ENVI Image Registration

Whitepaper

Exelis Visual Information Solutions
4990 Pearl East Circle Boulder · CO · 80301
303.786.9900 · www.exelisvis.com

Table of Contents

Exelis Visual Information Solutions
4990 Pearl East Circle Boulder · CO · 80301
303.786.9900 · www.exelisvis.com

Introduction

Image Registration geometrically aligns two images with different viewing geometry and/or different terrain distortions into the same coordinate system so that the corresponding pixels represent the same objects. You can typically obtain the geometric relationship between a warp image and a base image through a number of tie points, and you can model the relationship using transformation capabilities. Automatic tie point generation and accurate image-to-image registration is essential for many applications including:

- **Georeferencing:** Register an image with no or poor georeferencing information to an orthorectified reference image to have it geo-referenced. Image registration allows you to align the image to your existing base map image, such as NGA's Controlled Image Base imagery. Accurate planimetric geolocation of images is critical for earth monitoring and mission planning.

- **Change detection:** Register two images from different times. Temporal registration can be used for change detection and earth resources observation, including monitoring of changes of land cover, agricultural, and geological features extracted from images over a period time.

- **Data fusion:** Register images with different modalities, such as optical, radar, thermal, etc. Multi-modality registration enables the integration of complementary information from different sensors, and to combine information from different sources to extract information and help the decision-making process.

- **Image mosaicking:** Register images that have overlapping geographic areas to create a seamlessly mosaicked image. Seamlessly mosaicked images can be used to create scientific visualization of the earth. Mosaicked, orthorectified images can also be used as a base map image for many geospatial applications.

- **DEM extraction:** Automatically generate tie points from stereo images to extract DEM information. The tie points model the geometric relationship between the stereo images and are used to define the epipolar geometry, create epipolar images and stereoscopic images, and extract the elevation information from the images.

- **3D modeling:** Multiview images of a 3D scene contain local geometric differences due to variation in local terrain relief and differences in imaging view angle. Registering multiview images can be used to integrate information from a sensor or multiple sensors from different viewing angles into three-dimensional models.

Exelis Visual Information Solutions' geospatial software package ENVI provides a solution to streamline the image registration workflow. It allows you to automatically and accurately generate many tie points, and then align and resample the second image (warp image) based on those tie points to match the base image. With the automated image registration workflow, the human interaction in registering images from different times, different sensors or different viewing angles is minimized or eliminated. You can use automated image registration in a batch processing environment. You can also incorporate image registration into other automated production systems.

This white paper will provide an introduction of ENVI's Image Registration solution. It will overview how it can help you to accurately, reliably, and automatically generate tie points from images and register images obtained over a period of time, from the sensors of multiple modalities, or from a sensor or multiple sensors from different viewing angles.

Overview

Image registration is the process of aligning two or more images. Image registration involves locating and matching feature points in the two images to be registered. Those points are typically called tie points. The corresponding tie points are then used to compute the parameters of a geometric transformation between the two images.

In manual registration, a human operator performs these tasks visually using interactive software. The process is repetitive, laborious, tedious and prone to error. Manual registration becomes prohibitive for a large amount of data and large geographic coverage.

An automated registration solution is highly desired in a production environment. In automated registration, algorithms automatically generate tie points and align the image. A few commercial software packages follow an automated registration approach. However, remote sensing images have various characteristics that make automated registration difficult. Location errors may occur in the navigation and during spacecraft maneuvers. The atmospheric scattering and absorption affect the fidelity of remote sensing data. Various image characteristics due to multitemporal effects, terrain effects, different sensor modalities and different spatial resolution all make automated registration a challenging task. Automated registration in remote sensing does not always offer the needed reliability and accuracy, so often manual editing of tie points is needed.

ENVI Image Registration streamlines the registration process in a workflow. The Registration Engine generates many tie points automatically and accurately. It takes advantage of all the available spatial reference information to achieve the best accuracy and automation during registration. It combines a number of registration approaches to improve the reliability, accuracy, performance and automation of image registration. It is robust in the situations of images obtained from different viewing angles, in different time and seasons, with various terrain relief, and by sensors with different modalities. The algorithm is automated and optimized so that human interaction and editing is minimized or eliminated.

ENVI Image Registration offers the main advantages below:

- **An easy-to-use workflow wizard.** It guides you through selecting input images, generating tie points automatically, reviewing and editing tie points, previewing image warping results, and exporting image registration results and tie points.

- **Automatic and accurate tie point generation.** The tie points are automatically extracted and outliers are automatically removed. The algorithm is automated and optimized so that the needs of human interaction and tie point manual editing are minimized.

- **High precision of tie points.** The tie points are extracted on distinctive feature points, such as building corners, road intersections, salient point features, etc with pixel or sub-pixel accuracy.

- **Fast to generate results.** The core algorithm is optimized and takes advantage of high-performance multi-threaded computation. It provides an efficient solution in a production environment.

- **Robust to variation in local terrain relief.** If the base image or warp image includes RPC information, you can specify a DEM file. The Registration Engine performs orthorectification on-the-fly, and automatically generates tie points in the common ground coordinate space. It improves the tie point generation, especially in the mountainous areas.

- **Capability to register multi-modality images.** An image matching method that is suitable for registering images with different modalities (e.g., registering radar with optical images, or thermal with visible images) is provided to allow registering multi-modality images.

- **Robust in registering multitemporal images.** A multi-trial strategy is used to reliably generate tie points in images with considerable scene content differences due to changes in time or season, new constructions, deforestation, and differences in imaging view angle.

- **Capability to register multiview images.** Epipolar geometry models are used to automatically remove the outliers of tie points generated from multiview images. Two epipolar geometry models are available: one is suitable for the imagery taken by frame camera, and the other is suitable for the imagery taken with a pushbroom sensor that has RPC information.

- **An easy way to review tie points.** You can review tie points by visually examining and sorting the points by the quality metrics. You can also use the Error Overlay to view the relative geometric errors of your tie points in a graphics overlay.

- **Capability to preview output image.** A preview provides a What You See Is What You Get (WYSIWYG) result while you are adding or deleting tie points or changing the warping parameters.

