial EOPs adjusted and coordinates of the triple tie points are adjusted by including the parameters in the observation equation. Through this method, we adjust the unstable initial EOPs and the positions of triple tie points, and use the adjusted values to generate the underwater mosaic image.

2.3 Mosaic image generation

A mosaic image is generated using the adjusted EOPs. It is created by applying the direct georeferencing method with the established sensor model equation. An alpha-blending method is used to eliminate any misalignment in the overlapping areas of the images. The position data of the triple tie points are used to generate the mosaic image instead of the digital surface model.

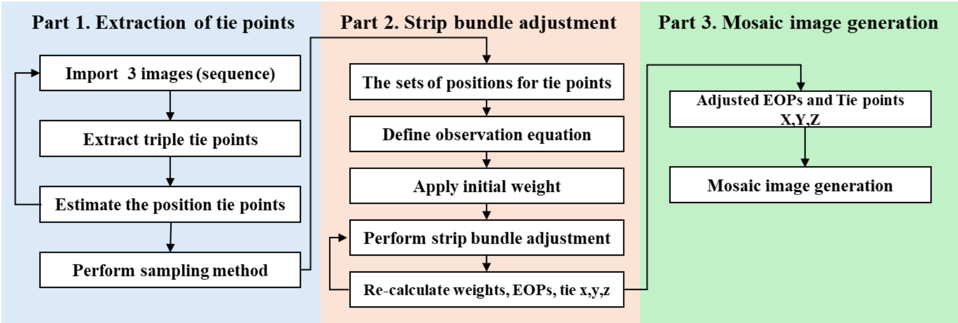

Figure 1: Process of generating a mosaic image.

3. RESULTS

Figure 2 shows sections of the mosaic image before and after bundle adjustment for each strip. In the images before bundle adjustment (Figure 2: (a), (c), (e)), the instability of the initial EOPs can be indirectly recognized by the gaps between images, where the same object appears multiple times. On the other hand, as shown in Figure 2: (b), (d), (f), we confirmed that these gaps were effectively removed in each image after bundle adjustment. Table 3 demonstrates that the change in EOPs after bundle adjustment was quite substantial compared to the initial EOPs, further confirming the instability of the initial EOPs. In particular, variability was observed in the z-height and roll values across all strips, suggesting that the AUVs exhibited a movement pattern consistent with ascending motion. Each strip converged for all images within 6 loops, and the number of tie points used is shown in Table 2.

Table 2: The number of tie points, loop, and convergence images.

Strips	The number of tie points	Loop	Convergence
1	46450(1443)	6	96/96
2	35447(1331)	6	104/104
3	46617(1571)	6	105/105

Table 3: The changes in EOPs after bundle adjustment.

Strips	**ΔX(m)**	**ΔY(m)**	**ΔZ(m)**	$\Delta\omega$(deg)	$\Delta\rho$(deg)	$\Delta\kappa$(deg)
1	0.720	1.547	8.295	16.285645	4.426492	1.819487
2	1.360	1.905	8.229	18.417205	5.844204	2.664072
3	0.629	1.621	8.328	15.345954	3.906709	1.631446

