Robust Image Registration Based on Features Extracted from Image of Edges

Slobodan Ribaric, Darko Mihalic
Faculty of Electrical Engineering and Computing
University of Zagreb
Unska 3, 10000 Zagreb, Croatia
slobodan.ribaric@fer.hr, daracm@net4u.hr

Abstract:
This paper describes a registration method of images taken from two different parts of the electromagnetic spectrum: the infrared and the visible range. Image registration includes development of the transformation in order to achieve an optimal overlapping of image pairs. The transformation is affine and consists of scaling along the *x*- and *y*-axis, translation, rotation and horizontal skew, and it is found based on features composed of two characteristic points (intersection of linear segments and/or corners) connected with one linear segment. These features are detected and extracted from the both images of edges (IR and RGB). As a measure of the best overlap, i.e., the optimal transformation, a function is used which takes into account the number of corresponding points in both images and the sum of their distances. The method is experimentally verified on numerous pairs of infrared and visible images of building facades. The examples of image registration and its evaluation are given.

Key words: image registration, feature detection, feature extraction, optimal transformation, fusion

I. INTRODUCTION

Image registration is a process of aligning and overlapping two or more images of the same scene, recorded from different points of view and/or recorded at the same or different time, with the same or different types of sensors. Usually, the data fusion process [1] – [4] follows the image registration in order to obtain more useful information necessary for later phases of the image interpretation of the scene.

Image registration has found application in medicine diagnostic, satellites observation, army, industry, traffic and cartography. Different authors carried out image registration in different ways, depending on the specific problem needed to be solved [5] – [13]. Methods of image registration can be classified into three main categories [14, 15]:

1. Image registration based on a space correlation,
2. Image registration by using correlation in a frequency domain,
3. Image registration based on local features extracted from images.

Very often methods from the third category are used for registration of images taken from different parts of electromagnetic spectrum. The choice of local features on which registration will be based, needs to take into consideration different characters of sensors and choose such features that are present in both images (IR and RGB). Such common local features can be extracted from images of edges obtained from IR and RGB images. While doing this, following problems can appear [6, 7]:

(i) Edges can be incomplete, abrupt or even not appear on expected position in one of the images;

(ii) A source segment (i.e. line segment in an IR image) potentially can match to every line segment in the destination image (RGB image) and this fact increases the number of possible hypothesis;

(iii) Length and orientation of extracted segments do not have to be preserved (this fact needs to be taken into consideration when determining scaling factor and skew).

Generally, a method of image registration by extracting local features from an image can be described in the following four steps [15]:

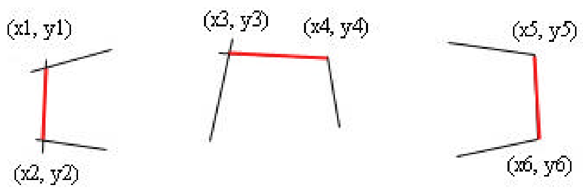
1. Features extraction;
2. Detection of compatible features in both images;
3. Estimation of the best parameters of transformation (optimal transformation);
4. Transformation of source image (IR image);

Generally, features can be edges (line segments, contours) or characteristic points (intersections of line segments, corners, points of maximum curvature, and centers of mass of some regions). Approaches to image registration based on extracted local features are described in [6] and [7]. Coiras et al. [6] define virtual straight lines by using line segments, and then, by using these straight lines they form virtual triangles in the source image (IR) and the destination image (RGB). Comparing these triangles, they find all possible transformations composed of scaling, translation, rotation and skew. As a measure of the transformation quality, they use a function which takes into consideration a distance from the middle point of transformed source segment to the virtual straight segment on which destination segment lies and the so-called angle distance, i.e. angle among straight lines on which respective segments lie. Krüger [7] uses line segments as robust features and tries to overlap them precisely. By using line segments, he constitutes compatible pairs of line segments to calculate transformation parameters. He defines the transformation quality through the goal function, which takes into consideration: (i) the distance between the corresponding end points of the transformed source segment and the end points of the destination line segment (segment in RGB image), and (ii) the length of overlapping these segments. He gets the best transformation by finding the maximum of the goal function. Ribaric et al. [16] represents experimental results obtained by using two registration techniques described above. They slightly modify the method described in [6] in order to adapt it to their application that has problematic extraction of segments that form triangles. They form triangles in such a way that every line segment joins virtual point p_3 which is not collinear with the start point (p_1) and end point (p_2) of this segment. In such a way, they get a virtual triangle defined with points p_1, p_2 and p_3. Further procedure of the registration is the same as in Coiras's work. Since virtual triangles are formed by the third virtual point, they lose information about skew in the transformation.