- **Options to choose output extent.** You can choose to warp the full extent of the warp image, for example, for georeferencing or image mosaicking purposes. You can choose to warp the overlapping area only, which is typical for change detection applications.

- **Options of image warping and resampling.** A few image warping and resampling methods are provided. If there are considerable geometric differences between the images due to variation in local terrain relief and differences in imaging view angle, triangulation warping is able to accurately align the images exactly at the tie point locations.

Image Registration Engine

The core engine of ENVI Image Registration is a Hybrid Powered Auto-Registration Engine (HyPARE). HyPARE's Registration Engine combines all available spatial reference information with a number of image registration approaches to improve the accuracy, performance, and automation of tie point generation and image registration.

The key components of the Hybrid Powered Auto-Registration Engine are shown in Fig. 1.

The hybrid spatial reference component combines all the available spatial reference information to achieve the best accuracy and automation during registration. The spatial reference information of the HyPARE Registration Engine may come from the following sources:

- Standard map information or RPC information of input images. Standard map information or RPC information establishes the approximate geometric relationship between a warp image and a base image. It reduces the search space and improves the reliability of automatic tie point generation.

- Tie point information manually defined by you or automatically generated from image matching techniques. For most applications, HyPARE can automatically generate tie points with no or minimized number of outliers. You can also manually define a few seed tie points and feed them into automatic tie point generation to improve the overall accuracy.

- Geo-location geometric constraints to search for and filter tie points. The images should align well in the common ground coordinate space in the orthorectified images or nadir view images; therefore, all the tie points are constrained by a global transform between the coordinates in the base image and the warp image.

- RPC sensor models and elevation used for orthorectification on-the-fly during image registration. This geometrically corrects the data to a common ground coordinate space, and achieves better accuracy in automatic tie point finding and filtering. The tie points can be automatically generated even in the image areas with big distortion due to terrain relief, such as mountainous areas.

- For images taken at different viewing positions and/or angles, the images of the same scene are related by the epipolar geometry constraint. For a feature point in the first image, the corresponding point in the second image must lie on the epipolar line or curve. Two epipolar geometry models are used in geometric filtering: one is suitable for the imagery with the frame central projection, and the other is suitable for the imagery obtained with a pushbroom sensor that has RPC information.

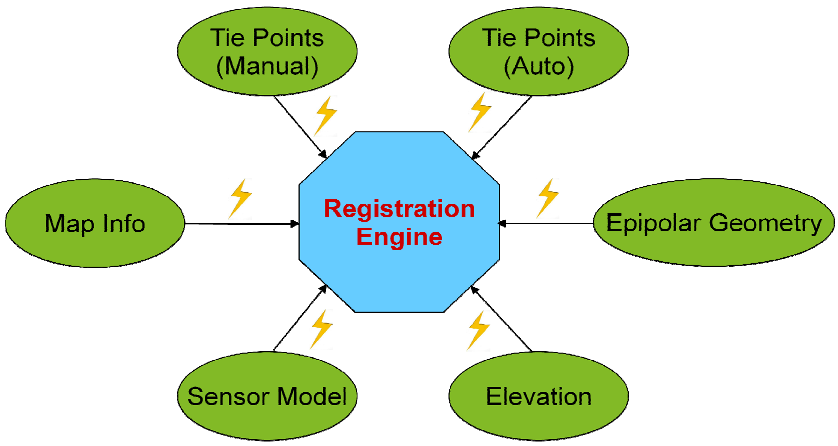


Figure 1. Hybrid Powered Auto-Registration Engine (HyPARE).

Image Registration Workflow

Exelis Visual Information Solutions' geospatial software package ENVI provides a streamlined image registration workflow.

The Image Registration workflow wizard guides you through the steps below:

- Select Files for Image Registration
- Generate Tie Points Automatically
- Review Tie Points and Preview Warped Image
- Export Image Registration Results and Tie Points

First, select a base image as the reference image and select a warp image to be registered with the base image. The base image can have standard map projections or RPC information; it cannot be pixel-based, arbitrary, or a pseudo projection. The warp image does not have restrictions. It is recommended that you use the image with higher georeferencing accuracy as the base image. If one input image is an orthorectified image, it is recommended that you use this image as the base image. If a pixel-based image or an image with pseudo projection or arbitrary projection is used as the warp image, you need to select at least three seed tie points to define the approximate relationship between the two images.

Tie points are automatically generated from the images by the HyPARE Registration Engine. Auto tie point generation compares the gray scale values of patches of two images and tries to find joined image locations based on similarity in those gray scale value patterns. Two image matching methods are available: a correlation-based method and a mutual information-based method. The Mutual Information-based method is optimized for registering images with different modalities (e.g., registering radar with optical images, or thermal with visible images). The false tie points with a low matching score are removed. The outliers are further removed by fitting and filtering by a geometric model. You can select the geometric model from a global transform model or two epipolar geometry based models.

If the base image or warp image includes RPC information, it is recommended that you use a DEM file. The Registration Engine performs orthorectification on-the-fly, and generates tie points in the common ground coordinate space. The image is geometrically corrected for automatic tie point generation. Radiometric matching and geometric filtering are performed in the common ground coordinate space to improve the reliability and accuracy of tie point generation. If you use a DEM file, the higher the resolution and accuracy of the DEM data, the more tie points that are generated, and the better the distribution of those points.

After tie points are automatically generated, you can choose to review, add, or delete tie points. The automatic tie point generation algorithm is optimized to minimize or eliminate the need for manual tie point editing. You can change image warping and resampling parameters and preview image warping results. You can choose to output the full extent of warp image or the overlapping area only. At the end, you can export the warped image which is registered with the base image. You can also save tie points to be used in other applications or systems.

See the ENVI documentation for a complete workflow description. (Exelis Visual Information Solutions, 2012).

A change detection application of image registration is shown in Fig. 2. Fig. 2a shows View Swipe on two images obtained on different dates before image registration. The two images do not align well and it is not easy to perform change detection analysis. Features align well after image registration and the result is shown in Fig. 2b.

