An Automated Image Registration System For SPOT Data

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PURPOSE:

This paper reports the development of a software system which automatically registers one SPOT image to another. The work is the second phase of a contract for the Western European Union Satellite Centre (WEU). The system is known as the Prototype Automatic Image Registration System (PAIRS) and has been carried out by Earth Observation Sciences Ltd, University College London, the Institute for Photogrammetry of the Technical University of Stuttgart and the University of Oporto. Future phases of the work will incorporate a three dimensional transformation and allow the co-registration of imagery from different sensors.

1. SYSTEM OVERVIEW

1.1 Rationale of the System

Image registration is a necessary precursor to many remote sensing applications, such as the detection of change. Manual selection of the large number of tie points required to achieve the required accuracy of image registration is often a laborious process. The system described below takes two panchromatic SPOT 1A images which have at least 50% overlap and registers the two images. This is achieved by the automated determination of tie points. Once these tie points are determined a geometric transformation is calculated between the two images and the second image resampled to co-register it with the first image.

1.2 Process Overview

Images are co-registered by the automated determination of tie points. From a set of tie points defining conjugate points in two images an n dimensional transformation can be defined. This is applied to an image pair, such that the second image is resampled to the first image.

The heart of the system is a set of processes which seek to define a set of reliable tie points which can be used in the definition of an image to image transformation. Possible tie points are found on each image of an image pair. These sets of points are considered and conjugate point pairs determined. A major part of the system is thus essentially an image matching system. The matching is of point features. Future phases on the system will attempt to match on the basis of other features such as regional features.

An important aspect of the system is that it is automated, or at least as automated as possible. The procedure of defining a set of good tie points, and hence good geometric transformation, is iterative, with a series of refining procedures removing tie points for which there is no strong evidence.

The procedure is also pyramidal. Matching is performed for different spatial resolutions of the imagery. The images are subsampled and matching is performed. The resulting transformation is used to kick off the matching procedure for images sub sampled at a different level.

2. SYSTEM DETAILS

2.1 The System Components

The system is designed in a modular manner. The system components are:

- initial image registration
- image smoothing
- image subsampling
- areas of interest
- interest point extraction
- feature point matching
- intensity matching

2.2 Initial Image Registration

The procedure requires an initial image registration, to kick off the hierarchic and iterative matching procedure. The initial registration is defined in one of three manners.

The user can define two tie points manually from which a Helmert transformation is defined using a method outlined by Maling (1991).

Alternatively a single tie point is manually defined by the operator. This allows for the translational component of the transformation between the two images. The scene heading information from the SPOT image header is used to determine the rotational component of the transformation.

An initial transformation can be determined solely from the SPOT image header information, using the latitude and longitude specified for the corner points and centre point of each scene. This is for SPOT products of 1A level processing. The initial transformation defined in this manner will normally be of poorer quality than that defined with control points.

2.3 Image Smoothing

A low pass Gaussian filter is applied to all imagery before features are extracted from the imagery. The width of the Gaussian function can be modified, resulting in variable degrees of smoothing. This procedure attempts to reduce high frequency noise in the imagery, and improve the results of the feature point extraction procedure.

2.4 Image Subsampling

The SPOT image is sub sampled to different resolutions. In practice this involves the selection of the nth pixel in each row and column. If this procedure is applied to a SPOT image pair for various resolution reductions then an image pyramid can be built up. The bottom of the pyramid is the full resolution image, the top of the pyramid is the image pairs with the most severe resolution reduction.

Matching is first performed on the top image pair in the pyramid. This is the image pair with greatest resolution reduction. Interest point extraction and point matching are applied at this resolution. The initial transformation defined between the two images may not be very precise, but this should not be a problem because interest points extracted at this resolution should correspond to major features. Moreover any error in the transformation at this scale should have little affect on the matching procedure

The resulting transformation defined between the two images should be an improvement on the initial transformation. This new transformation can be passed onto the next level of the pyramid. In this manner, the pyramid system allows an initial loose transformation to be redefined and improved, as the procedure passes down the pyramid.

In practice the image resampling is performed in synchronicity with the image smoothing, otherwise image aliasing would be a possibility.

2.5 Region Of Interest Definition

Within a SPOT image there may be areas which are particularly suitable for matching, or conversely areas, such as cloud, which will detract from the results of image matching. The operator can view the two images to be registered and highlight areas which will be used in the matching, or alternatively can mask out those areas that should not be considered in the image matching procedure.

2.6 Feature Extraction

Feature extraction is the process which determines in each image those features which have a particular characteristic that make them potentially good features to match. They are ideally features that exist in both images! The features matched in this phase of the PAIRS system are points (individual pixels). In the next phase of PAIRS matching will also be achieved by considering area (polygon) features.

In this process the Forstner operator is used to determine 'interest' points in an image. The Forstner operator in practice requires the passing of several filtering kernels over an image, followed by several arithmetic operations to define two quantities for each pixel. These quantities are 'weight' and 'roundness'. The image is thresholded on the basis of these quantities. Any remaining pixels are non maximally suppressed so that clusters of pixels are reduced to a single pixel (interest point).

The 'weight' value for each pixel is retained. It is used as an initial weighting for a pixel in the feature matching process.

2.7 Feature Matching

2.7.1 Objective

The feature matching process takes as its input a SPOT image pair, from which interest points have been determined. The objective is to match interest points in the first image of the pair to interest points in the second image of the pair.

