Invariant-Based Registration of Rotated and Blurred Images

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ABSTRACT

Image registration is a classical problem in remotely sensed image analysis. In this paper, attention is paid to control point matching in case the images are blurred and rotated one another. The matching is performed by means of a new class of moment invariants, which are calculated over the neighborhood of each candidate. The proposed invariants are invariant not only to rotation and translation but also to image blurring by any symmetric point spread function. Thanks to this, we can register blurred images directly without any de-blurring.

INTRODUCTION

Image registration is one of the basic image processing tasks in remote sensing. Image registration is the process of overlaying two or more images of the same scene acquired from different viewpoints, by different sensors and/or at different times so that the pixels of the same coordinates in the images correspond to the same part of the scene. Image registration is required as a pre-processing stage in image fusion, in automatic detection, monitoring and prediction of environmental changes, in GIS data integration and in map updating, among others.

A survey of the recent registration techniques used in remote sensing can be found in [1] and [2]. Regardless of the image modalities involved and of the particular application, image registration usually consists of the four major steps.

- *Control point (CP) detection.* CP's can be significant points easily locatable manually by a domain expert or feature points of distinguished geometry detected automatically such as corners, line intersections, region centroids, significant contour points, road junctions, buildings, etc.

- *Control point matching.* In this step, the mutual correspondence between the reference CP set and the CP's in the sensed image(s) is established. A common difficulty here is that there could be some CP candidates having no corresponding counterparts in the other frame(s). Matching methods can be based on correlation-like techniques, parameter clustering, graph matching, relaxation, or various invariant approaches.

- *Estimation of the mapping model.* In this stage, the type and parameters of spatial transform are determined. In case of global geometric differences between the images, linear, projective or quadratic transform model the coefficients of which are calculated via least-square technique is commonly used. When local non-linear image distortions are present, local mapping, radial basis functions and thin-plate splines are the most popular solutions.

- *Resampling and transformation.* Finally, the sensed image is transformed over the reference one according to the above mapping model. Appropriate resampling technique (nearest neighbor, linear or cubic interpolation) is employed to find image values in non-integer coordinates.

In this paper, the attention is paid to CP detection and matching in case the images involved in the registration are rotated and shifted one another and *blurred.* This means the relationship between the original scene f and its image g is given as $g(x', y') = (f * h)(x, y)$ where $h(x, y)$ is the point-spread function (PSF) of the imaging system. In practice, the PSF is often an unknown composite function describing the degradation effects of the sensor and the atmosphere [3]. Most of the earlier methods of CP detection and matching fail in case of blurred images. We present a new class of features defined on a CP neighborhood, which are invariant to rotation, translation and blurring. These invariants are used to establish the correspondence between the CP candidates.

ROTATION AND BLUR INVARIANTS

Image invariants introduced in this Section are based on *complex moments.* Complex moment $c_{pq}^{(f)}$ of image $f(x, y)$ is defined as

$$c_{pq}^{(f)} = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} (x + iy)^p (x - iy)^q f(x, y) dxdy, \qquad (1)$$

where i denotes the complex unit.

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Theorem 1: Let p and q be non-negative integers. Let us define the functional $K(p,q)$ as follows:
If $(p+q)$ is even then

$$K(p,q)^{(f)} = 0.$$

If $(p+q)$ is odd then

$$K(p,q)^{(f)} = c_{pq}^{(f)} - \frac{1}{c_{00}^{(f)}} \sum_{n=0}^{p} \sum_{\substack{m=0 \\ 0<n+m<p+q}}^{q} \binom{p}{n}\binom{q}{m} K(p-n,q-m)^{(f)} \cdot c_{nm}^{(f)}. \tag{2}$$

Then $K(p,q)^{(f*h)} = K(p,q)^{(f)}$ for any p and q, any image $f(x,y)$ and for any centrosymmetric function $h(x,y)$ normalized to unit integral.

Theorem 2: Let $n \geq 1$ and let k_j, p_j and $q_j; j = 1, \cdots, n$, be non-negative integers such that $(p_j + q_j)$ is odd for each j and that

$$\sum_{j=1}^{n} k_j(p_j - q_j) = 0.$$

Then

$$I = \prod_{j=1}^{n} K(p_j, q_j)^{k_j} \tag{3}$$

remains invariant to convolution and, moreover, it is invariant to rotation around the origin.

Translation invariance of the above features can be easily reached when using central coordinates in the definition of complex moments. Invariance to *scaling* and to *contrast changes* can be achieved by appropriate normalization.

The idea of blur invariants was firstly introduced in our recent work [4]. Unlike the invariants described here the former ones were based on regular moments instead of the complex ones. Due to this, a construction of rotation invariants similar to those from Theorem 2 was impossible.

NUMERICAL EXPERIMENT

- *Data.* This experiment was performed on real satellite data with simulated blurring. A subimage of the size 128×128 pixels that served as our reference image was extracted from the original SPOT scene, band 2 (see Fig. 1). Then the original scene was rotated by 15^o and another subimage covering approximately the same ground area as the reference one was extracted. To simulate a non-ideal acquisition, the sensed image was blurred by 5×5 averaging mask (see Fig. 2).