Figure 2. Image registration for change detection analysis. a) View Swipe before image registration. b) View Swipe after image registration.

Technical Guide

ENVI Image Registration allows users of all skill levels to generate data free of misalignment issues. For users with less experience, the parameters are adaptive and automatically set based on the input images, and the process is fully automated. The needs of user interaction and manual editing are minimized or eliminated. The user does not need a strong remote sensing background to use the workflow.

In some cases, there is not enough information in the input data or metadata for the algorithms to optimally set all parameters. For those cases, you may need to adjust parameters to control the quality of automatic tie point generation and image registration. See the ENVI documentation for a complete description of all parameters in the Image Registration workflow. (Exelis Visual Information Solutions, 2012).

For successful automatic tie point generation, the number of tie points generated should be reasonable amount. The closer the number is to the **Requested Number of Tie Points**, the better the automatic tie point generation process. The tie points should be well distributed across the overlapping areas. If there is a significantly uneven distribution of tie points, and the images contain local geometric differences due to variation in local terrain relief and difference in imaging view angle, you may need to manually add tie points to compensate.

In this section, we will provide technical guidance to help you adjust parameters and achieve the best registration results in different challenging scenarios.

Considerations when there is big misalignment between images

If the georeferencing information of the input image is poor, or if two images contain considerable geometric differences due to variation in local terrain relief and difference in imaging view angle, there is big misalignment between the two images. You have a few options.

Collect Seed Tie Points

If manual interaction is acceptable in your project, you can manually collect seed tie points from the images by selecting point pairs located at the same features in both images. The seed tie points you add do not need to be highly accurate, but provide information needed for automatic tie point generation. It is recommended that you select points on the distinctive image features, such as building corners, road intersections, salient point features, water boundaries, etc. A minimum of three tie points are needed.

Increase Search Window Size

The search window is a subset of the warp image that is searched to find feature matches for tie point placement. The default value of Search Window Size is 255 for most images. Increasing the **Search Window Size** may be necessary, but increases processing time. If the pixel offset of the same features in the two images is greater than the **Search Window Size**, the search will not be able to detect and match corresponding features. To determine a different **Search Window Size**, do the following:

- Show both base image and warp image. Select the warp image (the top layer), and set the transparency to 50%.
- Open the Cursor Value window.
- In the Image window, find a feature and click on it. Note the file coordinate on the base image in the Cursor Value window.
- Click on the same feature in the warp image and note the file coordinate on the base image in the Cursor Value window.
- Determine the distance in pixels between the two readings. Find the maximum distance across the image and use 2*(distance+5) as your new **Search Window Size** value.

Increase Maximum Allowable Error Per Tie Point

Multiview images of a 3D scene contain local geometric differences due to variation in local terrain relief and difference in imaging view angle. If image misalignment is mainly due to local geometric differences, you can increase **Maximum Allowable Error Per Tie Point**.

If using the **Fitting Global Transform** method, enter the maximum error to allow for each tie point in the **Maximum Allowable Error Per Tie Point**. The tie point with the largest error distance from the predicted location is iteratively removed until no tie points have an error greater than this value. The default value is 5 pixels. Setting this field to a higher value keeps more tie points with larger fitting errors. If you would like to keep most tie points and review them in the Review Tie Points step, set it to a high value such as 100.

Considerations when registering images with RPC information

Many images from commercial satellite are distributed with RPC information, for example, QuickBird, IKONOS, GeoEye-1, WorldView-1, and WorldView-2, etc. Rational Polynomial Coefficients (RPCs) are a set of coefficients to express image pixel coordinates as the ratios of polynomials of ground coordinates. RPC models the relationship between the 2D image coordinates and 3D ground coordinates. Vendors often provide RPCs as a replacement to the physical sensor model to protect proprietary sensor designs. It also facilitates processing in remote sensing software that uses sensor-independent models.

Images with RPC information that is obtained from off-nadir view and especially in mountainous areas typically have local distortion due to variation in terrain relief. For those images, it is always recommended to specify a DEM data in the workflow. You can combine the two options below to improve the accuracy of automatic tie point generation and image registration.

Specify DEM Data

If the input images have RPC information, the workflow allows you to specify DEM data. The Registration Engine performs orthorectification on-the-fly, and generates tie points in the common ground coordinate space. It improves the tie point generation, especially in the mountainous areas. If you use a DEM file, the higher the resolution and accuracy of the DEM data, the more tie points that are generated, and the better the distribution of those points. Using a DEM takes longer to run as more processing is involved.

Use Pushbroom Sensor as the Geometric Model

For images obtained with pushbroom sensor(s), the images of the same scene are related by epipolar geometry constraint. For a feature point in the first image, the corresponding point in the second image must lie on the epipolar curve. The Registration Engine uses this information to filter tie points automatically. Epipolar geometry of a pushbroom sensor is different from that of a conventional frame camera. Select **Pushbroom Sensor** from the **Geometric Model** list when images have RPC information and are obtained with pushbroom sensor(s). It improves the robustness of automatic tie point generation, especially if the scene terrain consists of mountainous and high-terrain relief.

Considerations when the image pairs have a large parallax

Multiview images of a 3D scene contain local geometric differences due to variation in local terrain relief and difference in imaging view angle. Enough parallax information is essential for DEM extraction and 3D modeling; however, it makes automated image registration difficult. You can combine the two options below to improve the registration accuracy.

Decrease Minimum Matching Score

Minimum Matching Score is used to automatically filter tie points based on radiometric criteria. For automatic tie point generation, a window around the tie point location is used as a matching window, and the matching score between the window in the base image and the window in the warp image is computed. Tie points with a matching score less than this value are considered as outliers and are removed. If the image pairs have a large parallax, it is likely that the matching score is low so it is suggested to decrease this value. When **Cross Correlation** is used as matching method, the default value of **Minimum Matching Score** is 0.6 for most images. It is suggested to change it to a lower value, such as 0.4.

Use Frame Central Projection as the Geometric Model

For images of a 3D scene obtained with a conventional frame camera, the images of the same 3D scene are related by epipolar geometry constraint. For a feature point in the first image, the corresponding point in the second image must lie on the epipolar line. The Registration Engine uses this information to filter tie points automatically. Select **Frame Central Projection** from the **Geometric Model** list when images are obtained with a frame camera. It improves the robustness of automatic tie point generation, especially if the image pairs have a large parallax.

