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A REVIEW ON IMAGE REGISTRATION TECHNIQUES FOR BLUR REMOVAL

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ABSTRACT

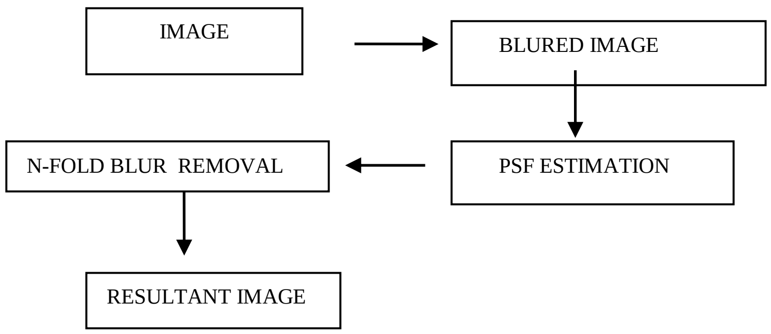
The original method works for unknown blurs, assuming the blurring point-spread function (PSF) exhibits an N-fold rotational symmetry. Here, we also generalize the theory to the case of dihedrally symmetric blurs, which are produced by the PSFs having both rotational and axial symmetriess. Such kind of blurs is often found in unfocused images acquired by digital cameras, as in out-of-focus shots the PSF typically mimics the shape of the shutter aperture. Where blurred image registration must be used as a preprocess step of an image fusion algorithm, and where common registration methods fail, due to the amount of blur. We demonstrate that the proposed method leads to an improvement of the registration performance, and we show its applicability to real images by providing successful examples of blurred image registration followed by depth-of-field extension and multichannel blind deconvolution.

KEYWORDS — Image registration, blurred images, N-fold rotational symmetry, dihedral symmetry, phase correlation.

INTRODUCTION

Registration of two-dimensional (2-D) images acquired from the same scene at different times, from different viewpoints, or different sensors is a fundamental process in image processing. It is needed before further analysis and fusion of the images. Typical applications include image mosaicing, super-resolution, and the fusion of multimodal images in the fields like remote sensing, medicine, and computer vision. Image registration methods can be divided into the feature and area based methods. The former attempts to match the features of salient details of images while the latter attempts to match the whole images, also called template matching. In practical applications, images contain various degradations due to imperfect imaging conditions including blur, which can result from atmospheric turbulence, out-of-focus, or relative motion between the camera and the scene. The out-of-focus PSF's of several common cameras that they not only have N-fold rotational symmetry but they mostly also have axial symmetry with respect to N axes; such "combined" symmetry is in mathematics called dihedral symmetry. We can see the PSF's of three cameras obtained by taking a photo of a single bright point. The shape of the PSF is sometimes apparent even in real scenes. Axial symmetry was not considered at all, although it carries additional information about the PSF. In this system, we extend the theory and the registration method originally proposed to the blurs with dihedral symmetry by defining new dihedral projection operators. We show this extension has a practical impact because we essentially utilize more information about the PSF compared to the pure N-fold rotational assumption, which increases the registration performance particularly in case of noisy images and of a low image overlap.

BLOCK DIAGRAM



A method for translational registration of blurred images. The approach presented in the paper is based on the concept of invariance w.r.t. uniform blur with point-spread functions (PSF) manifesting rotational symmetry. Blur PSFs with rotational symmetries are typically observed in optical systems that are equipped with a shutter made of a certain number of blades arranged circularly around the lens. The idea proposed in this paper is the one of obtaining a blur-invariant representation of the images, and then perform a “phase correlation” between these two representations, in order to estimate the shift between the images. This method is shown to be considerably more robust than other well-known types of blur-robust image registration algorithms, and it is successfully implemented as a pre-processing step for multichannel blind deconvolution. A developing a registration algorithm that is robust to blur w.r.t. to PSFs having both rotational and axial symmetry (dihedral symmetry). Dihedral phase correlation requires two parameters to be known a priori, i.e. the number of blades that compose the shutter, and the orientation of the symmetry axis of the shape of the aperture. Our recent analysis of the out-of-focus PSF’s of several common cameras has shown that they not only have N-fold rotational symmetry but they mostly also have axial symmetry with respect to N axes; such “combined” symmetry is in mathematics called dihedral symmetry. In Fig. 2 we can see the PSF’s of three cameras obtained by taking a photo of a single bright point. The shape of the PSF is sometimes apparent even in real scenes, see Fig. 11 top-right for an example. Axial symmetry was not considered [22] at all, although it carries additional information about the PSF. In this paper, we extend the theory and the registration method [18] to the blurs with dihedral symmetry by defining new dihedral projection operators. We show this extension has a practical impact because we essentially utilize more information about the PSF compared to the pure N-fold rotational assumption, which increases the registration performance particularly in case of noisy images and of a low image overlap.

