# Defocus-Invariant Image Registration for Phase-Difference Detection Auto Focusing

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***Abstract*—This paper presents a defocus-invariant image registration method for measuring the shifting value between two differently located patterns in an imaging sensor. Existing registration methods fail with unfocused images since features or regions of interest are degraded by defocus. In order to solve this problem, the proposed method consists of three stages: i) pre-generation of the set of point spread functions (PSFs) estimated in different focusing positions, ii) the geometric transformation estimation using estimated PSF data, and iii) registration using estimated transformation matrix. The proposed method improves out-of-focus degradation through estimation of PSF. For this reason, the proposed method can accurately estimate the difference of phase between two out-of-focus images. Furthermore, it can be applied to phase-difference detection auto focusing, and provide accurate auto focusing performance.**

***Keywords—elastic registration; constrained least square filter; floating values; phase difference detection auto focus***

## I. INTRODUCTION

A phase detection auto focusing system measures the phase difference between two images taken from opposite sides of the lens. The distance between these two images indicates the amount of out of focus, and the relative position of them can predict whether the lens needs to move nearer or further for the right focusing position. The traditional phase detection system was used in only high-end cameras since it needs an additional set of sub-mirrors and auto focus sensors. However, modern phase detection systems embed micro lenses into the imaging sensor to simplify the hardware structure [1]. However, these methods require high computational complexity to guarantee the focusing accuracy.

Image registration-based methods calculate a transformation matrix between two images [2]. Feature-based methods are faster than the registration-based methods because they perform feature-based estimation of the transformation matrix using normalized cross correlation at the cost of feature-mismatch error [3]. Phase correlation-based estimation of a global transformation between two images can easily register two images using the Fourier transform at the cost of difficulty in computation with subpixel precision.

On the other hand, elastic registration can accurately register the images because it estimates the transformation parameters by detecting the edges using the image pyramid, and analyzes detected edges in a global manner [4],[5],[6]. Thus, it has the advantage of the accurate registration of warped images. However, it fails in registering out-of-focus images because they lose important edge information. To overcome this problem, the proposed method first estimates the point spread function (PSF) to restore the out-of-focus images. Next, the transformation parameters are estimated using elastic registration. Because of the restoration process prior to registration, elastic registration can successfully estimate the distance between two input images using the enhanced edge information. For this reason, the proposed method can make fast, accurate auto focusing possible in light-weight, inexpensive consumer imaging devices.

This paper is organized as follows. In section Ⅱ, the PSF estimation-based elastic registration is presented, experimental results are given in section Ⅲ, and section Ⅳ concludes the paper.

## II. POINT SPREAD FUNCTION ESTIMATION-BASED REGISTRATION METHOD

The space invariant out-of-focus image degradation model is defined as

$$g(x,y) = h(x,y) * f(x,y) + \eta(x,y), \tag{1}$$

where $f$ represents an original well-focused image, $h$ the point spread function (PSF), $\eta$ the additive noise, $(x,y)$ the image coordinate, and $g$ the degraded image by out-of-focus blur. There are many restoration methods to estimate $f$ given $g$ and $h$. Instead of using a computationally expensive restoration method, a simple constrained least squares (CLS) restoration filter is used since it is the simplest restoration filter that can successfully reconstruct sharp edges for the accurate registration of two images. The CLS filter is defined as

$$F(u,v) = \left[ \frac{H^*(u,v)}{\left|H(u,v)\right|^2 + \gamma \left|\mathcal{L}(u,v)\right|^2} \right] G(u,v), \tag{2}$$

where $F(u,v)$, $H(u,v)$, and $G(u,v)$ respectively represent the Fourier transforms of $f$, $h$, and $g$, and $\mathcal{L}(u,v)$ the Fourier transform of the Laplacian filter. The regularization parameter $\gamma$ controls the trade-off between noise ampoifiction and sharpness of the restored image.

