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Optimal depth estimation by combining focus measures using genetic programming

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ABSTRACT

Three-dimensional (3D) shape reconstruction is a fundamental problem in machine vision applications. Shape From Focus (SFF) is one of the passive optical methods for 3D shape recovery that uses degree of focus as a cue to estimate 3D shape. In this approach, usually a single focus measure operator is applied to measure the focus quality of each pixel in the image sequence. However, the applicability of a single focus measure is limited to estimate accurately the depth map for diverse type of real objects. To address this problem, we develop Optimal Composite Depth (OCD) function through genetic programming (GP) for accurate depth estimation. The OCD function is constructed by optimally combining the primary information extracted using one/or more focus measures. The genetically developed composite function is then used to compute the optimal depth map of objects. The performance of the developed nonlinear function is investigated using both the synthetic and the real world image sequences. Experimental results demonstrate that the proposed estimator is more useful in computing accurate depth maps as compared to the existing SFF methods. Moreover, it is found that the heterogeneous function is more effective than homogeneous function.

1. Introduction

Estimating three-dimensional (3D) shape of an object from its two-dimensional (2D) images is a fundamental problem in computer vision [1,28,39]. Broadly, 3D shape recovery algorithms based on the optical reflective model can be categorized into active and passive techniques. In active techniques, light rays are projected whereas, in passive methods, simply the reflection of light rays is captured without any projection. The Shape From Focus (SFF) is one of the passive methods, to estimate 3D structure of the object, based on the image focus analysis. It is a famous one in the paradigm of shape from X, where X denotes the cue used to infer the shape as stereo, motion, shading, de-focus, and focus. The SFF technique has been successfully utilized in many industrial applications, i.e. microelectronics [29], industrial inspection [33], medical diagnostics [5], 3D cameras [23], TFT–LCD color filter manufacturing [2], and comparison of polymers [26].

In SFF techniques, an image sequence is acquired by translating object along the optical axis. It is important to note that acquired images from lenses with limited depth of field have both the areas in and out of focus. However, it is possible to compute the well-focused image from the image sequence taken at different focus levels by computing the high frequency image contents. A criterion, usually known as focus measure, is used to compute the focus quality of each pixel in the image sequence and a focus volume is obtained. An initial depth map is extracted from the focus volume by maximizing the focus

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measure along the optical axis. In the literature, many focus measure operators are reported in spatial [10,16,36] and transform domains [18,19,25,37,42]. Once an initial depth map is computed, an approximation technique is applied to further refine these results [24,28,35]. Most of these techniques use a single focus measure to estimate the initial depth map. Due to the diverse nature of real images, it is difficult for a single focus measure to perform equally well under different scenarios. Moreover, it is hard to select a suitable focus measure for specific conditions. Another drawback with existing techniques is the error introduced in computing initial depth map also propagates to the approximation step. This demands to develop a new generalized optimal depth estimator that can effectively incorporate useful information from more than one focus measures.

In this work, we propose a novel idea of combining the initial depth and focus values extracted from various focus measures. Using this concept, the advantages of one focus measure can overcome the shortcomings of other focus measures. However, the problem is how to combine them in a best possible way. Under such circumstances, we introduce genetic programming (GP) based technique that optimally combines the initial information extracted from one or more focus measures. GP approach works on the principles of natural selection and recombination to search the space for possible solutions under a fitness criterion. Due to the flexibility of adjustable parameters, GP optimization technique [8,13,14,17,27] is widely used in the applications of image processing [31], pattern recognition [21], and computer vision [22]. In the proposed scheme, GP based Optimal Composite Depth (OCD) functions are developed using homogeneous and heterogeneous feature sets. In the first step, features consisting of initial focus and depth values are computed through existing focus measures. The useful feature information and the random constants are combined through arithmetic operators to develop the OCD function. The composite function is then used to compute the optimal depth map. The improved performance of the developed function is investigated using the synthetic and the real images. Experimental results demonstrate the superiority of the proposed GP based scheme over the conventional focus measures.

In the remainder of the paper, Section 2 describes the SFF scheme and presents a summary of existing focus measures and approximation techniques. Section 3 describes the effect of focus measures on the depth map based on experimental results. Section 4 describes the proposed GP based scheme in detail. Section 5 explains experimental setup and comparative analysis. Finally, Section 6 concludes this study.

2. Background

2.1. Shape From Focus

Shape From Focus techniques retrieve the spatial information from multiple images of the same scene taken at different focus levels. In SFF, the objective is to find out the depth by measuring the distance of well-focused position of every object point from the camera lens. Once distances for all points of the object are known, the 3D shape can be recovered. Fig. 1 shows the basic geometry of image formation of focused and de-focused objects through the convex lens. Suppose the lens is stationary and the images are obtained on image plane by translating object along the optical axis. All light rays, which are radiated from the object, are intercepted by the lens and converged at the image plane. A point O on the object is well focused and its image is obtained at point O' on image detector. A well-focused point O satisfies the lens law:

$$\frac{1}{t} = \frac{1}{u} + \frac{1}{v}, \tag{1}$$

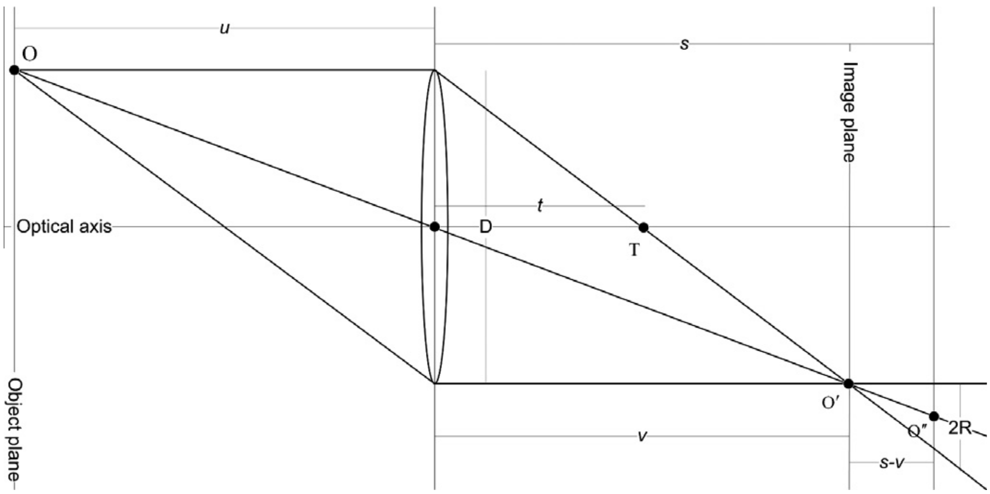

Fig. 1. Image formation in convex lens for focused and de-focused object.