A NEW APPROACH TO AUTOMATIC FEATURE BASED REGISTRATION OF SAR AND SPOT IMAGES

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ABSTRACT

It has long been known that by combining multi-source or multi-temporal Earth observation images, the ability to detect and recognise features on the ground is greatly increased. In some specific cases models have been successfully developed for automatically integrating images from different sensors, but in general the problem of fully automatic data integration has not yet been solved. This paper introduces a new approach to automatic feature based image registration, based on multiple feature extraction and matching techniques, in order to solve the problem of automatic registration of SAR and SPOT imagery.

Application of this model to pairs of small images showed that a substantial number of tie points could be found. Using these tie points with a first order transformation function consistently gave a RMS residual of less than two pixels. The model was also applied to full scene images. A method of processing based on tiling was used, rather than one based on image pyramids, since this was found to be computationally more efficient. Results showed that a large number of tie points could be located across the images. Close inspection of the matched features revealed that there were no blunders and hence the feature extraction and matching algorithm was successful.

Most importantly, the approach to feature based registration using multiple feature extraction techniques clearly improved the quality and quantity of the tie points compared to traditional feature based registration techniques which rely on only one feature extraction algorithm.

1 INTRODUCTION

Image registration is fundamental to remote sensing. With the ever increasing number of remote sensing satellites, advances in data fusion and the functionality of modern geographic information systems, the use of multi-image spatial information products is swiftly becoming commonplace. However, in order to meet the requirements of the user, each individual image making up the multi-image product needs to be expressed in the same geometric reference frame. This means the images have to be accurately registered to each other and preferably (but not necessarily) expressed in a local geodetic co-ordinate system. Manual image registration is well established, but the procedure can lead to inaccurate results, and can be slow to execute, especially if a large number of images need to be registered. The subject of automatic image registration addresses, and in many cases solves, the problems associated with manual image registration. However, there still exists a number of scenarios where automatic image registration is not well developed and robust paradigms have not been established for multi-source image registration and image to map registration (Dowman and Dare, 1999).

Feature based image registration relies on extracting and matching similar features from pairs of images so that common points (or tie points) can be located in those images. A survey of previous research shows that although a wide variety of feature based techniques exist, each one generally relies on a single algorithm for extracting the features to be matched. In the new approach to feature based registration presented in this paper, multiple algorithms are used to extract features. The consequence is that not only are many more features extracted, but also different types of features (such as points, lines and polygons) can be extracted and matched. As a result it is possible to match many more features, and therefore increase the number of tie points and the quality of the registration of the images. This technique has been incorporated into an automatic image registration system, and tested using pairs of small and full scene multi-source images.

The automatic image registration system that has been developed is a three step procedure. In each step the images are registered progressively more accurately than in the previous step. Firstly, the images are approximately aligned using four manually selected tie points and a first order transformation, in order to remove large differences in scale and rotation. Secondly, areal features (patches) are extracted from the images using multiple feature extraction algorithms (automatic thresholding, homogeneous patch extraction and segmentation). Patches are matched based on their attributes, such as size, shape and location. A number of algorithms have been developed which optimise the results of the feature extraction and matching algorithms to ensure that (1) the maximum number of matches are found, and (2) the system operates fully automatically. In the third stage of the automatic image registration system, the quantity and quality of the previously located tie points are refined using an edge extraction and matching algorithm. Edges are extracted using a combination of smoothing, edge detection operators and thresholding, and matched using an algorithm based on dynamic programming. The result of this processing is a dense network of tie points spread across the pair of images. These tie points can be incorporated into either a polynomial or a photogrammetric model for performing the image registration.

2 PRINCIPLES OF FEATURE BASED REGISTRATION

2.1 The old way

The procedure for registering multi-source images based on feature matching is well-established, and has been discussed in the past by many authors (Fonseca and Manjunath, 1996). The fundamental methodology is illustrated in its most simple terms in figure 1. For spatial domain feature based automatic image registration, matching primitives (such as points, lines or regions) are firstly extracted from both images using a feature extraction algorithm. These primitives are then matched based on similarities of their attributes (size and shape, for example), and from corresponding matched features, a set of tie points is derived. These tie points can either be used to calculate the parameters of a polynomial transformation function, or used in a photogrammetric model, depending on the type of ephemeris data that is available.