BLURRED SENSED IMAGE

An observed blurred image g captured with an acquisition device can be mathematically described in the following way suppose f is an ideal “sharp” image, understood as a two-dimensional function f.

$$g(\mathbf{x}) = (f * h)(\mathbf{x} - \Delta) \qquad (1)$$

where h is a two-dimensional convolution kernel. The convolution kernel h mostly depends on the properties of the optical system, and it represents the point-spread function (PSF), which can be intuitively understood as the impulse response of the imaging system. It must be emphasized that Equation (1) is an adequate model to formalize the effect of uniform blur in an image. Mathematical models to describe spatially varying blur however, the generality of such models invariably introduces a wide range of technical difficulties that make it very hard to extend a theory formulated for uniform blur to the case of spatially varying

Fig.1.Referance image and Blurred sensed image

blur Since the observed PSF is directly related to the shape of the aperture described by P, it is possible to deduce that, whenever the aperture function manifests any symmetry (e.g. rotational symmetry and/or axial symmetry)[18], the out-of-focus blur PSF will have exactly the same type of symmetry. Very often, the mechanical design of the diaphragm shutter of ordinary cameras is such that the shutter blades arearranged symmetrically. This contributes to the typical appearance of out-of-focus scenes, where in correspondence of brighter spots, it is possible to discern very clearly the blur PSF with its symmetries (see Figure 2). This kind of symmetry is called N-fold symmetry, since the PSF appears the same as its rotated versions by 2Лj/N radians (j = 1… N). other types of symmetric PSFs, like circularly symmetric PSFs. There are two main reasons that motivate us to study the symmetry properties of PSFs:

1. Symmetric apertures (and symmetric PSFs) are observed very often in images suffering out-of-focus blur.

2. It is relatively easy to construct blur-invariant operators for symmetric PSFs
The derivation of invariants w.r.t. to blur, necessitates the identification of a family of PSFs having the property of closure with respect to the operation of convolution. Many families of symmetric PSFs possess this property: i.e. convolving two symmetric functions of the same kind yields another function with the same type of symmetry.

BLUR COORDINATE EXTRACTION

We have seen that the construction of the blur-invariant registration method is possible thanks to the N-fold symmetry of the PSF. Any extension and generalization to other types of PSF's must be based on studying their symmetric properties; Symmetry in 2D has been traditionally studied in group theory. It is well known that in 2D there exist only two kinds of symmetry groups which are relevant to our problem: cyclic groups CN that contain N-fold rotational symmetry and dihedral groups DN that contain rotation and reflection symmetry [18] see in Fig.2. The relationship between these two symmetries is that if a function shows N-fold rotational symmetry, then it may only have either none or N symmetry axes. On the other hand, having N symmetry axes immediately implies N-fold rotational symmetry. Therefore, DN $\subsetneq$ CN for finite N, and D∞ = C∞. Hence, it is meaningful to deal with registration of images with PSF's having dihedral symmetry, for two reasons – such situation appears frequently in practice, and at the same time is mathematically tractable. Since the group CN has only one generator (elementary rotation R1), while DN has two generators (elementary rotation and reflection), we may expect that in case of dihedral symmetric PSF there exist two times more projections analogous to (2) and the method will double the number of delta-peaks, which should further lead to a more robust fit, especially in such cases when the localization of the peaks is difficult due to noise.

