

Multi-resolution Image Registration Algorithm(MIRA):Robust Automated Image Registration using Python

Warren J. Hack and Nadezhda Dencheva

Space Telescope Science Institute, Baltimore, MD, 21218

Abstract. A primary problem with combining images taken at different epochs remains the difficulty in determining the offset between the images in an automated manner. Automated multi-scale techniques have been adopted for use in aligning images taken with ground-based telescopes with great success. However, several characteristics of Hubble Space Telescope (HST) images made direct application of the ground-based multi-scale techniques problematic. This paper describes how an algorithm developed for automated image alignment of Earth observing satellite imagery was merged with a multi-scale analysis of the images to produce a new image registration task. This task was developed using Python, with C extensions for efficiency, and has undergone initial testing to successfully align HST images of the core of 47Tuc and, separately, mosaics of HST images of the Orion Nebula without any differences in the parameter settings. More work needs to be done to improve the run time and to generalize it to work on non-HST images before making it publicly available on all platforms which run Python.

1. Popular image registration techniques

A relatively few techniques have been developed and widely accepted for image registration, with each tuned to work best for a different set observations. The most common algorithms are cross-correlation, catalog matching and, more recently, multi-resolution techniques. Understanding each of these techniques provided the basis for selecting a general algorithm which can be applied to any astronomical image regardless of content.

1.1. Cross-correlation

This technique works best for aligning images containing primarily indistinct objects such as nebulae, galaxies, unresolved clusters and so on. Unfortunately, cross-correlation does not work efficiently on images which are rotated relative to each other. It can also be very memory intensive, and it can be fooled by variability of objects from one exposure to the next.

1.2. Catalog matching

This technique was developed to provide highly accurate alignment of sources by matching cross-identified source positions between exposures. Sources positions

are determined for each object using any number of techniques, PSF fitting for stars and/or isophote fitting for extended sources. Matching of the positions, though, will not work for extended sources that fill a large fraction of the field of view due to a lack of well-defined sources necessary for accurate positions. It can also be fooled by large offsets, rotations, cosmic-rays, and sometimes even variability of the sources, especially when the images get crowded. The accuracy also relies on source position determination accuracy, both in terms of image position and cross-identification of same source from one image to the next.

1.3. Multi-resolution matching using wavelets

Wavelets provide a means of sampling each exposure at different resolutions to identify and later match sources, as demonstrated and described initially by Vandame (2002). This initial work which demonstrated the utility of wavelets to astronomical imaging was done on ground-based images generally free of cosmic-rays. Cosmic-rays are difficult (impossible) to detect and ignore in each exposure without considerable pre-processing and wavelets actually enhance their signature confusing the matching process. This makes the use of wavelets themselves unsuitable for space-based images such as those from the Hubble Space Telescope (HST).

The disadvantages listed for each technique represent an obstacle which would need to be overcome by any new algorithm in order to be automatic and robust. The technique developed for use with HST images and described in this paper attempts to combine the advantages of each technique and while overcoming many of the problems.

2. Multi-resolution image analysis

Each exposure contains information on many different scales, and this information can be used to constrain the cross-identification of sources from one exposure to the next. Wavelet transforms, and in particular algorithm *à trous* (Vandame, 2002), provide the most common transformation to build views of an exposure at increasingly lower resolutions. This wavelet transformation has been replaced in this algorithm by the simple median filtering. Those sources which exhibit the greatest signal at the lowest resolution would be identified as objects for matching. This eliminates any confusion from weaker targets, while reducing the confusion generated from crowded fields. The pixel area covered by these objects would then be examined at successively lower resolutions for the positions of any bright sources to refine the position. These positions would then be used for matching images taken at different positions or times.