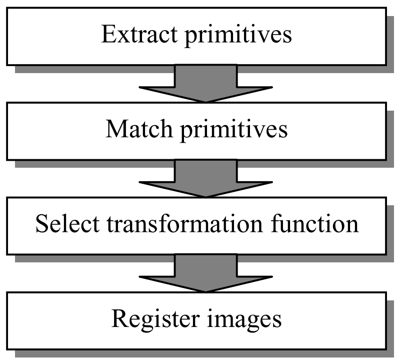

Figure 1. Fundamental model for automatic image registration.

However, there are two principal problems associated with feature based image registration which have to be addressed if the procedure is to be implemented automatically and still produce consistently reliable results. These are:

- recognising similar features in multi-source images; and,
- developing algorithms which are robust enough to produce reliable results from a range of different types of imagery.

The first issue is central to feature based image registration: if features cannot be automatically extracted and accurately matched, then it is not possible to register the images using this method. Depending on which sensors are used, multi-source images of the same target area can appear very different. Figure 2 shows two images (SPOT PAN and ERS SAR) of the Rhône Valley in southern France.

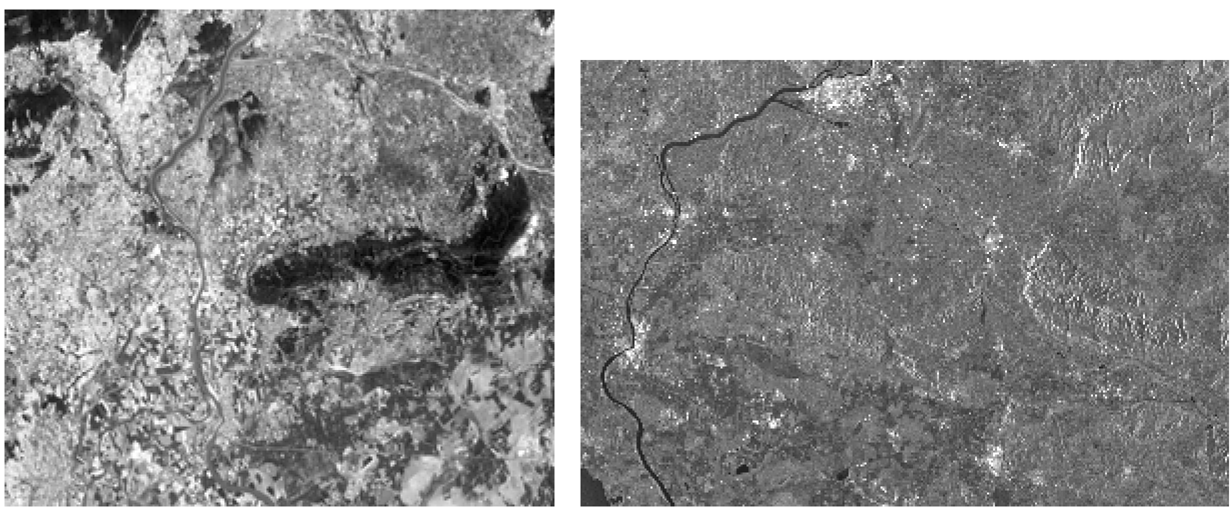

Figure 2. SPOT PAN and ERS SAR images of the Rhône Valley.

The geometric differences caused by different projections, and radiometric differences due to different imaging systems means that it is very difficult to recognise more than just a few common features. The second issue concerns the generality of the automatic registration algorithm. For the algorithm to be truly useful, it must be able to produce quality results for a range of different types of images.

2.2 A new approach

The common theme to the various methods of feature based image registration proposed over the years is the use of a single feature extraction algorithm to extract the matching primitives from both images. The obvious consequence is that the potential for finding common features in a pair of images is severely limited. A new approach to automatic feature based image registration is the use of multiple feature extraction algorithms, rather than relying on just one. Following this methodology has the advantage of simultaneously addressing three distinct problems: reliable feature extraction, generality and automation.

To ensure the results of the registration are of the highest quality, it is extremely important to generate the largest possible set of tie points whilst keeping the number of poorly matched tie points (blunders) to a minimum. The only way to achieve this goal is to reliably match as many primitives as possible, which means extracting as many similar features from each image as possible. By using multiple feature extraction algorithms it is possible to widen the range of different feature classes (points, lines, regions) that are used, as well as ensure that through the redundancy of similar extraction algorithms, almost all features are extracted. For example, areal features which may be overlooked by a thresholding algorithm will be extracted by a segmentation algorithm.

The second advantage of using multiple feature extraction and matching is that the resultant image registration system is able to process many different types of imagery. The problem of trying to develop a single algorithm for extracting and matching features from different data sets, such as radar images, optical images and maps, is overcome.