Considerations when registering images with different modalities

Registering images with different modalities is a known challenging problem. The Registration Engine provides a solution to allow you to generate tie points automatically for cross-modality image data. You can choose one of the options below.

Use Mutual Information as Matching Method

The **Mutual Information**-based method is optimized for registering images with different modalities (e.g., registering SAR with optical images, or thermal with visible images). Mutual information produces more accurate results than the traditional correlation-based measures for cross-modality image registration. This method takes longer to run since it is more computationally intensive. However, it is more robust to generate tie points from images with different modalities.

Decrease Minimum Matching Score when Cross Correlation is used

If you would like a fast way to automatically generate tie points for images with different modalities, you can try **Cross Correlation**. The gray scale value patterns at the same features of two images will be less similar if the two images are obtained with different sensors. It is recommended to decrease **Minimum Matching Score** to a lower value, such as 0.4 so that more tie points are retained. You should visually examine the tie point in the Review Tie Points step.

Other considerations

Spectral consideration: Automatic tie point generation uses a single band if multi-band images are used to find the tie points. You will get the best results if the two bands selected have the same or similar spectral characteristics. If both images have wavelength information, the visible red band is appropriate and used by default.

Spatial consideration: Automatic tie point generation is more reliable when the two images have the same or similar spatial resolution. The features will have similar shape and be less impacted by the variation of mixed pixels if the two images have same or similar spatial resolution. ENVI Image Registration allows you to use two images that have a pixel size ratio up to 20.

Image warping transformation consideration: For orthorectified images, nadir, or near-nadir images, the transformation model between the base image and the warp image fits an **RST transform**. When the scene is rather flat and the sensor is very far from the scene, the transformation model between the base image and the warp image fits a **First-Order Polynomial Transform**. If there are considerable geometric differences between the images due to variation in local terrain relief and difference in imaging view angle, a global transformation may be inappropriate and **Triangulation Warping** is able to accurately align the images exactly at the tie point locations.

Tips for reviewing tie points

After tie points are automatically generated, you can choose to review tie points. The most reliable way to review tie points is through visual examination. The good tie points should locate at the same features on both images. For most images, the tie points should be well distributed across the overlapping areas. If there is a significantly uneven distribution of tie points, and the images contain local geometric differences due to variation in local terrain relief and difference in imaging view angle, you may need to manually add tie points in those areas to compensate.

In the ENVI Image Registration workflow, you can either use buttons on the user interface, or use keyboard keys on Windows platforms to navigate and review tie points. See ENVI documentation for details. (Exelis Visual Information Solutions, 2012).

Quality Metrics of Tie Points

Two quantitative metrics are provided for each tie point. The tie points attribute table includes SCORE and ERROR columns to indicate the quality measurement of the tie points.

- The SCORE is from radiometric matching. A patch around the tie point location is used as a matching window. Depending on the matching method you choose, the normalized cross-correlation or normalized Mutual Information between the window in the base image and the window in the warp image is computed as the matching score. Manually added tie points have a SCORE of 1.0. The higher the SCORE, the closer the gray scale patterns in the image patches match. You can sort the SCORE column in forward order to place the tie points with a lower score at the top of the table and examine them first.
- The ERROR measurement comes from the calculated error distance of the tie point from the predicted location. The predicted location is computed based on fitting a first-order polynomial transform from points on the base image to points on the warp image. If the base image or warp image have RPC information and you specified a DEM file, the error is measured in a common ground coordinate space. You can sort the ERROR column in reverse order to place the tie points with a higher error at the top of the table and examine them first. The ERROR measurement reflects the quality of fitting to the first-order polynomial math model. Higher errors may indicate bad tie points, or an inappropriate geometric model used. It does not necessarily reflect the positional errors in the tie points. The best way to check the accuracy of the tie points is to visually examine their placement in the Image window.
- The total root mean square (RMS) error displays at the bottom of the Tie Points Attribute Table. RMS error could indicate the overall tie point quality. However, it could be a fitting error of the geometric mode that is used. You should always perform visual examination along with the RMS error analysis.

Error Overlay

If you have five or more tie points, you can select to overlay a transparent color gradient that shows the relative geometric errors of your tie points. The Error Overlay is based on ERROR values in the Tie Points Attribute Table. The ERROR measurement reflects the quality of fitting to the first-order polynomial math model. Higher errors may indicate bad tie points, or an inappropriate geometric model used. The best way to check the accuracy of the tie points is to visually examine their placement in the Image window.

Dark grey areas represent tie points with negligible error magnitudes, while orange-to-white areas represent tie points with higher error magnitudes. It is recommended that you examine the tie points in orange-to-white areas and delete those tie points or add new ones as needed. Dark-red to bright-red areas represent tie points with error magnitudes within a reasonable range (2.5 to 10.). Examine the tie points in those areas depending on the level of accuracy you desire. You should always perform visual examination along with the error analysis.

See Fig. 3 for an example of Error Overlay and Tie Points Attribute Table. In this example, most generated tie points with a higher error value locate in the mountainous areas.