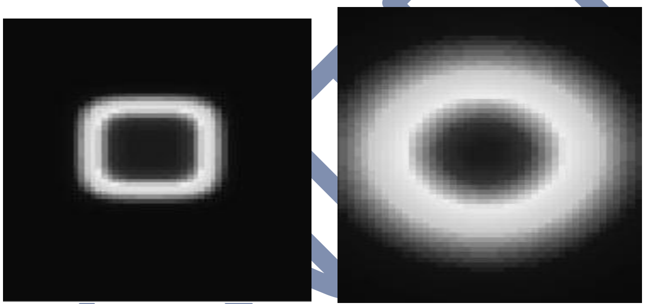


Fig.2.4-Fold Symmetry and 6-Fold Symmetry

For our purpose we use the following invariants to dihedral blur

$$Kj = F\{ f \} / F\{ Rj\, f \} \qquad (2)$$

$$Lj = F\{ f \} / F\{ Rj\, S\, f \} \qquad (3)$$

for j = 1, . . . , N. Note that the invariants Kj are the same as symmetric PSF. while the invariants Lj are new. Now we have 2N invariants, which is a redundant number.

RECOSTRUCTED BLUR IMAGE PSF

The invariants introduced in the previous section will be now used to design a robust blur-invariant registration method. The main idea is that we may consider the invariants to be Fourier transforms of hypothetical non-blurred images, which can be registered by phase correlation. We calculate the normalized cross-power spectra.

$$Cj = \frac{Kj^{(f)}\, Kj^{(g)*}}{|Kj^{(f} |Kj^{(g)}|} \qquad (4)$$

and

$$Bj = \frac{Lj^{(f)} Lj^{(g)*}}{|\, Lj^{(f)}\, Lj^{(g)}|} \qquad (5)$$

for every j = 1, . . . , N.The registration is completed by fitting a circle over all the delta-peaks. The fitting algorithm minimizes the localization error.

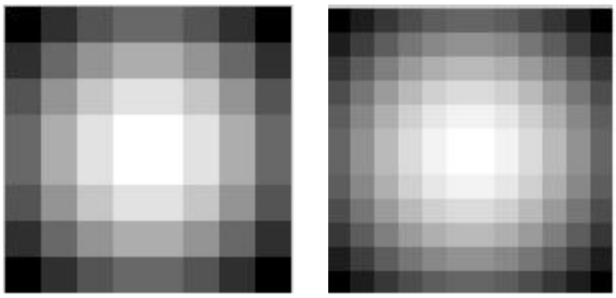


Fig.3. 4-Fold PSF metric and 6-Fold PSF metric

The only difference is that here we fit a double number of peaks (2N instead of N), which generally leads to an improvement. Both N-fold and dihedral peaks. From this it is clear that adding new peaks cannot worsen the fit. This is the main advantage of the presented method. While N is fixed for the particular camera and mostly known in advance, the orientation of the symmetry axis of the PSF depends on the camera rotation and also changes as the aperture opens/closes, so it may not be known a priori. In some cases the axis orientation can be estimated directly from the bright patterns in the blurred image, but in other cases a general estimation algorithm is required. We propose here a simple algorithm to estimate the orientation of one of the symmetry axes of a PSF having dihedral symmetry.

PSF RECONSTRUCTED WITH DEBLUR

The inverse Fourier transform of Cj and Bj yields a shifted delta function

$$F^{-1}\{Cj\}(\mathbf{x}) = \delta(\mathbf{x} + \Delta - R_N - j\Delta) \quad (6)$$

and

$$F^{-1}\{Bj\}(\mathbf{x}) = \delta(\mathbf{x} + \Delta - SR_N - j\Delta) \quad (7)$$

Hence, we can see that F−1{Bj} is also a shifted delta function. All peaks produced by both $F^{-1}\{Cj\}$ and $F^{-1}\{Bj\}$ lie on the same circle, the center of which is at −Δ