The final advantage of using multiple feature extraction and matching algorithms is that it is a simple to automate the whole system. A typical attribute of almost all feature extraction algorithms is that one or more parameters have to be manually set by the user in order to achieve optimum results. By applying the same feature extraction algorithm to the same image numerous times with different parameters removes the need for manual intervention and further improves the results by increasing the number of features extracted. It is a common occurrence that algorithms will extract some features with one parameter setting, and other features with a different parameter setting. Thus, by using a range of parameters ensures maximum feature extraction.

The only disadvantage with using multiple feature extraction algorithms, and multiple parameter settings, is that processing time is increased. However, in the tests that were performed this was not found to be a significant problem, since most algorithms generated results in just a few seconds.

2.3 Bringing it all together

The automatic image registration model described in this paper is based on a three step procedure in which registration accuracy increases at each stage of the processing. The three processing steps are:

1. initial alignment using manually selected tie points;
2. approximate registration using patch matching; and,
3. accurate registration using edge matching.

In the first step the images are approximately aligned with each other using a few manually selected tie points in order to remove any gross differences in scale and rotation. Although this step has the disadvantage of introducing manual intervention into the processing, it also has two distinct advantages. Firstly it considerably simplifies the subsequent processing to such a large extent that it enhances the efficiency of the overall procedure. Secondly, it provides the user with the opportunity to view images being registered to ensure there is sufficient overlap and coverage of the area of interest on the ground. The alignment only needs to be very approximate, so three or four tie points and either a similarity or affine transformation function is sufficient.

The second step in the processing improves the accuracy of the registration using tie points located by automatically extracting and matching areal features. In the automatic registration system described in this paper, four patch extraction algorithms have been used, the results of which are combined into a multi-layer data set *before* proceeding to the matching stage of the processing. Feature matching is subdivided into three steps. The first step uses a cost function to match as many patches as possible, even though it is possible that some of the matches may be incorrect. The second and third steps refine the matches using the shape and spatial distribution of the matched patches respectively, until only correct matches remain. The centroids of the matched patches form a set of tie points which are used to generate the parameters of a transformation function, which is subsequently used to register the images. At this point it is possible to increase the quantity and/or quality of the matches by using the patches extracted from one of the images to guide the patch extraction in the other image. Patches are re-extracted and combined with the patches extracted originally, and the matching is repeated. The result is a more refined set of tie points.

The third step in the proposed image registration model improves and refines the accuracy of the registration by extracting and matching edge features. A derivative edge extraction algorithm extracts edges which are matched using an algorithm based on dynamic programming (Newton et al., 1994). The advantage of using this particular edge matching algorithm is that it provides a much larger number of tie points with a more extensive spatial distribution than the patch matching algorithm. However, the images have to be closely aligned with each other (maximum offset of about 3 pixels, with very small rotation and scale differences) for the algorithm to produce reliable results. It is for this reason that patch matching is used to initially register the images.

The result of these three processing steps is a large set of tie points distributed across the master and slave images. The user is now able to select the most appropriate transformation function and resampling algorithm to meet the requirements of the application and register the images.

Further details of the patch and edge extraction and matching algorithms can be found in Dare and Dowman (2000), Dare (1999) and Dowman and Dare (1999).

3 APPLICATION TO RADAR AND OPTICAL IMAGERY

3.1 Small images

Two experiments were performed using radar and optical imagery. Firstly, the traditional method of feature matching was applied to two pairs of approximately aligned ERS-1 SAR and SPOT PAN images of southern France (figure 3). Six different feature extraction algorithms were applied individually to each image. The extracted features were matched with each other, but in each case a maximum of only four corresponding features could be located in each pair of images. Next, the proposed algorithm based on multiple feature extraction was implemented. This time it was found that when the results from all the feature extraction algorithms were combined, the number of matched features doubled. Therefore, it is clear that the combined use of multiple feature extraction algorithms greatly improves the matching results.

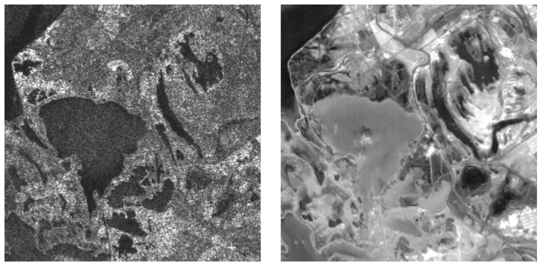

Figure 3a. SAR and SPOT images of Camargue

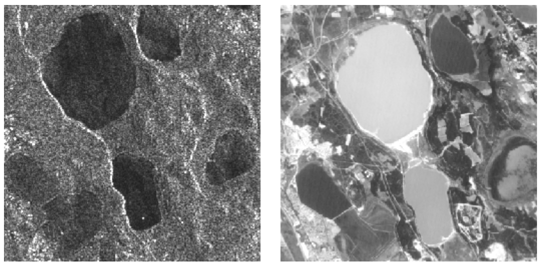

Figure 3b. SAR and SPOT images of Istres

The centroids of the matched features were used as tie points which were in turn used to determine the parameters of an affine transformation and register the images.

