COMPREHENSIVE PARADIGM FOR SEMI-AUTOMATIC REGISTRATION OF MULTI-SOURCE IMAGERY

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ABSTRACT:

The enormous increase in the volume of remotely sensed data, which might be in different formats and relative to different reference frames, has created the need for robust data processing techniques that can fuse data observed by different acquisition systems. This need is motivated by the fact that collected data by these sensors are complementary in nature. Therefore, simultaneous utilization of the collected data would guarantee full understanding of the object/phenomenon under consideration. In this regard, a registration procedure can be defined as being concerned with the problem of how to combine data and/or information from multiple sensors in order to achieve improved accuracies and better inference about the environment than could be attained through the use of a single sensor. Registration of multi-source imagery captured under different conditions is a challenging problem. The difficulty is attributed to the varying radiometric and geometric resolutions of the acquired imagery. In general, an automatic image registration methodology must deal with four issues; registration primitives, transformation function, similarity measure and matching strategy. This paper outlines a comprehensive image registration paradigm that can handle multi-source imagery with varying geometric and radiometric properties. The most appropriate primitives, transformation function, and similarity measure have been incorporated in a matching strategy to solve the registration problem. Experimental results using real data proved the feasibility and the robustness of the suggested paradigm.

1. INTRODUCTION

Image registration is concerned with the problem of how to combine data and/or information from multiple sensors in order to achieve improved accuracies and better inference about the environment than could be attained through the use of a single sensor. In some applications, image registration is the final goal (e.g., interactive remote sensing, medical imaging, etc.) and in others, it is a prerequisite for accomplishing high-level tasks such as sensor fusion, surface reconstruction, and object recognition. With the flux of high resolution scenes captured by space-borne platforms (e.g., LANDSAT-7, IKONOS, QUICKBIRD, ORBVIEW, EROS-A1, and SPOT-5), there is an increasing need for a robust registration technique, which can tolerate varying geometric resolutions of the available scenes.

In general, an automatic image registration methodology must deal with four issues. First, a decision has to be made regarding the choice of the registration primitives, which refers to the features that will be extracted in the input imagery to solve the registration problem. The second issue is concerned with establishing the registration transformation function that mathematically describes the necessary transformation for the alignment of the images to be registered. Then, a similarity measure should be devised to describe the necessary constraints ensuring the correspondence of conjugate primitives. Finally, a matching strategy has to be designed and implemented as a controlling framework that utilizes the primitives, the transformation function, and the similarity measure to solve the registration problem (i.e., automatically determines the correspondences among conjugate primitives).

Automatic and even manual registration of imagery remains challenging for several reasons. First of all, imagery and/or data sets are usually acquired using different sensor types, each having its inherent noise. Furthermore, radiometric as well as geometric properties of the same object in the involved imagery might differ as a result of changes in the sensor view point, imaging methodology, imaging conditions (e.g., atmospheric changes, cloud coverage, and shadows), and spectral sensitivity of the involved imaging systems (e.g., panchromatic, multi- and hyper-spectral imaging systems). Finally, the registration process can be complicated by changes in object space caused by movements, deformations, and urban development between the epochs of capture associated with the involved images. This paper will investigate and develop a semi-automated, accurate, and robust registration paradigm that can cope with the abovementioned challenges and problems.

Although there has been a vast body of research that has dealt with automatic image registration (Seedahmed and Martucci, 2002; Dare and Dowman, 2001; Fonseca and Costa, 1997; Hsieh et al., 1997; Boardman et al., 1996; Flusser, 1992 and Wolfson, 1990), we still do not have a methodology that meets the current challenges posed by image registration. Drawbacks can be summarized by the following remarks:

- Points are usually used as a registration primitive. Even some techniques refer to regions and lines features such as lakes, rivers, cost-lines and roads. However, each of these features will be assigned one or more point locations (e.g. centroid of area, line endings, etc.) to be used as registration primitive (Fonseca and Manjunath, 1996). Points are not reliable choice for varying radiometric and geometric images (Section 2).