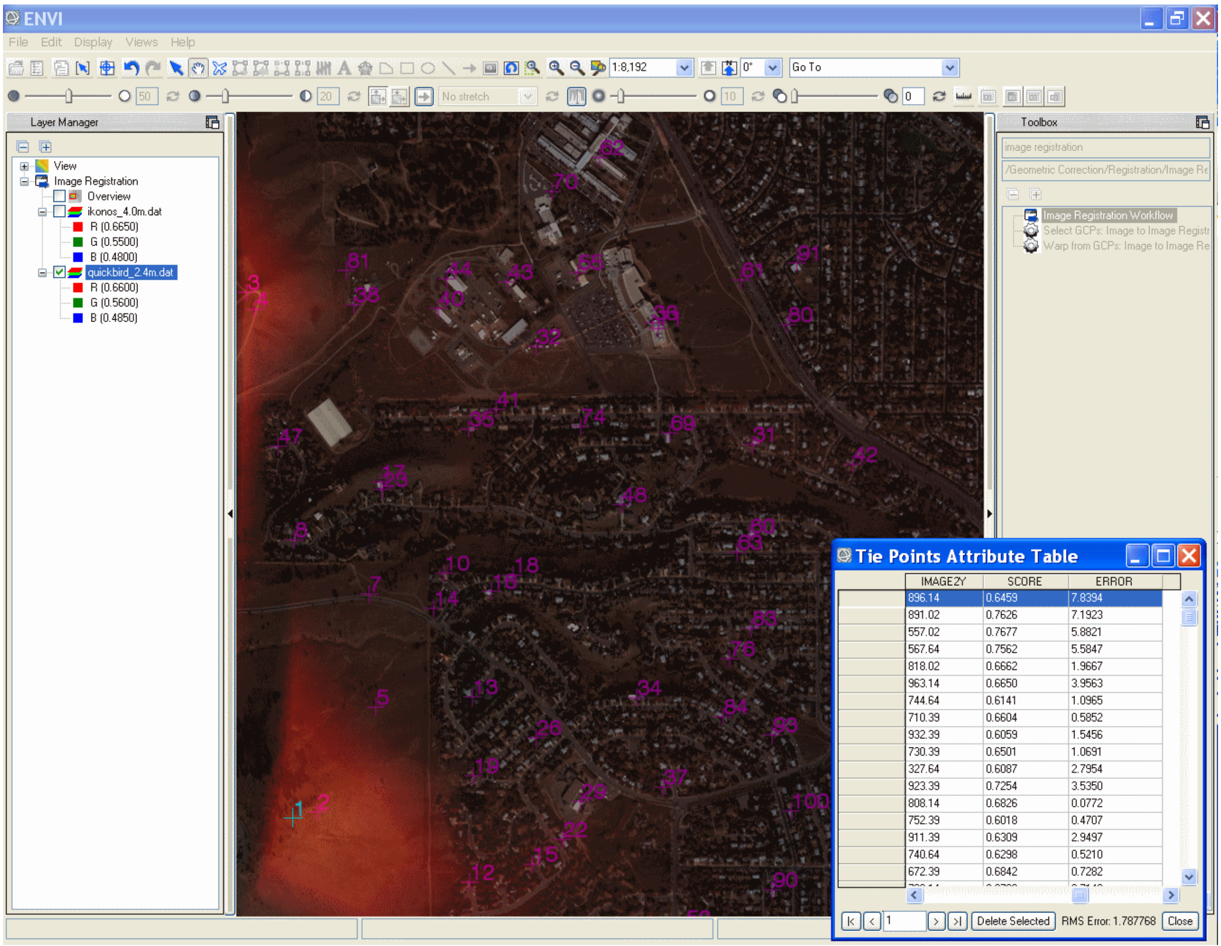


Figure 3. Image Registration workflow - Error Overlay and Tie Points Attribute Table.

Concluding Remarks

Accurate image-to-image registration is critical for many applications including georeferencing, change detection, data fusion, image mosaicking, DEM extraction and 3D modeling. Users need a solution to generate tie points accurately and geometrically align the images automatically. ENVI Image Registration provides a streamlined and automated workflow to register images. The Registration Engine is robust in situations of images obtained from different viewing angles, in different time and seasons, with various terrain relief, and by sensors with different modalities and suitable for many applications. The algorithm is automated and optimized so that human interaction and editing is minimized or eliminated. ENVI Image Registration creates an efficient and cost-effective way to register images, facilitates earth resources observation and helps the decision-making process.

As the field of remote sensing keeps evolving, Exelis Visual Information Solutions is continuing its research and development on new solutions to meet the changing requirements and scope of image registration and its related projects. Future direction is to extend the success of the automatic registration algorithm to even more challenging imagery, such as images with mostly forest and desert areas, images with considerable shadows and clouds, images acquired from highly off-nadir views, etc. Future work also includes automatically registering images to LiDAR point clouds, registering images to maps such as GIS vector layers, and supporting a full portfolio of data fusion and multi-intelligence applications.

More Information

For more information on the ENVI Image Registration, please visit www.exelisvis.com/envi or contact your ENVI representative at 303-786-9900.

Appendix

A few use cases and examples of automatic tie point generation and parameter settings are included in this appendix.

Register images with RPC information

Input data

- **Base image:** QuickBird panchromatic image of Boulder, Colorado data courtesy of DigitalGlobe. RPC information is included.
- **Warp image:** IKONOS panchromatic image of Boulder, Colorado data courtesy of GeoEye. RPC information is included.
- **DEM:** 10 meter National Elevation Data courtesy of the U.S. Geological Survey.