3. Algorithm

MIRA relies on a combination of techniques derived both from astronomical image analysis and from earth observation satellite image analysis as performed in the geo-sciences. The algorithm relies on multi-resolution analysis for preparing the images for source identification, and on the feature-based registration

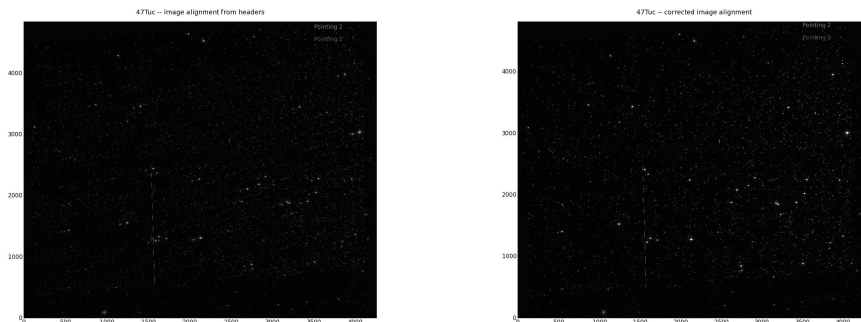


Figure 1. Mosaics of HST/ACS 47 Tucanae images taken at different epochs. (a) Mosaic based solely on WCS header information illustrating errors in alignment. (b) Mosaic produced after applying offset computed using MIRA.

algorithm described by Dai and Khorram (1999) for identifying the sources. Computation of the shifts for a set of images undergoes the following steps:

- Build initial mosaic relationship for exposures using WCS header information and PyDrizzle (Hack, 2002).
- Generate multi-resolution views of each undistorted chip using median filtering, doubling the filter size for each successively lower resolution.
- Starting with the lowest resolution view:
 1. Use Laplacian-of-Gaussian filter to generate contours of all sources in image.
 2. Closed contours with the strongest edges are identified using the Thin and Robust Zero-Crossing technique described by Dai and Khorram (1999). These will be the primary sources.
 3. Generate the modified Freeman chain-code for each sources contour (Li, et al., 1995). These chain codes are invariant to scale, rotation, translations as well as being robust against noise in the contours.
 4. Compute the invariant moments and center-of-gravity of the image within each sources contour.
- Repeat this process for each successively higher resolution for sources identified in the regions extracted from the lower resolution views of the image.
- Perform image matching between the reference image (by default, taken to be the first image listed on input) and the next image in the list.
- Compute 3 matrices based on the moments, center-of-gravity, and chain-codes for all the sources from the reference image and the comparison image.
- Search for potential matches with the matrices. For any pair of regions, there will be a threshold which defines the limit for differences between the sources in terms of the moments and contour coding.
- Use the 3 best matched points to perform an initial linear fit between the images and report the results.

4. Initial Verification

Initial verification of MIRA included running it on pairs of images containing vastly different types of sources; specifically, an extended source which filled the field of view and a crowded field of point sources. Images from the HST Advanced Camera for Surveys (ACS) taken of the Orion Nebula and 47 Tucanae were identified as initial test cases. The original WCS information in the headers of the images was used by PyDrizzle to combine each pair into a mosaic as well as an aligned pair of exposures on the same pixel grid as the combined mosaic to determine whether the images align properly. The 47 Tucanae mosaics can be seen in Figure ???. Errors in the WCS information in the image headers result in poor alignment in these pairs of images, as illustrated in Figure ??[a].

MIRA was then used to compute the offsets between the images in each pair with no user provided parameters except the input filenames. The computed offsets were then used to combine the images again using PyDrizzle. Figure ??[b] shows the alignment in the 47Tuc mosaic based on the corrections computed by this algorithm.

5. Summary

This algorithm has successfully computed the offsets between a couple of pairs of images representing widely discrepant types of observations without the need for any user specified parameters. This has demonstrated its potential for automatically and robustly computing offsets for astronomical images without regard for cosmic-ray contamination. Its greatest contribution will require working on large mosaics more efficiently while remaining robust enough for automated use. This program has been developed using Python, with C extensions for some pixel-based operations, and can be supported on any platform which the STScI_Python package can be ported; including Linux, Solaris, Mac, Mac-Intel, and Windows.

References

- Dai, X. & Khorram, S. 1999, IEEE Trans. On GeoScience And Remote Sensing, 37, 2351
- Hack, W.J., 2002, in ASP Conf. Ser., Vol. 281, ADASS XI, ed. D. A. Bohlender, D. Durand, & T. H. Handley (San Francisco: ASP), 197
- Li, H., Manjunath, B.S., Mitra, S.K., 1995, IEEE Trans. On Image Processing, 4, 320
- Vandame, B. 2002, in Astronomical Data Analysis II, Proc. SPIE, 4847, 123