This paper describes the robust image registration of facades that is based upon a set of local features formed by two characteristic points connected with one line segment (we call them combined features; Fig. 1). Characteristic points are defined as intersections of line segments and/or corners. Registration outcome is used as the grounds for fusion of information necessary for contactless diagnostic thermal isolation of facades of building.

II. FEATURE EXTRACTION

Inputs in registration procedure represent pair of images. One is low resolution IR image (wave length 7.5 - 13µm, 320 x 240 pixels); the other is high resolution RGB image (3264 x 2448 pixels). Images of edges [17, 18] of both images (IR and RGB) are used as a source of the local features. Before using the edge operator, RGB image is reduced by bilinear interpolation function on dimensions of IR image (320 x 240 pixels). Images of edges are obtained by applying the Canny operator [19, 20], and then filtrated by (line) size filter to reduce number of hypothesis about compatible features. It is experimentally determined that the best results are gained if we use size filter of dimension n = 16 pixels. Figures 2 and 3 show the images of edges (RGB image) before and after size filtering. Next, in the images of edges characteristic points were located: intersections line segments and corners. Afterwards, all pairs of characteristic points connected with one line segment were extracted (Fig. 1), and they form the set of combined features, which we use for finding compatible combined features.



a) b) c)

Fig. 1. Combined features: a) A line segment connects intersections of line segments, b) A line segment connects intersections of line segments with a corner, c) A line segment connects two corners.

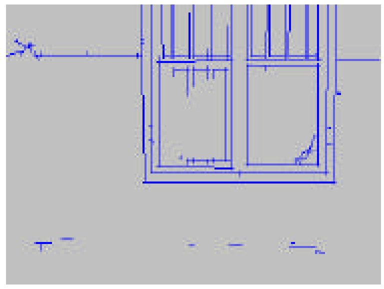


Fig. 2. A non-filtered image of edges

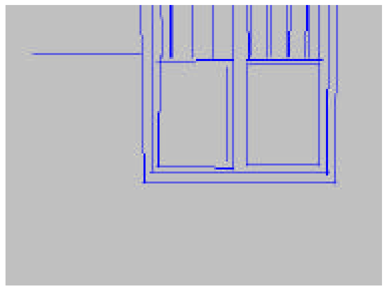


Fig. 3. A filtered image of edges

III. FINDING COMPATIBLE FEATURES

We use pairs of compatible combined features for determining all transformation parameters and we find them by using the following algorithm:

1. Form a set of combined features of IR image of edges (source) and a set of combined features of RGB images of edges (destination). Every combined feature has the following attributes: coordinates of the start point, coordinates of the end point (i.e., coordinates of the characteristic points), length of the line segment which connects the start and end point, and orientation of the line segment.
2. Select the first combined features in the source image.
3. Proclaim the start point of this combined feature (either the ending left or the first top point of the line segment which connects a pair of characteristic points, depending on the orientation of the line segment) to be the center of the square with side length ***d*** pixels.
4. Define the same square, with the same coordinates in the destination image.
5. Inside this square, in the destination image, find the start point of the combined feature which will fulfill the criterion of compatibility (called this combined feature the *compatible feature*).
6. When the compatible feature is found in the destination image, this feature is paired with the combined feature from the source image (feature from Step 1.) and this pair of combined features is proclaimed as a pair of compatible features. Such a

pair is a basis for the hypothesis generation about one of the possible transformations.

7. Go back to Step 5 and find the next combined feature (if it exists) in the square in the destination image;
8. Repeat Steps 5 – 7 until scanning all start points of the combined features in the square in the destination image.
9. Select next combined feature in the source image and repeat Steps 3 – 8.
10. Stop if there are no more combined features in the source image.

From the above algorithm it is obvious that one combined feature from the source image can have more compatible features in the destination image, and vice – versa.