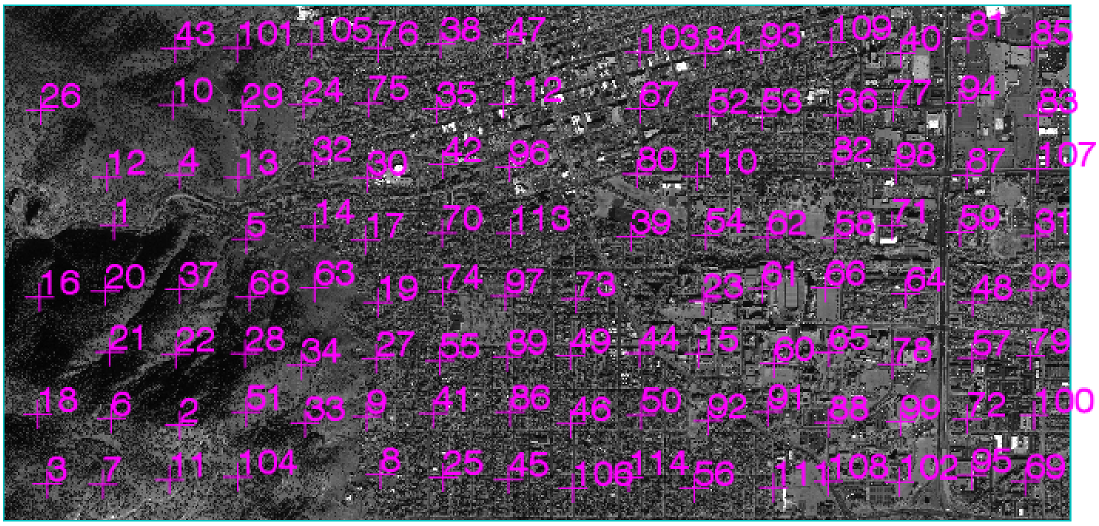
Parameters

- **Geometric Model:** Pushbroom Sensor
- Use default for all other parameters

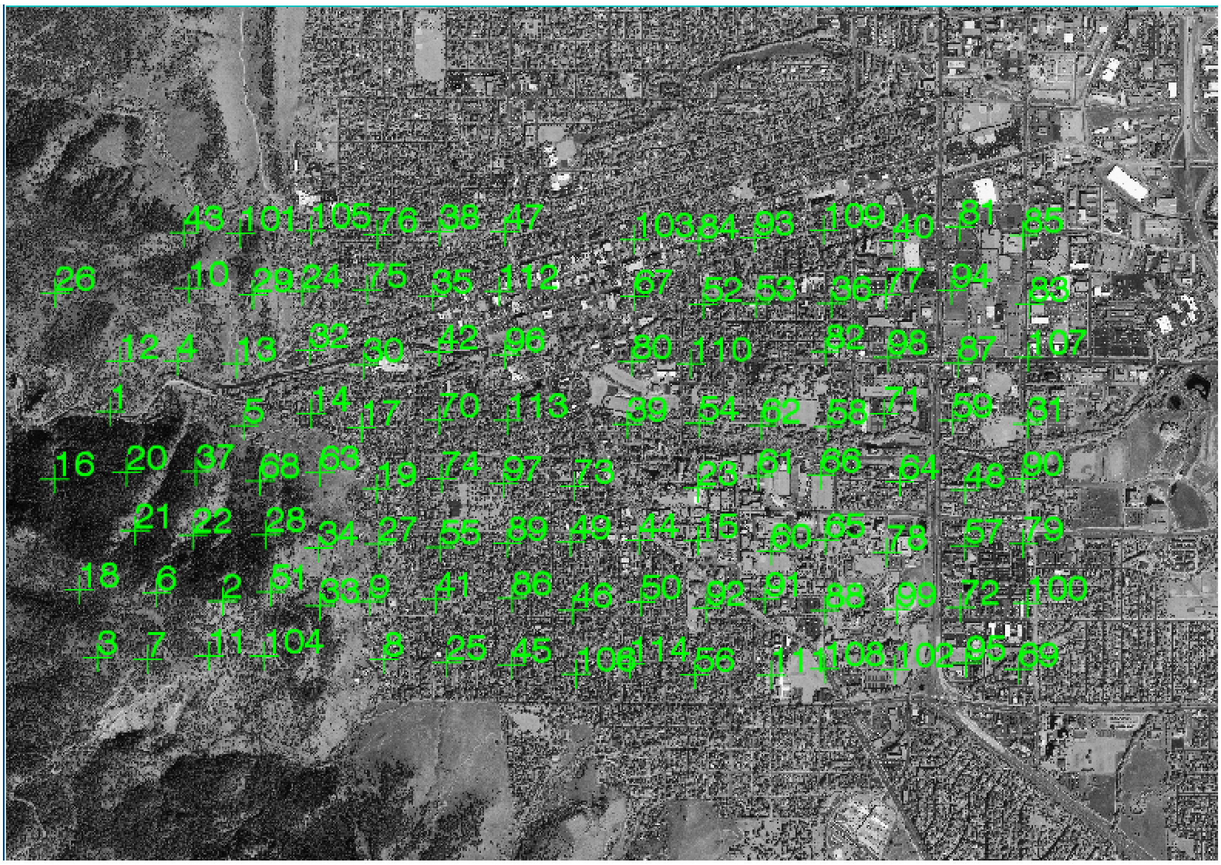
Automatic tie point generation

Requested 121 tie points, 114 tie points are reliably generated. There is no outlier after visual examination. The tie points are well distributed across the overlapping areas, even in the left mountainous areas.

Tie points overlain on the base image



Tie points overlain on the warp image



Register images obtained from different off-nadir viewing angles

Input data

- **Base image:** IKONOS multi-spectral mono image of Tokyo, Japan data courtesy of Japan Space Imaging.
  - Nominal Collection Azimuth: 224.3698 degrees
  - Nominal Collection Elevation: 69.74862 degrees
  - Sun Angle Azimuth: 131.1714 degrees
  - Sun Angle Elevation: 72.85867 degrees
  - Acquisition Date/Time: 2004-06-22 01:47 GMT
- **Warp image:** IKONOS multi-spectral mono image of Tokyo, Japan data courtesy of Japan Space Imaging.
  - Nominal Collection Azimuth: 144.3588 degrees
  - Nominal Collection Elevation: 68.63121 degrees
  - Sun Angle Azimuth: 146.5438 degrees
  - Sun Angle Elevation: 58.66753 degrees
  - Acquisition Date/Time: 2004-09-01 01:34 GMT
- Both images have Japan Plane Rectangular Coordinate System.

