Deep Depth from Aberration Map

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1. Introduction

In recent years, image sensing has become increasingly important in many sectors: robots moving objects, autonomous vehicles; remote-controlled inspecting infrastructure, and more. Stereo cameras are widely used as a means of achieving image-based distance measurement [1]. However, it is difficult to reduce the size of stereo camera systems incorporating two cameras. For the single-shot approach, deep monocular depth estimation (DMDE) [2] which is deep-learning approach based on semantic learning, is mainly proposed. However, it is limited to an image with sufficient contextual information. In particular, the simultaneous pursuit of high robustness, low cost, and high depth accuracy are challenging requirement for realizing production. In this paper, we present a single-shot depth measurement method utilizing an off-the-shelf camera lens aberration [3] (Fig.1) with deep learning approach. We demonstrate that our method outperforms a conventional method in qualitative evaluation, including outdoor scenes.

2. Method

Depth from defocus (DfD) method is a passive depth estimation based on modeling a bokeh radius. The bokeh radius b is derived from the lens-maker's formula,

$$b = (av_f / 2p)\,|1/f - 1/u - 1/v_f| \qquad (1)$$

where u, a = f/F, f, F, p and v_f are an object's distance, a diameter of the lens aperture, a focal length, an aperture number, a sensor pitch and a distance between the lens and the image sensor, respectively. Although the depth cue is physically given as bokeh, the depth still has the ambiguity of near or far side of the focal plane, because there is same bokeh radius in both planes. To solve this ambiguity, we focus on lens aberrations (mainly chromatic aberration) which are hard to be suppressed perfectly. We first measure point spread function (PSF) with a digital single lens reflex (DSLR) camera (Nikon D810) with a f=50mm lens and set aperture F= 4 to analyze characteristics of bokeh. We found that a shape of PSF has the distance and a position dependence of the image. We named this characteristics Aberration map (A-Map). We also developed neural network (AMA-Net) because the shape of PSF is too complicated to model mathematically. AMA-Net learns position and color data separately to properly perceive changes in bokeh shape. Moreover, we adopted patch-based architecture learning method in order to analyze bokeh feature efficiently. Through learning, the network is then updated to reduce any error between the estimated distance and actual distance.

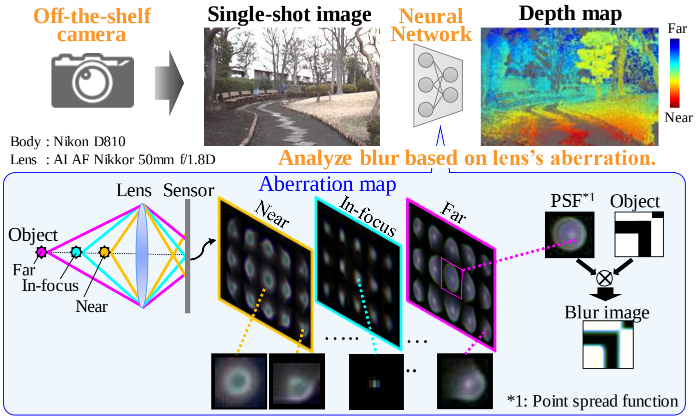

Fig.1 Overview

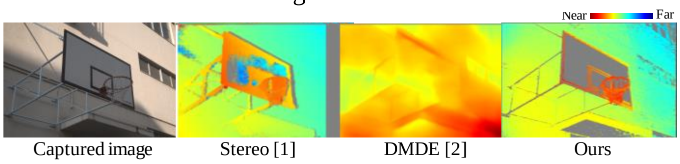

Fig.2 Depth estimation result

3. Results

Fig.2 shows the qualitative results on an outdoor scene which has not been learned by any method. Red to blue color gradation indicate near to far, and gray indicates no depth cues due to lack of texture. We compared with the stereo and DMDE methods. The stereo method composed of two cameras with 250mm baseline. The stereo method shows that depth can be accurately estimated, however, errors often occurred with occlusions. The result of DMDE shows large depth errors if there is no ground or sky. In contrast, our method achieved accurate depth maps for the failure cases of both methods.

4. Conclusions

We have presented a novel method for passive single-shot depth measurement using only an off-the-shelf camera without customization or additional supportive devices. We have verified that A-Map, which contains various types of aberrations and distance information, can be utilized as a depth cue. We demonstrated the effectiveness of A-Map for depth measurement through experimental analysis. The results of the experiment support this approach's achievement of highly accurate depth measurement and highly robust performance.

References

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