2.7.2 Defining Initial Matches

The first step is to determine possible matches between an interest point in the first image and any number of interest points in the second image. A geometric transformation exists between the two images, supplied by a higher level in the pyramid or by the operator. This is used to predict the position of a point from the first image, in the second image. From this predicted position a search is made within a window of specified size for interest points. Any points found inside this window are considered as possible matches.

The result of this procedure is a list with the identity of a point from the first image associated to the identity of possible matches in the second image. It should be noted that a single point in the first image can be matched to several points in the second image, and *vica versa*.

2.7.3 Cross Correlation

The above procedure tends to produce a large number of matches, some of which are ambiguous. Considering a given conjugate point pair, an image chip is placed around each pixel and image cross correlation is calculated. This may require the resampling of one of the chips if the is significant rotational or scale differences between the two images. If the cross correlation value falls below a given threshold then this conjugate pair is removed from further consideration.

2.7.4 Robust Transformation Estimation

The resultant conjugate points from the above procedure are then processed by a Robust Transformation Estimation procedure. This procedure seeks to determine a geometric transformation between the two images based on the conjugate points. It is an iterative solution in which each conjugate pair is initially weighted. These weightings are updated based on the calculated point residuals for each iteration. Outliers are removed at each iteration, and the procedure continues till convergence is achieved, or a maximum number of iterations has occurred. The initial weights of the conjugate points are based on each points 'weight' calculated by the interest operator.

The robust transformation estimation results in a trimmed set of conjugate points, in which unlikely conjugate points having been rejected. A new geometric transformation is also defined.

It is likely that some ambiguities still exist, with a single point in the first image matched to more than one point in the second image, or *visa versa*. These ambiguities are removed by selecting the conjugate point pair with the lowest residual (weight). Once ambiguities have been removed a new geometric transformation is defined.

2.7.6 Tile Matching

Feature matching is generally not performed over the whole image, but rather for tiles within the image. Tiles are used because a low order transformation cannot be extended over a whole SPOT scene without the introduction of unacceptable errors, during the matching process.

Large images are split into tiles of approximately 500 by 500 pixels. Matching will occur within these tiles. In practice only the first image of the image pair is tiled because points within a tile in the first image can be matched to points in several tiles in the second image.

A geometric transformation is calculated for each tile, and these must be appropriately propagated from one level of the pyramid to the next.

When matching has been completed for a tile, a tile from the first image is cross correlated with its corresponding area in the second image, based on the most recently defined image transformation. Again resampling will occur if rotation or scale differences require this. If the cross correlation is less than an operator specified threshold, then the transformation for the tile is rejected. This tile is then frozen and no more processing is performed on the tile at any level of the pyramid.

2.8 Image Based Intensity Matching

Intensity matching is performed only at the bottom of the pyramid, rather than at every level of the pyramid. Intensity matching is a final check on the validity of each conjugate point pair, either accepting or rejecting the pair, based on considering the grey level values of pixels around each point of the conjugate point pair (Ackermann 1984).

Given a conjugate point pair an image chip is considered around the points in each image. These two chips may differ due to radiometric and geometric inconsistencies. A transformation is sought to take into account these elements. Starting with approximate values for the unknown radiometric and geometric coefficients a least squares solution is found for the transformation between the two windows. The initial coefficients are updated after the first iteration and the second image chip is resampled based on the geometric coefficients. The procedure is iterated till convergence is achieved. If convergence is not achieved after some iterations then the conjugate point pair is rejected.

At the end of this procedure a trimmed down set of conjugate points can be XPECTed.

2.9 Transformation Calculation and Resampling

Procedures exist to allow the calculation of geometric transformations from a set of tie points. These are usually applied after the intensity matching. Based on a geometric transformation a SPOT image can be resampled, affecting the co-registration of two images.

2.10 Other Components

The system holds SPOT data in a unique internal format, but maintains all SPOT associated files. The system can ingest SPOT Panchromatic data and export files in the same format.

3. RESULTS

From some limited testing of the system the system has achieved sub pixel accuracy in image registration in ideal situations of low relief and plentiful matchable features, particularly arable farming scenes. In areas of greater relief change and much fewer matchable features the registration accuracy deteriorated to around 2 pixels.

4. SYSTEM ISSUES

4.1 Implementation of the System

The PAIRS system built in an open architecture concept, using ENVI/IDL COTS software, and is hosted on a SUN platform using the UNIX operating system. The system architecture is based on a software package developed by Earth Observation Sciences Ltd called XPECT.

XPECT is a visual programming environment in which modules (processes) are represented iconographically and visually strung together on a GUI to form chains which are processed. Chains can be saved, reloaded and modified. The modular design of the PAIRS system within XPECT results in a high degree of flexibility. All the procedures need not be run to produce an image registration. For example the Image Intensity process can be omitted if required.

The XPECT environment is also ideal for experimental work, as chains can be modified and re-executed at will, allowing the operator to quickly optimize system parameters.

5. FUTURE WORK

The next phase of the PAIRS work will build on the work outlined in this paper. The major diference is that in addition to SPOT data, the system will process other optical data, including MOMS and IRS-1C. The image registration will also be cross sensor, so for example a SPOT image will be registered with a MOMS image.

The system will also incorporate camera models two allow the generation of three dimensional coordinates and hence Digital Elevation Models (DEM).

6. References

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