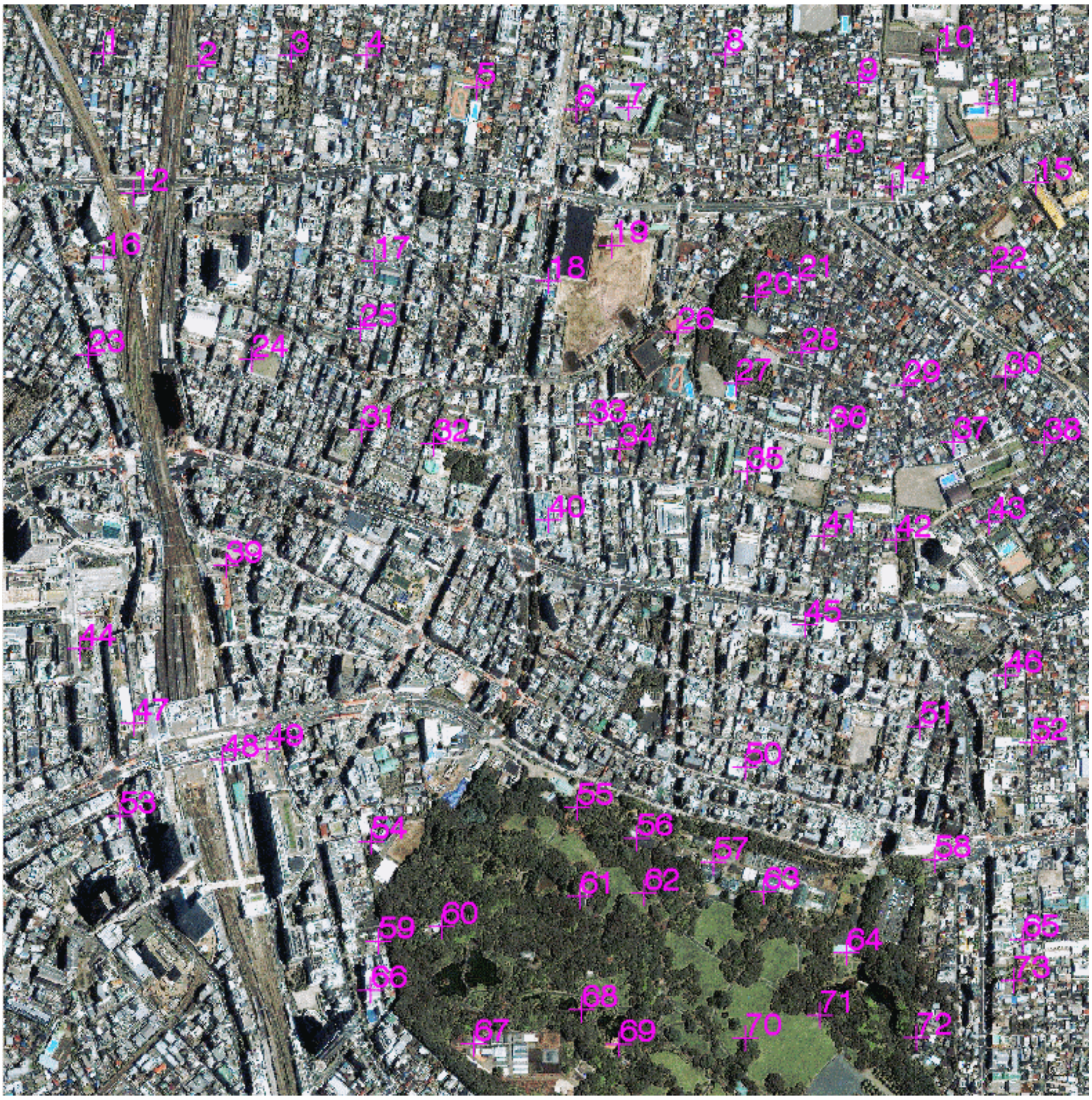
Parameters

- **Minimum Matching Score:** 0.4
- **Geometric Model:** Frame Central Projection
- Use default for all other parameters

Automatic tie point generation

Requested 121 tie points, 73 tie points are generated. There is only one outlier after visual examination. The tie points are well distributed across the overlapping areas, even if the images have significant local geometric differences.

Tie points overlain on the base image



Tie points overlain on the warp image

A closer view of tie points

Register optical image with radar image

Input data

- **Base image:** TerraSAR-X image of Roma, Italy data courtesy of DLR.
- **Warp image:** SPOT5 image of Roma, Italy data courtesy of CNES 2002 – Distribution Astrium Services/Spot Image S.A.

Parameters

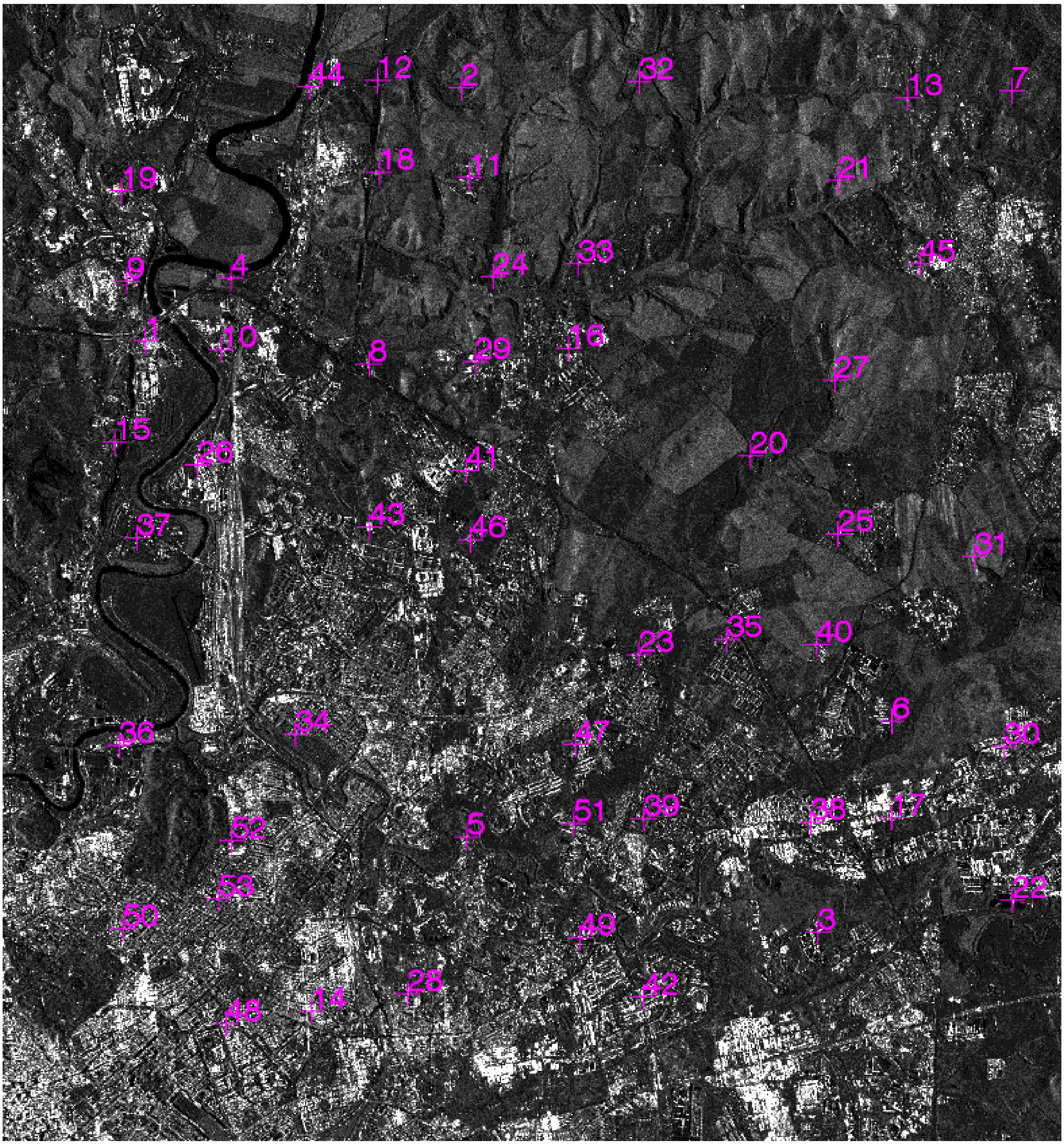
- **Matching Method:** [Cross-Modality] Mutual Information
- Use default for all other parameters