The third and final stage of the registration procedure is the extraction and matching of edge features. Edges were extracted from the registered images using a first derivate edge detection algorithm. Edge pixels were matched using an algorithm based on dynamic programming. For both pairs of images between 1500 and 2000 corresponding points were found in each image. Using half of these points to register the images (using an affine transformation function) and the other half as check points, led to an RMS error of 1.5 pixels for each image, or in ground co-ordinates, approximately 15 metres. Figure 4 shows the spatial distribution of a random selection of the residuals (magnitudes have been increased by a factor of 100 for display purposes). It is clear from these results that there is no systematic error present.

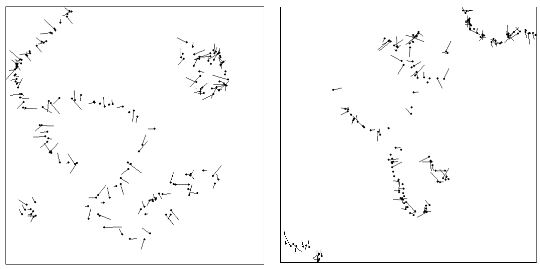

Figure 4. Residuals from registration of Camargue images (left) and Istres images (right)

3.2 Full scene images

The feature matching algorithm was subsequently tested using full scene SAR and SPOT images of the same region of southern France. For maximum efficiency, an approach based on tiling rather than pyramids was used (figure 5). In general images pyramids reduce the search space of the matching algorithm, but at the cost of increasing the feature extraction and matching (since features have to be extracted and matched on all levels of the pyramid). This is not a significant drawback if the extraction and matching processes are computationally efficient. However, the feature extraction and matching methods implemented here are comparatively inefficient, so repeating the process on many layers of an image pyramid increases the processing time. Furthermore, scale is also an issue. The is no guarantee that processing algorithms used to extract features at one scale will produce useful results at any other scale. For these reasons, tiling the images was deemed to be the most appropriate method to use. Tiling the approximately aligned images limits the search space to the size of an image tile, and minimises the feature extraction, since features only have to be extracted on one level.

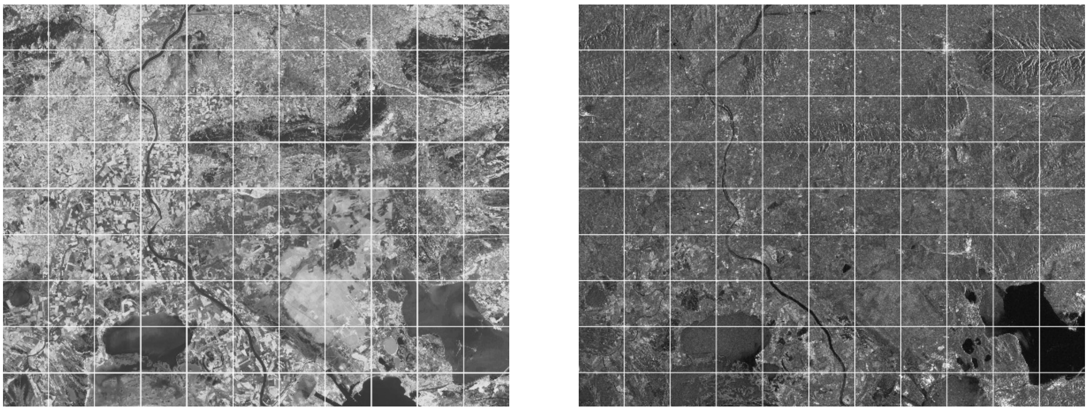

Figure 5. Tiled full scene SPOT (left) and SAR (right) images

The images were processed on a tile-by-tile basis, and as a result 39 matched patches were located in the two images. Using the centroids of these patches to register the images gave an RMS residual of approximately 15 pixels (when using an affine transformation function). The comparatively poor quality of this result is due to the fact that a first order polynomial is unsuitable for registering SAR and SPOT images of this nature, since it is not able to model the geometric distortions. Tiles from which patches had been extracted and matched were registered with each other (using an affine transformation derived from the matched patches within that tile) so that edge features could be extracted and matched. As a result a further 3648 matched points were found in the images from the extraction and matching of edge features. Once again the RMS residuals were calculated. It was now found that the RMS residual was approximately 11 pixels, an improvement of approximately 4 pixels on the result generated from patch matching only. A residual of this size can be accounted for by perspective and terrain effects.