- *Detection of CP candidates (CPC's).* To find CPC's in the both frames, a method developed particularly

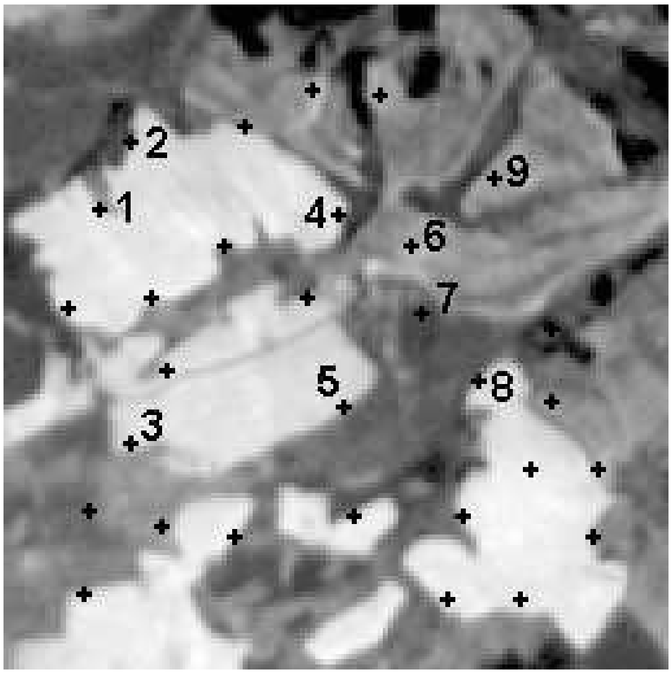

Figure 1: The reference SPOT subscene with 30 control point candidates. The numbers denote matched control points

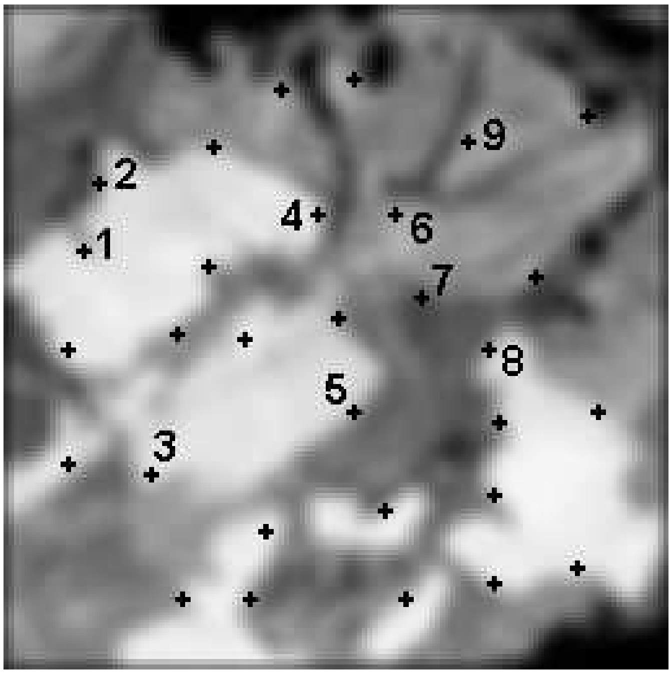

Figure 2: The sensed image with control point candidates and matched control points

for detection of dominant points in blurred images [5] was employed. This method looks for the points with characteristics robust to blurring. Sometimes they may co-incident with corners or line ends but it is not necessary. 30 selected CPCs in the reference and sensed images are depicted in Figs. 1 and 2, respectively.

- *Matching of the CP candidates.* Twelve invariants of the type (3) were calculated for a circular neighborhood of each CPC. The correspondence between the reference and sensed sets of the CPC's was established by minimum distance rule with thresholding in the space of the invariants. Nine established CPs' pairs are shown in Figs. 1 and 2 and their coordinates are listed in Table 1. This simple procedure was used to demonstrate the matching power of the invariants. In practical applications, more robust algorithms taking into account also spatial relationships among the CPC's [6] and a postprocessing that refines the CPs' positions should be employed.

Table 1: Coordinates of the control points

CP	Reference image	Sensed image
1	18, 39	15, 47
2	24, 26	18, 34
3	24, 84	28, 90
4	64, 40	60, 40
5	65, 77	67, 78
6	78, 46	75, 40
7	80, 59	80, 56
8	91, 72	93, 66
9	94, 33	89, 26

- *Mapping.* To transform the sensed image, similitude mapping function the coefficients of which were calculated via least-square technique was applied. Inter-pixel gray values were estimated via bilinear interpolation. The result is shown in Fig. 3.

CONCLUSION

In this paper we dealt with a registration problem of remotely sensed images which are degraded by unknown blurring and which are rotated and shifted one another. We proposed a new class of invariants to convolution and rotation that can be used to establish the correspondence among the CP candidates. The experiments we have done indicate good performance of this method.

Figure 3: Registered sensed image

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