Automatic tie point generation

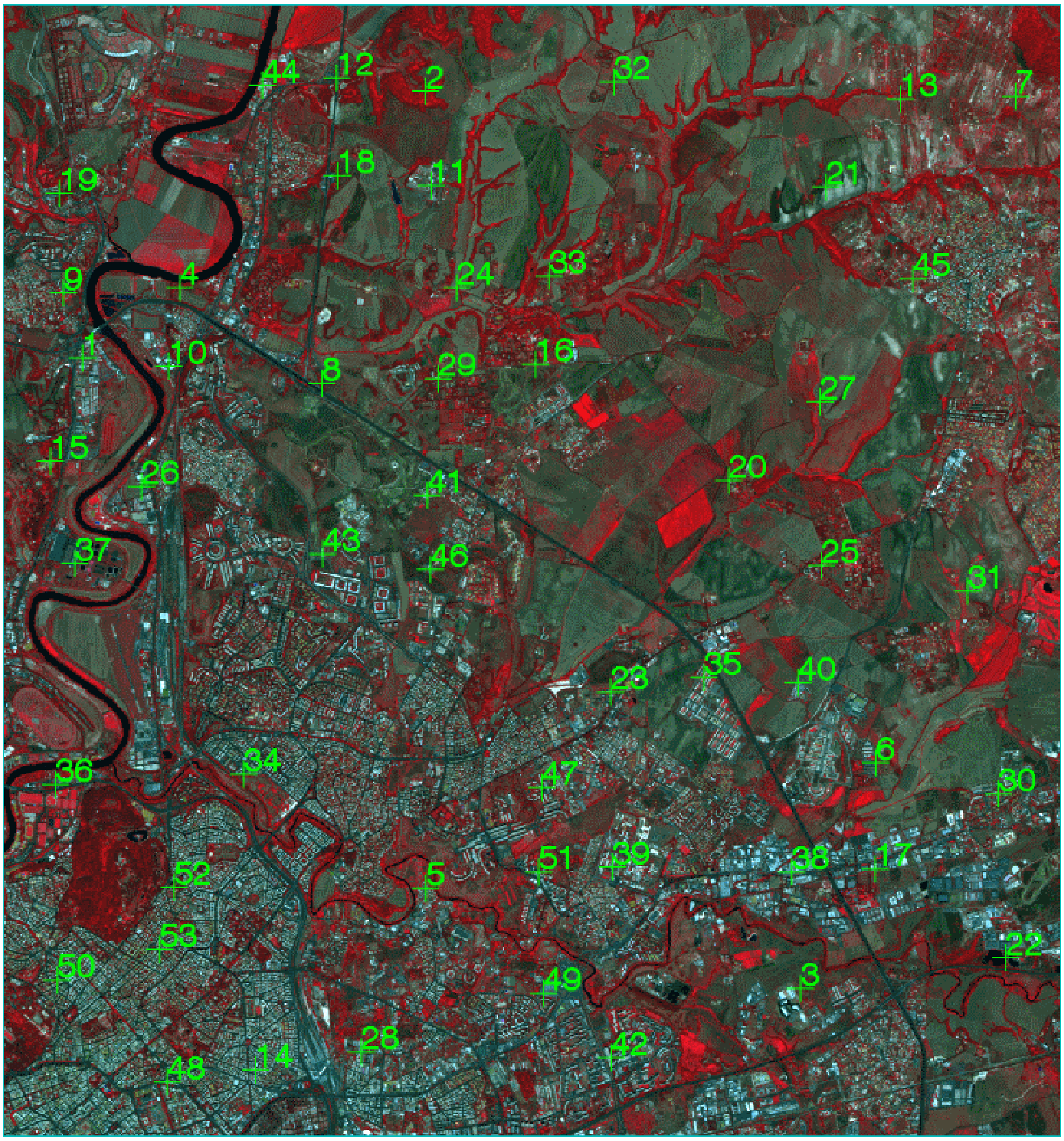
It is hard and tedious for a human operator to manually collect tie points to register radar and optical image. Manual collection of tie points in this case is also very prone to error.

Requested 121 tie points, 53 tie points are generated. After visual examination, most tie points are good. The tie points are well distributed across the overlapping areas. There are fewer tie points generated on the top-right valley areas. It is also very hard for a human operator to collect tie points in those areas since the features look significantly different there. Since the characteristics of raster and optical image are very different, it makes visual examination harder.

Tie points overlain on the base image



Tie points overlain on the warp image



A closer view of tie points