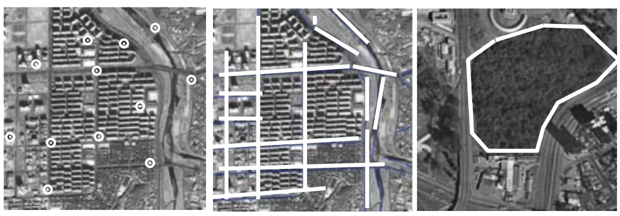
- The appropriate registration transformation function is not investigated (i.e., simplified and sometimes invalid registration transformation function is assumed).
- The developed similarity measures for matching primitives are empirical and sometimes subjective. Cross-correlation and least squares matching are the best known criteria to compare the degree of similarity. Here, the images to be matched have to be radiometrically very similar, preferably imaged by the same sensor. However, gray level characteristics of the images to be matched can vary from sensor to sensor and hence correlation measures become unreliable (Fonseca and Manjunath, 1996). Moreover, applying cross-correlation requires two images with same resolution which disagree with existing satellite images (i.e., IKONOS (1m), SPOT (10m), LANDSAT (30m), etc.)

Prior methods have certain advantages in computing the transformation parameters in a single step and in retaining the traditional way of thinking about registration in the sense of identifying similar features first and then computing the parameters of the registration transformation function. The suggested approach significantly differs from the other registration strategies as it uses straight lines features for simultaneously determining the correspondences between the involved primitives and solving for the parameters of the registration transformation function.

This paper outlines a comprehensive image registration paradigm that can handle multi-source imagery with varying geometric and radiometric properties. The most appropriate primitives (Section 2), transformation function (Section 3), and similarity measure (Section 4) has been incorporated in a matching strategy (Section 5) to solve the registration problem. Experimental results using real data proved the feasibility and the robustness of the suggested paradigm are discussed in Section 6. Finally conclusions and remarks are drawn in Section 7.

2. REGISTRATION PRIMITIVES

The registration primitives encompass the domain in which information is extracted from input imagery for the registration process, mainly: distinct points, linear features, and homogenous/areal regions, Figure 1.



Distinct points   Linear features   Areal regions

Figure 1. Alternatives of registration primitives

2.1 Points

Traditional procedures for manually registering an image pair require interactive selection of tie points in each image. Such tie points are then used to determine the parameters of a registration transformation function, which is subsequently used to resample one of the images into the reference frame associated with the other image. However, such a procedure can lead to inaccurate results and is slow to execute, especially if a large number of images with varying geometric and radiometric properties need to be registered. Visually inspecting the imagery, one can see that manual identification of conjugate points is extremely difficult if not impossible, Figure 1.

Automatic extraction of points based on the radiometric information results in different sets of points from each image due to varying radiometric properties of involved imagery. This situation extends to the problem of finding conjugate points where it would be unlikely that point extraction algorithms would be able to identify the same point. In other words, for multi-source imagery with varying geometric and radiometric resolutions, the texture and gray levels at the location of conjugate points will not be similar. Therefore, automatically and/or manually extracted points will be difficult to match and are not suitable primitives for registration. Consequently, linear and areal features will be considered and investigated for its suitability for multi-source image registration since the geometric distribution of the pixels making up the feature can be used in the matching, rather than their radiometric attributes.

2.2 Linear features

In contrast to point primitives, linear features have a set of appealing properties when they appear on multi resolution images especially in urban areas. These properties include the following facts:

- Compared to distinct points, linear features have higher semantics, which can be useful for subsequent processes (such as DEM generation, map compilation, change detection, and object recognition).
- Images of man-made environment are rich with linear features.
- It is easier to automatically extract linear features from imagery rather than distinct points (Kubik, 1991).
- Geometric constraints are more likely to exist among linear features. This can lead to a simple and robust registration procedure.