3.3 Automatic orthorectification of SPOT data

It has been shown how two full scene, multisensor images can be automatically registered using feature matching. However, the quality of the final result is compromised by the simplicity of the transformation function. It is obvious that the affine transformation function should not be used to register the images; an alternative, more rigorous mathematical model should be considered. If a digital elevation model of the whole coverage of the two images were available, and if it were of sufficient resolution, it would be possible to automatically register the images to a high degree of accuracy using well-established photogrammetric techniques. The proposed method for is summarised in the flow chart in figure 6.

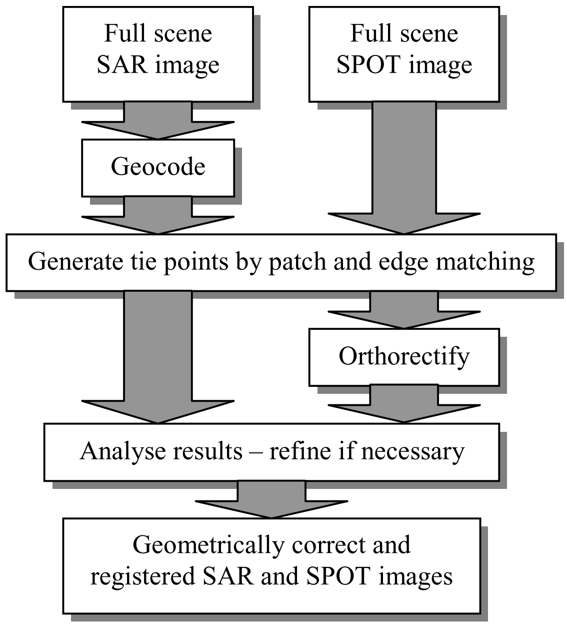

Figure 6. Automatic orthorectification of SPOT imagery

The first step in the procedure is to geocode the SAR data using the DEM. For ERS images supplied with detailed ephemeris data, this can be performed fully automatically with no need for human intervention. Other SAR images (such as Radarsat images) benefit from the use of a few manually measured GCPs (Schreier, 1993). After geocoding, each pixel in the SAR image can be expressed in three dimensional ground co-ordinates (x, y, z). The second step is to generate tie points between the SAR and SPOT images using the patch matching and edge matching techniques described in this paper. The result is that a number of points are found in the SPOT image which can be directly associated with points in the SAR image. Therefore, for each of these points located in the SPOT image, the (x, y, z) location is known in ground co-ordinates, effectively making these points ground control points. This means that all the information required to orthorectify the SPOT image is available: a DEM, a set of GCPs and a camera model. Thus, the next stage of the processing is to orthorectify the SPOT image using this data. The result is that both the SAR and SPOT images are now geometrically corrected, and expressed in the same ground co-ordinate system – they are effectively registered to each other. The final stage in the processing is to compare the locations of features in the images in order to assess the accuracy of the registration. Any inaccuracies could be reduced by repeating the patch matching procedure and generating a new set of tie points. These points would then be used to determine the parameters of a polynomial transformation function which, when applied to the images, would reduce any small errors that may exist. A similar method of orthorectifying SPOT images using the superior geometry of SAR images was proposed by Renouard and Perlant (1993). They found that the planimetric accuracy of SPOT products could always be increased when corrected with ERS data.

4 CONCLUDING REMARKS

This paper has presented an improvement to the traditional method of feature based image registration. By employing multiple feature extraction algorithms it was found that the quantity and quality of correctly matched features could be greatly increased. The result is a more accurate registration result, compared to if only one feature extraction algorithm were used. Although the proposed method increases the volume of processing, that increase is not significant, and it is justified by the results. This paper has also outlined how the method of automatic detection of tie points in multi-source imagery can be used in well-established geometric correction models in order to reduce manual intervention in the image geocorrection process. The techniques described in this paper are not limited to SAR and SPOT imagery, but can be applied to many different data sources. Work is currently under way to apply these techniques to high resolution satellite imagery and digital map data for automatic GCP measurement.

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