Keypoint Matching for Image Registration

Keypoint matching is a common technique in computer vision applications such as image registration and image stitching. The Auto-Register operation in the Georeference and Auto-Register to Reference processes in TNTmips provides the option to use keypoint matching to generate control points by registering an input image to a georeferenced reference image. In this application keypoint matching is primarily used for finding the correct orientation and approximate position of aerial images that have been "geolocated" with a single GPS position but that do not have a known orientation.

> **Image Keypoint**: a distinctive image feature that can be detected repeatably despite changes in 1) image scale (resolution), 2) illumination and noise, and 3) image orientation and perspective.

Image Keypoints

Keypoints are identified by analyzing the magnitude and direction of intensity changes in local image neighborhoods to detect high-contrast corners and edges. To insure that the keypoints can be detected at different image resolutions, this analysis extends across multiple reduced-resolution versions of the image that are constructed dynamically according to the rules of the particular keypoint detection algorithm.

The image neighborhood characteristics of each keypoint are recorded in a *descriptor*, a binary string that encodes information about the magnitude, pattern, and dominant direction of intensity gradients. This binary encoding allows very fast comparison of keypoints from different images during image registration.

Keypoints can be determined in TNTmips from a full resolution raster image (grayscale or color composite) and/or from one or more of its pyramid tiers. The keypoint descriptors are stored in a FeatureLocator subobject of the raster object or pyramid subobject.

Optimal keypoint creation methods must find a sufficient number of high-quality keypoints without excessive computational requirements. TNTmips provides two efficient keypoint detection

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> **TNTmips Processes Related to Image Keypoints**
> Main / Georeference
> Image / Auto-Register to Reference
> Image / Utilities / Compute Key Points
> Image / Utilities / Convert Key Points to Vector

algorithms, AKAZE and BRISK, which differ in their methods for locating and evaluating keypoints and in the information content and structure of their keypoint descriptors.

The BRISK method uses a variant of the FAST corner detector to assess the significance of prospective keypoints and uses sample locations on equally-spaced concentric circles around a keypoint to construct the keypoint descriptor.

S. Leutenegger, M. Chli and R. Y. Siegwart, 2011. BRISK: Binary Robust Invariant Scalable Keypoints, in *IEEE International Conference on Computer Vision (ICCV)*, pages 2548-2555.
   http://www.asl.ethz.ch/people/lestefan/personal/BRISK

The AKAZE method uses locally-adaptive smoothing to reduce noise while preserving boundaries in the image and the constructed pyramid levels for multi-scale keypoint detection.

P. F. Alcantarilla, A. Bartoli, and A. J. Davison, 2012. KAZE Features, in *European Conference on Computer Vision (ECCV)*, Fiorenze, Italy, pages 214-227.

P. F. Alcantarilla, J. Nuevo, and A. Bartoli, 2013. Fast Explicit Diffusion for Accelerated Features in Nonlinear Scale Spaces, in *British Machine Vision Conference (BMVC)*, Bristol, UK, pages 13.1-13.11.
   http://www.robesafe.com/personal/pablo.alcantarilla/kaze.html

Keypoint Matching

The keypoint detectors may find thousands or tens of thousands of keypoints in typical aerial images. When attempting to match images acquired in different years, seasons, and/or times of day, many keypoints in one image may have no corresponding keypoint in the other image due to differences in illumination direction, vegetation condition, and the location of cultural features (such as vehicles). For example, the edges of shadows cast by trees and
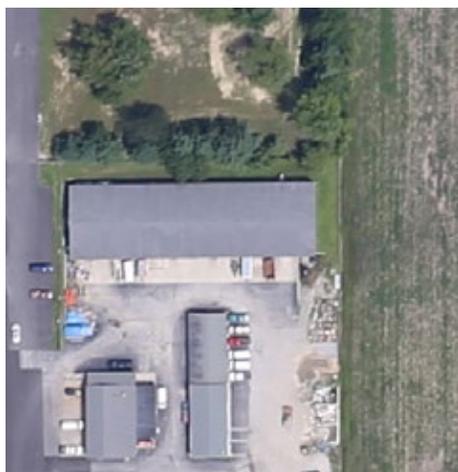
Detail of a natural-color aerial image

Image keypoint locations: AKAZE method

Image keypoint locations: BRISK method

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buildings are high-contrast features that create strong keypoints, but the shadow geometry is highly variable in time and thus these keypoints are not typically useful for image matching.

