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High resolution image fusion algorithm based on multi-focused region extraction ☆

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ABSTRACT

An efficient way to obtain the high resolution image of a scene is using a line scan camera in the manner of macro photography. Due to the limited depth of field, only some portions of the image are focused. A common solution to this problem is utilizing the multi-focus image fusion technique, in which a series of images with different focus settings is acquired and the images are fused to an all focused one. However, it is difficult to register these high resolution images. Firstly, the magnifications of different regions of an image are different because of the depths of the scene. Secondly, the accuracy of feature detection in the region out of focus is difficult to ensure. Misregistration of the multi-focus images leads to the misjudgment of focus measures and the failure of image fusion. In this paper, we propose a novel high resolution multi-focus image fusion algorithm to solve this problem. The focused regions of each image are extracted for image registration and fusion, which improves the accuracy of image registration and the quality of image fusion. Experimental results show the proposed method is superior to the traditional methods in terms of both subjective evaluation and objective evaluation.

1. Introduction

High resolution images not only have high definition but also contain rich spectral, texture and shape information. They can be used in many applications such as improving the performance of pattern recognition in computer vision [19] and digital protection of cultural relics [5]. These images are usually obtained by a line scan camera in the manner of macro photography and the optical resolution is usually more than 600 dpi. However, large magnification causes the harsh compression of depth of field, which leads to the image defect that only some regions of the image are in focus.

A common solution to this problem is to acquire several images of a scene with focus on different depths and then fuse them in such a manner that all regions of the scene are in focus [2,3,24]. In the past few years, a number of multi-focus image fusion methods have been developed. These methods are mainly divided into two groups: spatial domain methods and transform domain methods [16]. In spatial domain, focus measures such as Sum of the Modified Laplacian (SML) [17], spatial frequency (SF) [4], etc. are directly applied to the source images to select the best pixels or regions. The major advantages of these methods are the low computational complexity and the image information directly originating from the source images [27]. However, focus measures are sensitive to misregistration [13]. Misregistration leads to the error selection of the best pixels, which degrades the image quality by replacing focused pixels with defocused ones. Some burrs are brought in the fused image, and they severely affect the visual effects. Although various image registration methods have been proposed (a survey can be found in [34]), it is a tough issue to accurately register the multi-focus images of 3D objects. First, the imaging of 3D objects is relevant to depth, which means the magnifying powers of different depths are different. It is difficult to establish the mapping among 2D images without depth information. Second, feature detection is the first basic step of image registration procedure [34]. The feature detection in the region out of focus is difficult to ensure.

In transform domain, Multi-scale transforms (MST) provide another useful manner for image fusion. The idea of MST-based image fusion methods is to integrate the multi-resolution decomposition of each source image into a composite fusion space, and reconstruct the fused image by performing an inverse multi-resolution transform. Common MST-based methods include pyramid transform [25,28], discrete wavelet transform [11,6,18,23,32], complex wavelet transform [26], redundant wavelet transform [15], curvelet transform [14], contourlet transform [31]. Research results show that the MST-based methods possess many

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advantages, including the improved signal-to-noise ratio, the increased fusion quality, etc. [27]. However, MST-based methods are not applicable to high resolution image fusion because they are complicated and time-consuming [7,29]. Furthermore, MST-based methods are also sensitive to misregistration [12,13]. Although some region-based methods [20,26] are proposed to reduce the adverse effect of misregistration, the misregistration on the boundary of regions still affects the image fusion quality.

In this paper, we propose a novel image fusion algorithm which is based on focused region extraction. Different from other methods, our method discards the majority of the defocused regions. The focused regions of each image are extracted for image registration and fusion, which improves the accuracy of image registration and the quality of image fusion.

The paper is organized as follows. The methodology is presented in detail in Section 2, including the imaging system we use and the proposed image fusion algorithm. Then, experimental results and performance evaluation are given to test the effectiveness of the algorithm in Section 3. Finally, conclusion is drawn in Section 4.

2. Methodology

2.1. The imaging system

There are three ways to obtain multi-focus images: moving the sensor, moving the lens and moving the imaging system. We choose the third one because the image distance is fixed. The magnifications of the focused regions in different images can be seen as the same. The schematic diagram of our high resolution imaging system is shown in Fig. 1. The light emitted by the two white line sources is projected onto the surface of the object. The reflected light travels through the lens and enters the line scan camera which converts the optical signal to the electrical signal. Finally, images are acquired by the image grabber and they are saved to the computer.