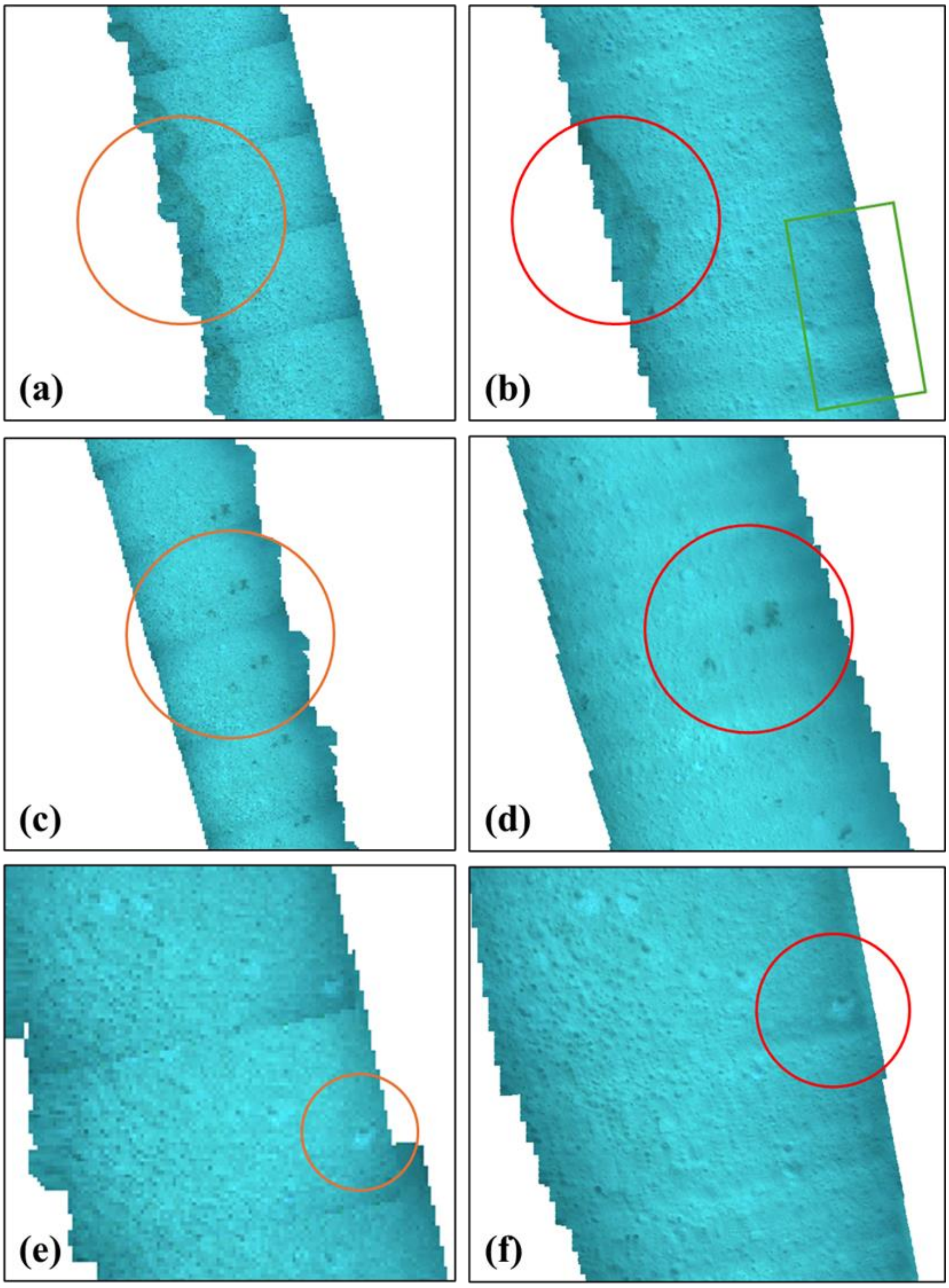

Figure 2: Comparison of mosaic images (each line represents strip 1, 2, or 3). (a), (c), (e) before bundle adjustment, (b), (d), (f) after bundle adjustment.

4. CONCLUSION

Through this study, we confirmed several key findings. Firstly, traditional photogrammetry methods were applicable in underwater environments. While previous research primarily focused on UAV platforms, our study suggested that photogrammetry-based image mosaicking could be extended to various fields. We also identified limitations in underwater environments. Although mosaic images were generated, errors persisted in some areas. In featureless environments like underwater settings, extracting corresponding points was challenging, and cumulative errors could affect estimates. The z-values and deviations in Table 3 are attributed to these errors. Vignetting effects, causing shadows at image edges, were observed in Figure 2(b), impacting tie point extraction crucial for bundle adjustment. Additionally, lens distortion and turbidity presented challenges for optical cameras in underwater settings. Despite this, the study confirms the potential for optical cameras in such environments. Future research will focus on analyzing these error factors and developing methods to adjust for vignetting effects.

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