Fig.4. Deblured image for 4-Fold and 6-Fold

The distribution of the peaks along the circle is generally not uniform, although within each of the two sets of peaks the peaks are equally spaced. The distance between the peaks from the first and the second set depends not only on N but also on the angle between the shift vector and the symmetry axis of the PSF [22]. In the limit case, the two sets of peaks coincide. We should also mention that while the peaks coming from $F^{-1}\{Cj\}$ could lie anywhere in the plane depending solely on the shift vector, the positions of the peaks generated by $F^{-1}\{Bj\}$ are constrained to lie on straight lines passing through the origin. The parameter N of the blur PSF is generally determined by the mechanical design of the shutter, and it normally coincides with the number of shutter blades, thus it remains fixed for a specific device. N is often known in advance, or at least, easy to obtain by visually inspecting either the shutter or a blurred image where the shape of the PSF manifests itself. However, in some cases, the user might need to estimate N directly from the blurred image. Most of the techniques seen in Section V can be re-used to derive a simple algorithm for the estimation of N.

EXPERIMENTS

See in Fig.5.to Fig.6. Two images reference image and a blurred image where the shape of the PSF manifests itself. However, in some cases, the user might need to estimate N directly from the blurred image. Then converted them to grayscale for simplicity (the algorithm works with color images as well, treating them band by band). For each of these, a corrupted version was artificially created by blurring the original image with a PSF of 31 × 31 pixels, a specified degree N of dihedral symmetry, and random but known symmetry axis. The new dihedral phase correlation and the N-fold phase correlation were used to register them. We evaluated the performance of the methods by counting the number of misregistration.The blur was introduced intentionally by changing the focus settings. In each pair, we changed settings between acquisitions and we also moved the camera slightly, which resulted in differently blurred and mutually shifted images. Assuming the PSF's are close to circular, we chose N = 4 and N=6 and applied the N-fold phase correlation to register the images. In order to demonstrate one of the possible applications of this registration technique, we used the registered images as an input for the multichannel blind-deconvolution algorithm [22]. In both cases, the resulting deblurred images have much better appearance than the blurred inputs, with almost no artifacts, which is an indication that the registration was accurate enough.

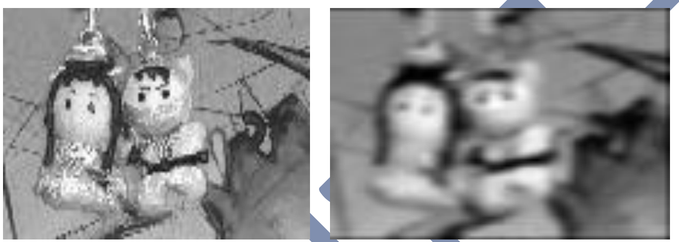


Fig.5. Original image and Blurred image

Fig.6.4-Fold PSF and PSF Reconstructed with Deblur

The registration algorithm has proven sufficient robustness to such deviations from the assumed PSF shape. We tested our method also in real situations, where both blur and noise were introduced by the camera settings and the assumed acquisition model was valid only approximately or locally, and the symmetry of the PSF was not perfectly N-fold. Here we present the results of an experiment, where we took a short video of a static 3D scene by slowly panning the camera. The focus settings were automatically re-adjusted when we changed the place we were pointing at. As in the previous case, the SIFT-based registration failed due to the blur [18]. Then we used the proposed method of dihedral phase correlation to register these two frames images, and although our method is not specifically designed to handle spatially-varying blur, the result of registration was still accurate. Since we do not know the ground truth, we illustrate the accuracy by performing multifocus fusion. The fused product contains only tiny artifacts that are due to the parallax.

CONCLUSION

This thesis presented several contributions in the theory of blur-invariants. First, an algebraic framework to constructively obtain blur-invariants is described. The blur invariant operators that are derived from the framework are complete, and they can be trivially constructed from the knowledge of the type of symmetry of the point-spread functions. In the second part of the thesis, we focused our attention on the problem of blur invariant image registration. The problem of blur-invariant image registration is first reformulated within the group theoretical framework, and afterward it is reinterpreted within a signal processing context Generalizations of our method to handle also rotation and scaling are possible in an analogous way to how it was done in traditional phase correlation [8], i.e. by mapping the FT magnitudes into log-polar domain, in which the rotation and scaling are converted to shifts, and rotational symmetry of the PSF is converted to translational symmetry. One could then define projection operators w.r.t. translational symmetry and proceed analogously to the presented method. However, if the axis orientation is unknown, it must be estimated in advance as in the current version.

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