The line scan camera can only get a line image at a time. In order to obtain a frame image, the imaging system should be moved along the main scanning direction. Once the acquisition of a frame image is over, the imaging system will be moved along the height adjustment direction for a short distance to get the next frame image. The moving distance should be less than the depth of field. The procedure will continue until all images are obtained.

Note that the image distance is fixed in the process of image acquisition and the depth of field is much less than the object distance. The magnifications of the focused regions in all images can be considered as a constant, which provides a shortcut for the registration between the focused regions and the adjacent image. Detailed registration procedure will be shown in Section 2.2.

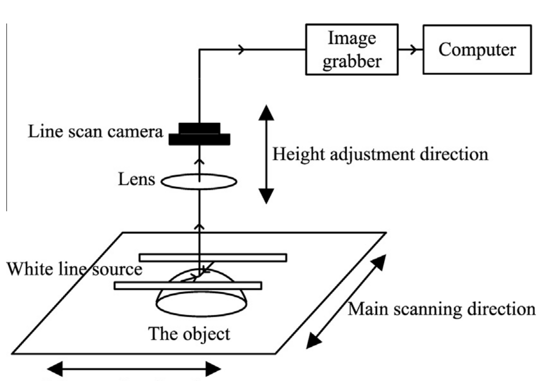

Fig. 1. The schematic diagram of high resolution imaging system.

2.2. The image fusion algorithm

The flow diagram of our image fusion algorithm is shown in Fig. 2. The algorithm consists of four steps: initial registration, focused region extraction, accurate registration, and image fusion.

(a) Initial registration

According to the imaging characteristic of the line scan camera in Fig. 1, we use the following global mapping model for initial registration.

$$\begin{aligned} x' &= ax + t_x \\ y' &= y + t_y \end{aligned} \tag{1}$$

where (x, y) is the coordinate of the pixel in the reference image; (x', y') is the coordinate of the pixel in the target image; a is a parameter for scaling transform; t_x and t_y are parameters for translation transform.

(b) Focused region extraction

After initial registration, a focus measure operator is used to search for the best focused pixels in the sequence of images. Experimental results of Huang and Jing [8] show SML focus measure provides better performance, and we use it as the focus measure in this paper. The best focused pixels are saved to a new sequence of images and other pixels are discarded. However, the new images are defective. The matching error in step (a) can cause the misjudgment of the best focused pixels. Some defocused pixels are introduced and some focused pixels are lost in the new images. To solve this problem, probability filtering is used for further judgment. Set a window on the pixel of the new image and calculate the probability of "the best focused" pixels in the window. If the probability is greater than a threshold, the central pixel will be considered to be the best focused. Our experience shows that 50% is a good threshold and probability filtering can improve the robustness of focus measures to misregistration. Nevertheless, probability filtering is not perfect. A small number of focused pixels are still lost, especially in the misjudgment concentrated area. To recover the lost focused pixels, we expand the focused regions. Region expansion makes focused regions of adjacent images overlapped with each other. The defocused pixels introduced by region expansion will be eliminated in the process of image fusion.

(c) Accurate registration

As shown in Fig. 3, the solid lines show the imaging geometry of focused regions and the dotted lines show the imaging geometry with a moving distance δu. Since the depth of field is much less than the object distance, the magnifying power can be seen as a constant [17]. It can be expressed by:

$$m = \frac{v}{u} \tag{2}$$

where v is the image distance and u is the object distance. With a moving distance δu, the magnifying power becomes:

$$m' = \frac{v}{u - \delta u} \tag{3}$$

A scaling is necessary for the registration between the focused regions and the adjacent image:

$$s = \frac{m'}{m} = \frac{u}{u - \delta u} \tag{4}$$

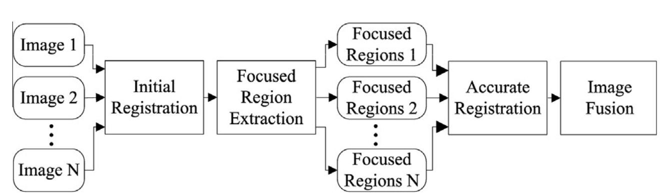

Fig. 2. The flow diagram of the proposed image fusion algorithm.