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Consistent Image Registration for Multi-view Focus Bracketing in Micro-Scale Photogrammetry

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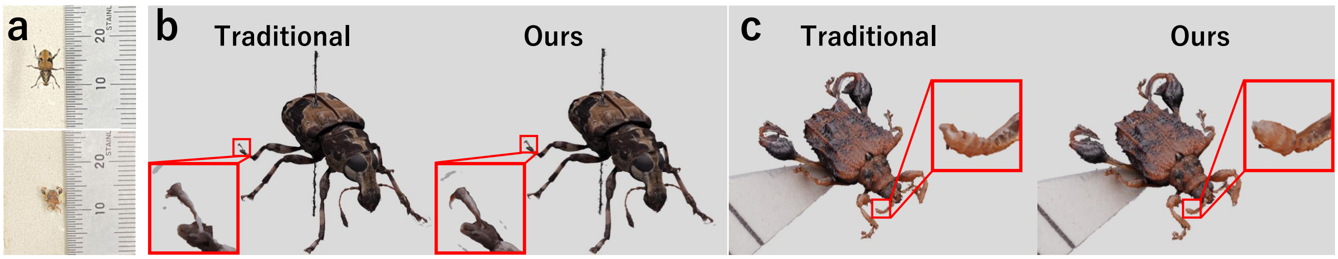

Figure 1: We measure specimens of Tropideres roelofsi (a, top) and Dinorhopala takahashii (a, bottom) to reconstruct their 3D models (b, c). Each of (b, c) presents 3D models reconstructed with a traditional method (left) and our method (right).

CCS CONCEPTS

• **Computing methodologies** → **Image processing**; **Shape modeling**.

KEYWORDS

photogrammetry, 3D modeling, focus bracketing, focus stacking, image registration, microscopic measurement

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1 INTRODUCTION

Insect specimens have been important targets for image-based 3D reconstruction [Gallo et al. 2014; Nguyen et al. 2014; Qiu et al. 2019], because digital formats offer various benefits, such as preservation, compact storage, and easy accessibility. When reconstructing small specimens requiring a macro lens with a shallow depth of field (DoF), focus bracketing and focus stacking are commonly applied. Focus bracketing involves capturing a sequence of photographs by varying the focus distance. Focus stacking then merges these photographs into a single image with an extended DoF.

The typical procedure for reconstructing small specimens involves: (i) conducting focus bracketing from various viewpoints, (ii) registering sequential photographs taken at each viewpoint independently, (iii) performing focus stacking, and (iv) employing structure from motion (SfM) on the focus stacking images from all viewpoints to derive a 3D shape. Notably, during focus bracketing, the field of view (FoV) changes as the focus distance changes, necessitating registration (ii). Traditional methods perform registration independently for each viewpoint using feature points within the photographs, leading to inconsistent registration across viewpoints and affecting reconstruction accuracy.

This study proposes a method for consistent registration across all viewpoints. Initially, we compute a registration parameter from sequential photographs of a calibration checkerboard and then apply this parameter to all viewpoints. A comparison between traditional and our methods, using multi-viewpoint focus stacking images synthesized by a renderer, reveals that our method achieves higher accuracy. To demonstrate the feasibility of our approach, we reconstruct 3D models of small insect specimens (Fig. 1).

2 METHOD

We conduct multi-viewpoint focus bracketing on a specimen using a turntable and a digital camera (Fig. 2a, b). For this study, we utilize the OLYMPUS OM-D E-M1 Mark II, equipped with an automatic focus bracketing function, and the M.ZUIKO DIGITAL ED 90mm F3.5 Macro IS PRO lens. The step size of focus distance for bracketing remains fixed across all viewpoints. After capturing the specimen, we perform focus bracketing on a checkerboard tilted approximately 30°, with cell size of 0.5 mm (Fig. 2c, d).

Given sequential photographs of the checkerboard, $I_0, I_1, ..., I_{N-1}$, we compute their registration parameters assuming a perspective projection model where changes in focus distance cause FoV variation. As focus bracketing moves the focus distance from front to

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back, the in-focus area shifts from the bottom to the top of the image space (Fig. 2d). We first extract the central height of the in-focus area y_i^* of I_i by applying a Laplacian filter to I_i, accumulating absolute Laplacian values in the horizontal direction (x-axis), and identifying the height maximizing the accumulated value (Fig. 2e). Subsequently, we calculate the scaling value s_i and translation offsets (t_i^x, t_i^y) aligning adjacent photographs I_i and I_{i+1} as,

$$\underset{s_i, t_i^x, t_i^y}{\arg\min} \sum_{\mathbf{p} \in \omega_{i,i+i}} ||I_i(\mathbf{p}') - I_{i+1}(\mathbf{p})||^2, \quad (1)$$

$$\mathbf{p}' = \begin{pmatrix} s_i & 0 & W/2 \cdot (1 - s_i) + t_i^x \\ 0 & s_i & H/2 \cdot (1 - s_i) + t_i^y \end{pmatrix} \begin{pmatrix} p_x \\ p_y \\ 1 \end{pmatrix}, \quad (2)$$

where W and H denote the width and height of the photographs, and $\omega_{i,i+i}$ represents the in-focus area of I_i and I_{i+1} defined as $(p_x, p_y) \in [500, W - 500] \times [y^* - 100, y^* + 100]$, where $y^* = \frac{y_i^* + y_{i+1}^*}{2}$. We utilize gradient descent to solve this optimization.