2.3 Areal Features

Areal primitives might not always be available especially when dealing with satellite scenes over urban areas. Moreover, registration procedures based on areal primitives use the centers of gravity of these features as the registration primitives. The estimated centers of gravity are susceptible to potential errors associated with the identified boundaries of these patches.

Compared to linear features, areal features are less appropriate considering availability in nature, complexity of extraction algorithms, and existence of geometric constraints. Areal features can be represented as a sequence of linear features through the replacement of its boundaries.

Based on the above analysis of different candidate primitives, this paper will adopt the linear features in the registration process. Straight lines, a subset of linear features, possess further attracting benefits that made it the premium choice as explained in the following subsection.

2.4 Straight Lines

Linear features can be represented either by an analytical function (e.g., straight lines, conic sections, or parametric functions) or by a free form shape. Straight-line segments have been chosen as the registration primitives for the following reasons:

- Straight lines are easier to detect and the correspondence problem between conjugate features in the input imagery becomes easier.
- It is straightforward to develop mathematical constraints (similarity measures) describing the correspondence of conjugate straight-line segments.
- Free-form linear features can be represented with sufficient accuracy as a sequence of straight-line segments (polylines).

It should be mentioned that proposed approach in this paper doesn't require end points corresponding between conjugate line segments

Once straight lines are adopted as the most suitable primitive to be used in the registration process, the next step is to select a valid and proper transformation function that can faithfully represent the transformation between the conjugate straight lines identified in the input and reference images.

3. REGISTRATION TRANSFORMATION FUNCTIONS

At this stage, one should establish a registration transformation function that mathematically relates geometric attributes of corresponding primitives. Given a pair of images, reference and input images, the registration process attempts to find the relative transformation between these images. The type of spatial transformation needed to properly overlay the input and reference images is one of the most fundamental and difficult tasks in any image registration technique. Images involved in the registration process might have been taken from different viewpoints, under different conditions, using different imaging technologies, or at different times. The registration transformation function must suit multi-resolution and multi-spectral images that might have been captured under different circumstances.

There has been an increasing trend within the photogrammetric community towards using approximate models to describe the mathematical relationship between the image and object space points for scenes captured by high altitude line cameras with narrow angular field of view (e.g., IKONOS, SPOT, LANDAST, EROS-A1, QUICKBIRD, and ORBVIEW). Among these models, Rational Function Models (RFM) are gaining popularity since they can handle any type of imagery without the need for a comprehensive understanding of the operational principles of the imaging system (Tao and Hu, 2001). RFM are fractional polynomial functions that express the image coordinates as a function of object space coordinates. RFM have been extensively used in processing satellite scenes in the absence of the rigorous sensor model (e.g., IKONOS scenes). However, using RFM would not allow for the development of a closed form transformation function between the coordinates of conjugate points in the reference and input images.

For scenes captured by high altitude line cameras with narrow angular field of view, parallel projection approximates the mathematical relationship between image and object space coordinates (Habib and Morgan, 2002). Image to object space coordinate transformation using parallel projection involves eight parameters. For relatively planar object space (i.e., height variation within the object space is very small compared to the flying height), the parallel projection can be simplified to an affine transformation involving six parameters. In other words, corresponding images (either in the reference or the input image) and the planimetric object coordinates are related through a six-parameter affine transformation. Due to the transitive property of an affine transformation, the relationship between corresponding coordinates in the input and reference images can be represented by an affine transformation as well. For situations where the image is almost parallel to the object space, the affine transformation function can be approximated by a 2-D similarity transformation. Once again, since similarity transformation is transitive, coordinates of conjugate points in the reference and input image can be related to each other through a 2-D similarity transformation, Figure 2.