For available database of images, the parameter d = 60 pixels is experimentally determined.

Two combined features (one from the IR image of edges and the other from the RGB image of edges) are compatible if the following conditions are fulfilled:

1. Start points coordinates of both features are situated inside the same square defined in both images,

2. Length ratio of the line segments of these features: 0.8 < l/l' < 1. 35, where l is the length of the line segment in the source image and l' is the length of the line segment in the destination image,

3. The angle f that form these two line segments is less than 5°.

IV. OPTIMAL TRANSFORMATION

The procedure of finding optimal transformation begins with calculation of all possible transformations, i.e. all possible quintets of transformation parameters (S_x, S_y - scaling, f - rotation, t_x, t_y – translations, S_k - skew). This starting transformation set is calculated on the basis of the pairs of compatible features. The scaling factors along x- and y-axis (S_x and S_y, respectively) are determined on the basis of the compatible line segments ratio as follows: $S = l / l'$, where S is either S_x or S_y, depending on whether we calculate ratio of horizontal or vertical line segments, respectively. For an arbitrary orientation of the line segments, the ratios of their corresponding projections on y- and x-axis determine S_x and S_y, respectively.

Translations t_x and t_y can be calculated in the following way:

$$t_x = S_x \cdot (x' - x) \quad \text{and} \quad t_y = S_y \cdot (y' - y),$$

where (x, y) are start point coordinates of compatible line segment from the IR image, and (x', y') are start point coordinates of compatible line segment from the RGB image.

The skew factor is determined as follows: $S_k = (x' - x) / y$.

To calculate an angle f, for two line segments with no common points, first translate one of them until is reached matching in one point (Fig. 4), and then calculate the angle between them as follows:

$$j = \arccos \frac{\overrightarrow{T_0T_1} \cdot \overrightarrow{T_0T_2}}{\left\|\overrightarrow{T_0T_1}\right\| \cdot \left\|\overrightarrow{T_0T_2}\right\|}$$

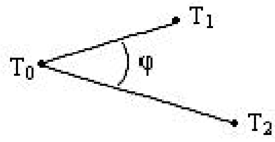


Fig. 4. Angle between two line segments

By calculation of transformation parameters t_x, t_y, S_x, S_y, S_k and f for all pairs of compatible line segments, the starting set of all possible transformations is obtained. Whence we deal with image registration from two different spectral bands, with regard to problems noticed in introduction, an extra adjusting of transformation parameters is needed. We perform extra adjusting of these parameters so that from the starting set of all transformations we select the top ten transformations according to criterion of overlapping quality (criterion of overlapping quality is described in detail in Section V). Afterwards, we vary transformation parameters in some narrow range around the starting values until we achieve the best overlapping of characteristic points in both images. We vary translation parameters for ± 20 pixels around starting values in steps by 4 pixels. Scaling parameters varying for ± 0, 05 around starting values with step of 0, 01. Angle f varies around starting values for ± 3,6° with steps of 0,3° and skew we alternate from – 2,4 to +2,4 around starting values in steps of 0,2. The above-mentioned parameters are determined experimentally. Thereafter, the best transformation parameters are obtained (S_x, S_y, S_k, t_x, t_y and f) regarding to criterion of overlapping quality. Hereby, finding of best parameters is done and the found transformation is considered as the optimal transformation. We transform source image according to founding parameters of the optimal transformation.

V. CRITERION OF OVERLAPPING QUALITY

If we apply affine transformation on a point A (x, y) from the IR image, with known transformation parameters S_x, S_y, S_k, t_x, t_y and f , the point A (x, y) will map into point A' (x', y') in the RGB image:

$$A' = M \cdot A,$$

where M is the affine transformation given by:

$$M = \begin{bmatrix} m_0 & m_1 & m_2 \\ m_3 & m_4 & m_5 \\ 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & t_x \\ 0 & 1 & t_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos j & -\sin j & 0 \\ \sin j & \cos j & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & S_k & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} S_x & 0 & 0 \\ 0 & S_y & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

The overlapping quality is evaluated as follows. For every transformation from the transformation set:

1. Transform the all characteristic points (start and end points of compatible feature) from the IR image of edges to the