The transformation matrix is estimated using two restored images using elastic registration originally proposed by Periaswamy at el. [5]. If two input images, the reference and target images, have a phase difference in the same image plane without rotation, the relationship between the two images is defined as

$$f_T(x,y)=f_R(x-m_x,y-m_y)\,, \tag{3}$$

where $f_R$ and $f_T$ respectively represent the reference and target images, and $\begin{bmatrix} m_x & m_y \end{bmatrix}^T$ the shifting vector between two images. The optimum shifting vector minimizes the following error

$$E(m_x,m_y)=\sum_{x,y\in\Omega}\left[\hat{f}_R(x,y)-\hat{f}_T(x+m_x,y+m_y)\right]^2, \tag{4}$$

where $\Omega$ represents the region to be registered, and $\hat{f}_R$ and $\hat{f}_T$ respectively represent the restored reference and target images using the CLS Filter in (2).

Given the optimum shifting vector, the registration is performed by shifting the target image by $-\begin{bmatrix} m_x & m_y \end{bmatrix}^T$. By measuring the intensity variation of two images, the proposed elastic registration method can determine the accuracy of the shifting vector in the sense of a sum of absolute difference (SAD) [7] SADs of registered and unregistered images are respectively computed as

$$SAD_R=\sum_{x,y\in\Omega}\left|\hat{f}_R(x,y)-\hat{f}_T(x+m_x,y+m_y)\right|, \tag{5}$$

and

$$SAD_U=\sum_{x,y\in\Omega}\left|\hat{f}_R(x,y)-\hat{f}_T(x_x,y)\right|. \tag{6}$$

If $SAD_R < SAD_U$, the corresponding shifting vector is considered to be reliable. Otherwise the proposed algorithm restores the reference and target images again using another PSF in the predefined database, and repeats the registration with the reliability test.

## III. Experimental Results

In the experiment, we used a personal computer equipped with a 2.67 GHz CPU and 8 GB RAM. Fig. 1(a) shows the image whose phase difference is +0.4 pixel. Fig. 1(b) to 1(f) show the same images with phase differences are +0.2, 0.0, -0.2, -0.4, and -0.6 pixels, respectively. The registration results with SADs and optimum shifting vectors are given TABLE I.

TABLE I. Estimated SAD values with the optimum shifting vectors.

| Fig. 1 | (a) | (b) | (c) | (d) | (e) | (f) |
|---|---|---|---|---|---|---|
| $SAD_U$ | 1969.07 | 2341.11 | 3750.13 | 1043.71 | 529.39 | 122.19 |
| $SAD_R$ | 60.64 | 39.27 | 577.29 | 259.79 | 174.91 | 59.14 |
| $m_x$ | 1.0874 | 0.8940 | 0.6998 | 0.4908 | 0.2935 | 0.0857 |
| $m_y$ | 1.0963 | 0.9007 | 0.7013 | 0.4983 | 0.2966 | 0.0885 |

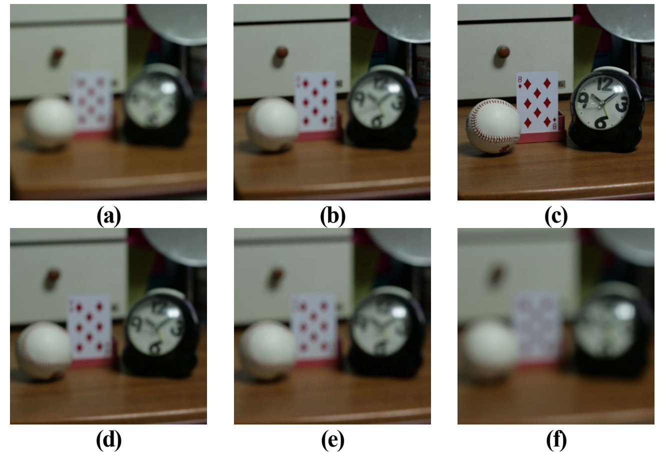

Fig. 1. Images with different phase differences: (a) 1.1 (+0.4) pixels, (b) 0.9 (+0.2 pixels, (c) 0.7 (0.0) pixels, (d) 0.5 (-0.2) pixels, (e) 0.3 (-0.4) pixels, and (f) 0.1 (-0.6) pixels.

## IV. Conclusions

In this paper, a novel image registration method is presented for phase detection auto focus. The proposed method estimates the PSF of the out-of-focus image for restoring the image, and then registers the images. As shown in experiment results, the proposed method can estimate the transformation parameters of the out-of-focus images with subpixel precision. The simple image restoration process can enhance edge information, which results in more accurate registration.


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