The Auto-Register operation uses a modified RANSAC procedure (RANdom SAmple Consensus) to separate valid from non-matching keypoints and create an image match. This is an iterative procedure that creates a prospective matching model based on a minimal subset of keypoints chosen randomly (with the restriction that the model points must have sufficient spatial separation to span a large portion of the image). The model parameters are then used to test the spatial fit of all other keypoints. If a sufficient number of matching keypoints are found, these points become the *consensus set* of keypoints and the nonmatching points are considered as outliers. These steps are repeated in each iteration; if the model used in the current iteration results in a larger number of matches than the previous model, its matching keypoints become the new consensus set. Iterations continue until various quality criteria are met.

Using Image Keypoints in Auto-Register

The Auto-Register operation can utilize keypoint matching and/or image cross-correlation techniques to register input images to a reference image. MicroImages has found that keypoint matching is most useful for determining the correct orientation and approximate location for geolocated aerial images with unknown initial orientation, whereas cross-correlation can produce a denser and more uniform distribution of control points for images that have been approximately registered and oriented. The Auto-Register operation can use a combination of keypoint matching and cross-correlation to create a well-distributed set of georeference control points for geolocated aerial images. See the Technical Guide entitled *Auto-Register to Reference Image* for more information.

Creating Image Keypoints

Image keypoints are created and stored automatically by the Auto-Register operation as needed for both input and reference images. However, you can use the Compute Image Key Points process (Image / Utilities / Compute Key Points) to create keypoints for images prior to their use in Auto-Register. For example, you can precompute keypoints for an image that will be used as a reference for georeferencing a large group of aerial camera images. Lens distortion in aerial camera images should be removed in the Lens Correction process (Image / Resample and Reproject / Lens Correction) before creating keypoints.

Use the *Select* pushbutton on the Convert Image Key Points window (illustrated below) to choose one or more images to process. The columnar list in the upper part of the window shows information about the selected images, including the raster data type, cell size, cell value range(s), the image extents, and coordinate
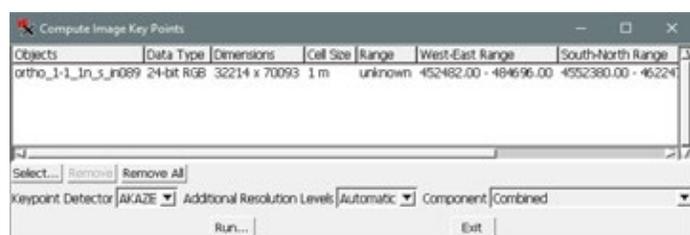
reference system. You can left-click on a list entry to highlight it, shift-click to highlight a range of entries, or control-click to toggle highlighting off or on for an entry. Pressing the *Remove* pushbutton removes highlighted entries from the list; pressing *Remove All* removes all entries.

Use the *Keypoint Detector* menu to choose the desired keypoint detection method. Keypoints created by the AKAZE and BRISK detectors are stored and used separately, so you can create keypoints using both detectors in separate processing runs for the same image(s). Keypoints are created at the full resolution of each input image and for reduced-resolution pyramid tiers as determined by the setting on the *Additional Resolution Levels* menu. The Automatic option on this menu determines the selection of pyramid tiers based on the row-column dimensions of the image. You can also manually select the number of pyramid tiers to use (from 1 to 7). Pyramid tiers are created by the process automatically if needed.

For color-composite images, use the *Component* menu to set whether the keypoints are computed for the Red, Green, or Blue color component or choose Combined to compute keypoints based on the average of the component cell values.
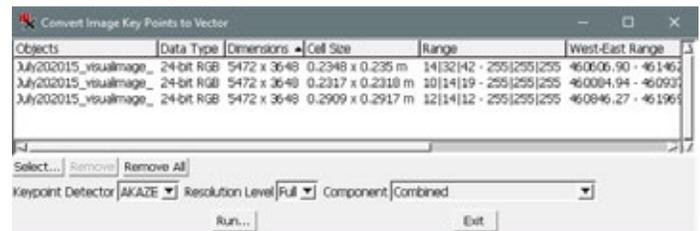

Image keypoint locations cannot be viewed directly. The Convert Image Key Points to Vector process (Image / Utilities / Convert Key Points to Vector) can be used to create a vector object showing the keypoint locations if you are interested in viewing them. The Convert Image Key Points to Vector window (illustrated above) is nearly identical to the Compute Image Key Points window. Use the *Keypoint Detector* menu to choose the detector method, and the *Resolution Level* menu to choose to create vector points for the full image resolution or for a numbered pyramid tier. This process will also create keypoints using the specified settings if they do not already exist.

Vector points (orange) showing locations of over 125,000 keypoints (AKAZE detector) for a lens-corrected aerial camera image.