RGB image of edges, by using the corresponding affine transformation *M*,
2. Compare positions of these transformed points with positions of the points in the RGB image of edges.
3. If the distances $d_x = |x - x'|$ and $d_y = |y - y'|$ are such that $d_x \leq k$ and $d_y \leq k$ then proclaim these two points to be a pair of correspondent points. The parameter $k = 5$ is determined experimentally.
4. The criterion of overlapping is based on the total number of such correspondent points for the transformation - the transformation that gives the largest total number of correspondent points is the *best transformation.*

Moreover, in case when two different transformations have the same (largest) total number of correspondent points, we have to apply addition criterion which takes into consideration the total sum of distances of correspondent points for the transformation.
More formally, the above process can be described as follows:

A total sum of correspondent points $N_{CP} = \sum_{i=1}^{n} a_i$, where

$$a = \begin{cases} 1 \text{ ako } d_x \leq k \text{ i } d_y \leq k \\ 0 \text{ ako } d_x > k \text{ i } d_y > k \end{cases} \quad \text{and}$$

$$n = \min(N_{IR}, N_{RGB});$$

N_{IR} – A total number of characteristic points in the IR image of edges,
N_{RGB} – A total number of characteristic points in the RGB image of edges.
In case when two or more transformations from the set of possible transformations have the same (largest) total number of correspondent points, calculate for every such

transformation: $Q^j = \sum_{i=1}^{N_{CP}} \left(d_{x_i} + d_{y_i} \right)$, where $j = 1, 2, ...,$

m; m is a number of transformations that give the same (largest) total number of correspondent points and select the transformation with index *w* for which is

$$Q^w = \min_{i \in 1,2,...m} Q^i \ .$$

VI. EXPERIMENTAL RESULTS

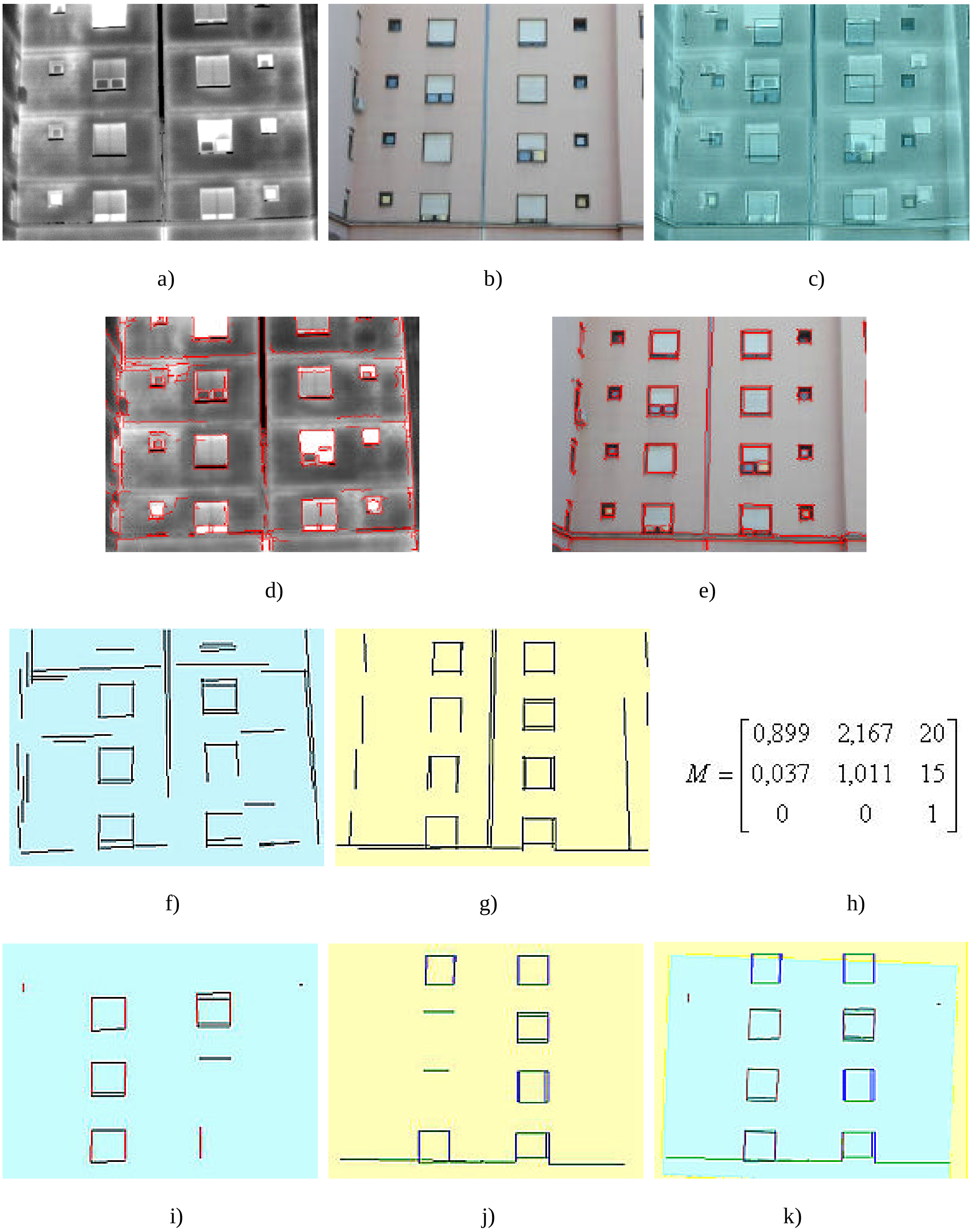
The registration method is verified on more than 60 pairs IR - RGB images and it confirms efficiency and robustness.
Figure 5 illustrates the phases of the image registration.
Figure 6 shows the overlapped transformed IR image and RGB image.
Experimental results for efficiency in terms of running time and number of generated hypothesis are listed in Table 1.
The number of generated hypothesis depends on initially adjusted parameters of image processing and on the nature of images. It reaches from ten in the simplest cases to hundred hypotheses for much demanding cases. Depending on initially adjusted parameters of processing, image processing takes about 4 seconds and finding optimal transform takes additional few hundreds of millisecond to few seconds in the most demanding cases (personal computer based on Atlon 1.3 GHz processor, 256 MB RAM memory).