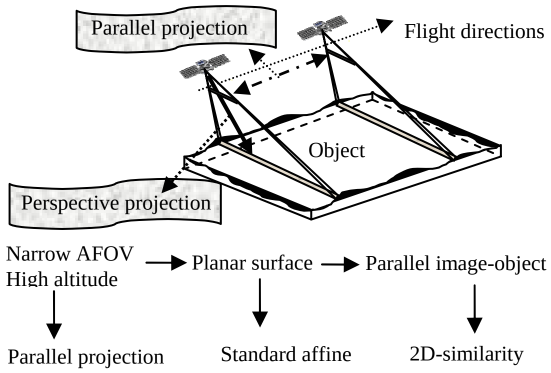


Figure 2. Approximate models

After discussing the choice of the most appropriate registration primitives as well as the transformation function between the reference and input images, one can proceed to the third issue of the registration paradigm: the similarity measure.

4. SIMILARITY MEASURE

The similarity measure, which mathematically describes the coincidence of conjugate line segments after applying the registration transformation function, incorporates the attributes of the registration primitives to derive the necessary constraint(s) that can be used to estimate the parameters of the transformation function relating the reference and input images. In other words, having two datasets, which represent the registration primitives (straight-line segments) that have been manually or automatically extracted from the input and reference images, one should derive the necessary constraints to describe the coincidence of conjugate primitives after applying the appropriate registration transformation function.

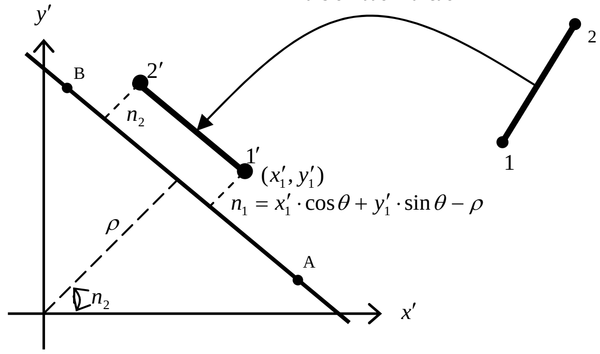


Figure 3. Similarity measure using straight line segments

Let's assume that we have a line segment (1-2) in the reference image, which corresponds to the line segment (AB) in the input image, Figure 3. As mentioned earlier, the end points of the two segments need not be conjugate. The similarity measure should mathematically describe the fact that the line segment (1-2) should coincide with the corresponding line segment (AB) after applying the transformation function relating the reference and input images. Such a measure can be derived by forcing the normal distances between the end points of a line segment in the reference image, after applying the transformation function, and the corresponding line segment in the input image to be zero (i.e., $n_1 = n_2 = 0$, Figure 3).

Equation 1 mathematically describes such a constraint for one of the end points of the line segment in the reference image.

$$x_1' \cdot \cos\theta + y_1' \cdot \sin\theta - \rho = 0 \tag{1}$$

where

(ρ, θ) :are the polar coordinates representing the line segment AB in the input image

(x_1', y_1') :are the transformed coordinates of point 1 in the reference image after applying the registration transformation function.

The mathematical relationship between the coordinates of a point in the reference image (x_1, y_1) and the coordinates of the conjugate point in the input image (x_1', y_1') can be described either by Equations 2 or 3 depending on whether we choose affine or 2-D similarity registration transformation function, respectively.

$$\begin{bmatrix} x_1' \\ y_1' \end{bmatrix} = \begin{bmatrix} a_0 \\ b_0 \end{bmatrix} + \begin{bmatrix} a_1 & a_2 \\ b_1 & b_2 \end{bmatrix} \begin{bmatrix} x_1 \\ y_1 \end{bmatrix} \tag{2}$$

$$\begin{bmatrix} x_1' \\ y_1' \end{bmatrix} = \begin{bmatrix} a_0 \\ b_0 \end{bmatrix} + \begin{bmatrix} a_1 & b_1 \\ -b_1 & a_1 \end{bmatrix} \begin{bmatrix} x_1 \\ y_1 \end{bmatrix} \tag{3}$$

One pair of conjugate line segments would yield two constraints of the form in Equation 1. Using a given set of corresponding line segments, one can incorporate them in a least squares adjustment procedure to solve for the parameters of the registration transformation function.

