Focus stacking by multi-viewpoint focus bracketing

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ABSTRACT

We present an approach to obtain high-quality focus-stacking images. The key idea is to integrate the multi-view structure-from-motion (SfM) algorithm with the focus-stacking process; we carry out focus-bracketing shooting at multiple viewpoints, generate depth maps for all viewpoints by using the SfM algorithm, and compute focus stacking using the depth maps and local sharpness. By using the depth-maps, we successfully achieve focus-stacking results with less artifacts around object boundaries and without halo-artifacts, which was difficult to avoid by using the previous sharpest pixel and pyramid approaches. To illustrate the feasibility of our approach, we performed focus stacking of small objects such as insects and flowers.

CCS CONCEPTS

• **Computing methodologies** → **Image processing**.

KEYWORDS

Focus stacking, focus bracketing, structure from motion.

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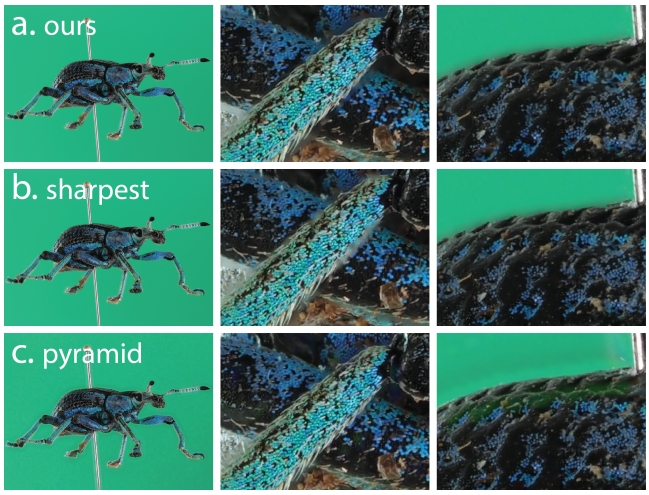

Figure 1: Focus-stacking images generated with (a) our approach, (b) sharpest pixel, and (c) pyramid. In (a), we captured multi-focus-sets at 9 viewpoints.

1 INTRODUCTION

Focus stacking is an image-processing technique that integrates multiple photographs taken with different focus distances into one photograph with a greater depth of field. Some recently available consumer-grade cameras support automatic *focus bracketing*, that takes multiple photographs with varying focuses in a short time, and subsequent focus stacking. Focus stacking is especially useful when taking photographs of small objects, such as insects and flowers, because such objects often require the use of a macro lens with a shallow depth of field.

Existing focus-stacking approaches can be roughly divided into two groups, sharpest pixel and pyramid [Wang and Chang 2011] approaches. Given a set of photographs taken at the same viewpoint and with different focus distances, which we call a multi-focus-set, both approaches first deform all photographs so that the content is aligned pixel-by-pixel. After the alignment, the sharpest-pixel approach selects the source photograph for each pixel of the output image. This approach uses local sharpness, e.g., contrast, as the selection metric. However, this approach often fails to select correct photograph, causing artifacts around the object boundary. As in Figure 1b, the boundary of the insect leg is greatly blurred. Given a multi-focus-set, the pyramid approach computes Laplacian pyramids of all the input photographs, performs maximum intensity projection at each pyramid level to obtain a fused pyramid, then generates the final image by inverse Laplacian pyramid transform. However, this approach often causes halo-artifacts around strong edges. As in Figure 1c right, green color of the background is mixed to the foreground.

This study presents a novel focus-stacking approach that uses depth maps computed from multi-view images. We carry out focus-bracketing shooting at different viewpoints to obtain multiple multi-focus-sets. We then compute a depth map for each viewpoint by adopting the structure from motion (SfM) algorithm. We then select source photographs by considering both the depth maps and local sharpness. By using the depth maps computed using the SfM algorithm, our approach achieves high-quality focus-stacking results with less artifacts around object boundaries (Figure 1a). To illustrate the feasibility of our approach, we provide focus-stacking results for small targets, such as insects and flowers. We also argue that our approach is useful for 3D digitization.

2 OUR APPROACH

Our approach consists of the following four steps.

Step 1. Focus bracketing and alignment. Focus-bracketing shooting is carried out at different viewpoints to obtain multiple multi-focus-sets. After that, we deform the photographs in each set

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