Given the registration parameter, we apply it to register all viewpoints. Finally, we compute a focus stacking image at each viewpoint and perform photogrammetry using the focus stacking images from all viewpoints to obtain a shape model of the specimen. Focus stacking is computed using commercial software, Helicon Focus, and photogrammetry via Agisoft Metashape.

3 RESULTS AND DISCUSSION

To evaluate the accuracy of our method, we employed a renderer, Cycles, to generate focus bracketing photographs of a checkerboard by simulating shallow DoF. Additionally, we created focus bracketing images of a Stanford bunny from 36 viewpoints and produced all-in-focus images at each viewpoint by setting DoF to infinite. As achieving a perfect all-in-focus image with a real-world camera is difficult, we opted for computer graphics techniques. Subsequently, we evaluated the accuracy of focus stacking images computed by our and a traditional methods. While our method performed consistent registration and computed focus stacking using Helicon Focus, the traditional method computed both registration and focus stacking at each viewpoint independently using Helicon Focus.

Figure 3 summarizes the accuracy of the two methods across 36 viewpoints. Our method consistently outperformed the traditional method at all viewpoints. Leveraging registration parameters from the checkerboard facilitated consistent registration in our method, resulting in focus-stacking images closer to the ground truth.

To demonstrate the feasibility of our method, we measured two specimens, namely Tropideres roelofsi and Dinorhopala takahashii. We conducted focus bracketing at 72 viewpoints, with a 5° rotation angle variation. At each viewpoint, we captured 30 photographs with varying focus distances. Subsequently, we reconstructed 3D models using both our and traditional methods (Fig. 1). The resulting models revealed that the traditional method failed to reconstruct intricate structures such as insect claws and antennae. Independent registration at each viewpoint in the traditional method led to variations in registration parameters and subsequent errors in SfM alignment. In contrast, our method successfully reconstructed detailed structures by ensuring consistent registration, thus achieving more precise alignment in SfM and accurate reconstruction.

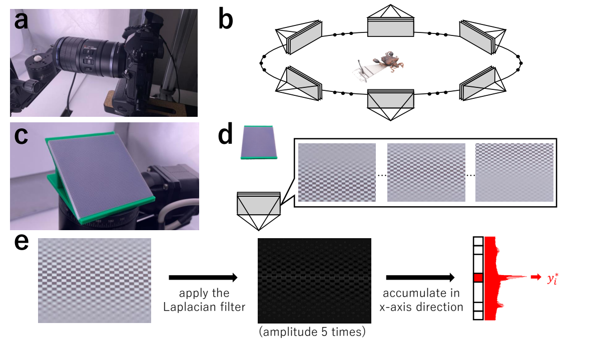

Figure 2: We use a turntable and a digital camera (a) for multi-viewpoint focus bracketing (b). We perform focus bracketing on the calibration checkerboard (c) to obtain sequential photographs (d). We accumulate absolute Laplacian in the horizontal direction (e) for extracting the in-focus area.

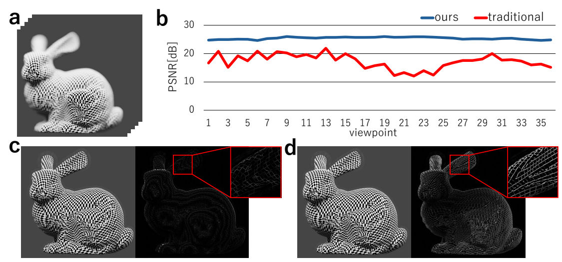

Figure 3: We simulated multi-viewpoint focus bracketing using Cycles (a) and evaluated the focus stacking images generated by our method (c) and the traditional method (d). The images on the right side of (c) and (d) represent differences from the ground truth. A summary of PSNR for all viewpoints is presented in (b).

In summary, we have introduced a consistent registration method for multi-viewpoint focus bracketing photography to facilitate accurate 3D reconstruction. Evaluation using both artificial and actual measurement datasets demonstrated that our method achieved higher accuracy than the traditional approach. Our future work involves applying our method to various 3D reconstruction techniques, including NeRF and Gaussian splatting, and dealing with even smaller specimens.

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REFERENCES

A. Gallo, M. Muzzupappa, and F. Bruno. 2014. 3D reconstruction of small sized objects from a sequence of multi-focused images. *Journal of Cultural Heritage* 15, 2 (2014), 173–182.

C. V. Nguyen, D. R. Lovell, M. Adcock, and J. La Salle. 2014. Capturing Natural-Colour 3D Models of Insects for Species Discovery and Diagnostics. *PLOS ONE* 9 (04 2014), 1–11. https://doi.org/10.1371/journal.pone.0094346

Y. Qiu, D. Inagaki, K. Kohiyama, H. Tanaka, and T. Ijiri. 2019. Focus stacking by multi-viewpoint focus bracketing. *SIGGRAPH ASIA 2019, posters* (2019).