5. MATCHING STRATEGY

To automate the solution of the registration problem, a controlling framework that utilizes the primitives, similarity measure, and transformation function must be established. This framework is usually referred to as the matching strategy. In this research, the Modified Iterated Hough Transform (MIHT) is used as the matching strategy. Such a methodology is attractive since it allows for simultaneous matching and parameter estimation. Moreover, it does not require complete correspondence between the primitives in the reference and input images. MIHT has been successfully implemented in several photogrammetric operations such as automatic single photo resection and relative orientation (Habib et al., 2001, Habib and Kelley 2001a, 2001b).

MIHT assumes the availability of two datasets where the attributes of conjugate primitives are related to each other through a mathematical function (similarity measure incorporating the appropriate transformation function). The approach starts by making all possible matching hypotheses between the primitives in the datasets under consideration. For each hypothesis, the similarity measure constraints are formulated and solved for one of the parameters in the registration transformation function. The parameter solutions from all possible matching hypotheses are stored in an accumulator array, which is a discrete tessellation of the expected range of parameter under consideration. Within the considered matches, correct matching hypotheses would produce the same parameter solution, which will manifest itself as a distinct peak in the accumulator array. Moreover, matching hypotheses that contributed to the peak can be tracked to establish the correspondence between conjugate primitives in the involved datasets. Detailed explanation of the MIHT can be found in Habib et al., 2001. The basic steps for implementing the MIHT for solving the registration problem are as follows:

- Approximations are assumed for the parameters which are not yet to be determined. The cell size of the accumulator array depends on the quality of the initial approximations; poor approximations will require larger cell sizes.
- All possible matches between individual registration primitives within the reference and input images are evaluated, incrementing the accumulator array at the location of the resulting solution, pertaining to the sought-after parameter, from each matching hypothesis.
- After all possible matches have been considered; the peak in the accumulator array will indicate the most probable solution of the parameter in question. Only one peak is expected for a given accumulator array.
- After each parameter is determined (in a sequential manner), the approximations are updated. For the next iteration, the accumulator array cell size is decreased to reflect the improvement in the quality of the parameters. Then, the above two steps are repeated until convergence is achieved (for example, the estimated parameters do not significantly change from one iteration to the next).
- By tracking the hypothesized matches that contributed towards the peak in the last iteration, one can determine the correspondence between conjugate primitives. These matches are then used in a simultaneous least squares adjustment to derive a stochastic estimate of the involved parameters in the registration transformation function.

6. EXPERIMENTAL RESULTS

To illustrate the feasibility and the robustness of the suggested registration process, experiments have been conducted using real data from different imaging systems, Table 1. These scenes were captured at different times (multi-temporal) and exhibit significantly varying geometric and radiometric properties.

Table 1. Multi-temporal images for the city of Calgary with various geometric and radiometric resolutions

Source	**Date**	**Size Rows ×Columns**	**Ground Resolution**
Aerial	1956	1274 × 1374	5.0 (m)
Aerial	1972	1274 × 1374	3.5 (m)
Ortho-photo	1999	2000 × 2000	5.0 (m)
Landsat_7	2000	500 × 500	15 (m)
Landsat_7	2001	300 × 300	30 (m)

First, the parameters of the registration transformation function (using 2-D similarity and affine transformation functions) are estimated using well distributed tie points, which have been manually identified in the scenes, Table 2. The variance component ($\hat{\sigma}_o^2$) in (Pixel ^{2}) derived from the least squares procedure summarizes the quality of fit between the involved primitives in the registration process. Smaller variance component indicates a better fit between the registration primitives. The selection of common points in the various scenes proved to be a very difficult and time-consuming task. Analyzing the results in Table 2, one can see that the estimated variance component has improved using affine transformation when compared to that derived through 2-D similarity transformation.