Table 1. Number of generated hypotheses and execution time for the optimal transformation estimation (for 10 pairs of facade images)

Image of facade	Hypotheses number	Processing time [s]
1	18	1,53
2	9	0,61
3	68	6,11
4	41	2,38
5	26	6,1
6	31	1,89
7	8	1,15
8	31	2,66
9	77	5,40
10	53	5,19

VII. CONCLUSION

The registration method described in this paper is used for registration images taken from two spectral bands (IR and RGB range) and for solving a specific problem (registration of two images of facade). The method is based on local features consisting of two characteristic points (intersections of line segments and/or corners) connected by the line segment. A measure of quality of the transformation is based on a total number of correspondent points and a minimum total sum of distances of correspondent points in the destination image. The method was tested on more than 60 IR-RGB image pairs of facades and it has shown enough efficiency and robustness. Primarily, the described method was applied in finding mostly rectangular shapes but with a simple modification, in future, it could be applied to more complex polygonal shapes and circles.



$$M = \begin{bmatrix} 0,899 & 2,167 & 20 \\ 0,037 & 1,011 & 15 \\ 0 & 0 & 1 \end{bmatrix}$$

Fig. 5. Registration of IR – RGB pair images; a) A source IR image; b) A destination RGB image; c) Overlapped images (IR image over RGB image - before registration); d) Extracted edges from the IR image (IR image of edges); e) Extracted edges from the RGB image (RGB image of edges); f) Result of size filtering (IR image of edges); g) Result of size filtering (RGB image of edges); h) The transformation matrix M represents the best transformation; i) Extracted combined features from the IR image of edges; j) Extracted combined features from the RGB image of edges; k) Overlapped images features (after registration).

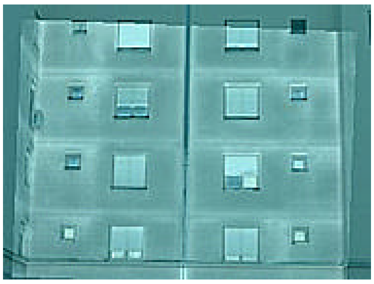


Fig. 6. The overlapped images (after registration).

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