Table 2. Transformation parameters based on manual point measurements

	Ortho-56	**Ortho-72**	**Ortho-00**	**Ortho-01**
$\hat{\sigma}_o^2$	4.3580	2.1334	1.5207	0.8402
a_o	95.0619	64.3973	89.8651	52.9031
b_o	-105.2252	272.1483	75.5173	30.9711
a_1	0.9164	1.3015	0.3347	0.1587
b_1	-0.0185	0.0590	0.0127	-0.0512
	Ortho-56	**Ortho-72**	**Ortho-00**	**Ortho-01**
$\hat{\sigma}_o^2$	4.1231	1.7976	1.504	0.8089
a_o	93.8898	63.4821	90.9108	51.4447
a_1	0.9120	1.2977	0.3360	0.1572
a_2	0.0162	-0.0622	-0.0116	0.0493
b_o	-105.5540	272.0775	73.9394	31.0340
b_1	-0.0216	0.0560	0.0123	-0.0488
b_2	0.9196	1.3038	0.3318	0.1601

Afterwards, straight-line segments were manually digitized in the available scenes. As an example, Figure 4 shows the digitized segments in Aerial 1956 and Ortho-photo 1999 scenes. In this figure, one can see that there is no complete (i.e., one-to-one) correspondence between the digitized primitives in the input and reference images. The digitized segments are then incorporated in the MIHT strategy to automatically determine the correspondence between conjugate line segments as well as the parameters involved in the registration transformation function. The estimated registration transformation parameters as well as the corresponding variance component for all the datasets are listed in Table 3.

Table 3. Transformation parameters based on automatically matched linear features using MIHT

	Ortho-56	**Ortho-72**	**Ortho-00**	**Ortho-01**
$\hat{\sigma}_o^2$	2.2298	2.7774	1.7599	0.8977
a_o	94.0756	65.4424	87.9770	53.1336
b_o	-106.6365	269.8632	75.8580	30.9736
a_1	0.9195	1.3041	0.3341	0.1595
b_1	-0.0210	0.0562	0.0132	-0.0507
	Ortho-56	**Ortho-72**	**Ortho-00**	**Ortho-01**
$\hat{\sigma}_o^2$	2.1785	2.0657	1.6761	0.8522
a_o	94.0991	64.6135	89.5263	52.7716
a_1	0.9181	1.3018	0.3355	0.1589
a_2	0.0181	-0.0592	-0.0105	0.0500
b_o	-106.6896	270.2862	75.7333	31.3885
b_1	-0.0229	0.0542	0.0142	-0.0506
b_2	0.9204	1.3053	0.3334	0.1612

Similar to the results from the point datasets, the affine transformation produced better results than the 2-D similarity transformation. Moreover, comparing the results in tables 2 and 3, one can see that utilizing linear features led to a better fit between the scenes than that derived using point features. This should be expected since identifying linear features in multi-resolution imagery is much more reliable and accurate than distinct points.

As mentioned earlier, the affine transformation is valid when assuming relatively flat terrain. In this context, linear features are advantageous since they restrict the selected primitives along relatively flat terrain as represented by the road network. This might not be the case for point primitives that might have significant relief distortions (e.g., simultaneous considerations of points along the terrain as well as high rise buildings). Finally, observing the estimated shift components among the registered scenes (a_0, b_0), one can see that the proposed strategy successfully converged without the need for approximate registration of these scenes.

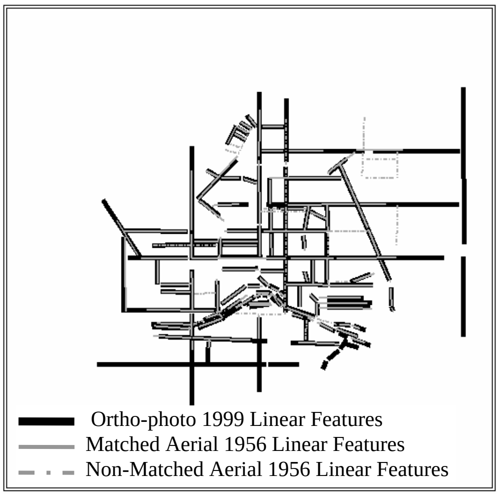


Figure 4. Established correspondences between the 1956 aerial image and the 1999 ortho-photo line segments

Figure 4 depicts established correspondences between the digitized primitives in the Ortho-photo 1999 and Aerial 1956 scenes. The estimated transformation parameters are used to resample the reference image to the coordinate system associated with the input image. Figure 5 shows a mosaic image derived by combining Landsat 2000, Orho-photo 1999, and Aerial 1956. A closer look to this figure reveals the following facts:

- Due to the limited area covered by Landsat image 2000, Figure 5(a), image completion concept has been applied to obtain full coverage for the city of Calgary. Aerial 1956 and ortho photo were used to achieve such a task Figure 5(b). One should note that multi–image integration has been accomplished. This is an important process that is needed to cope with large diversity of contemporary available images.
- In Figure 5(c), every other square patch in the reference image has been replaced by the corresponding resampled patch in the input image. It can be seen that features (e.g. roads, rivers, buildings) in the derived mosaic accurately fit each other (observe the smooth transition along the features within the resampled patches). This proves the validity of the estimated parameters of the transformation function relating these scenes.

- Discontinuities appear along the boundaries between some of the resampled patches in Figure 5(d) (highlighted by hollow circles). These discontinuities are attributed to real changes in the object space between the epochs of capture of the involved scenes (the Aerial photo has been captured forty three years earlier than the ortho photo scene). This is significant in change detection application where accurate image registration is a prerequisite for accurate and reliable change detection results.

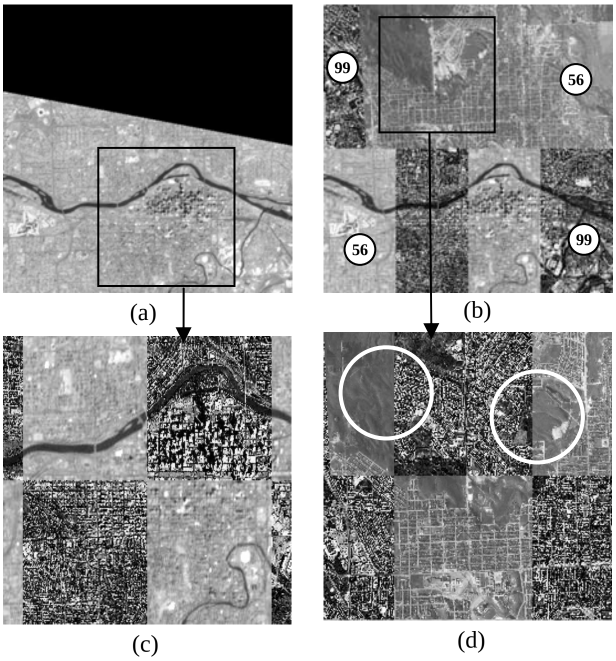


Figure 5. Multi-image mosaic

7. CONCLUSION AND REMARKS

This paper addressed the key issues of an efficient semi-automatic registration methodology that can handle multi-temporal multi-sensor images. The presented approach uses linear features (straight-line segments) as the registration primitives since they can be reliably extracted from the reference and input images. Then, the registration transformation function is analyzed to determine the mathematical relationship between conjugate primitives in the scenes to be registered. It has been established that affine transformation can be used as the registration transformation function for scenes captured by satellite imaging systems with narrow angular field of view. Moreover, 2-D similarity transformation can be used as another alternative for some applications with less demanding accuracy requirements. A similarity measure has been derived to ensure the correspondence among conjugate line segments. The similarity measure does not assume that the end points of corresponding line segments are identical. Finally, the primitives and the similarity measure are manipulated in a MIHT procedure to solve for the parameters involved in the registration transformation function while establishing the correspondence between conjugate primitives.

Experimental results showed the feasibility and the robustness of the suggested approach that could tolerate possible discrepancies between the imagery due to varying sensor operational principles as well as changes in the object space. Current research is focusing on automatic extraction of the registration primitives, affine transformation limitation and validity and image map registration for change detection and updating applications.

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