IMAGE REGISTRATION AND FUSION STUDIES FOR THE INTEGRATION OF MULTIPLE REMOTE SENSING DATA

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ABSTRACT

The future of remote sensing will see the development of spacecraft formations, and with this development will come a number of complex challenges such as maintaining precise relative position and specified attitudes. At the same time, there will be increasing needs to understand planetary system processes and build accurate prediction models. One essential technology to accomplish these goals is the integration of multiple source data. For this integration, image registration and fusion represent the first steps and need to be performed with very high accuracy. In this paper, we describe studies performed in both image registration and fusion, including a modular framework that was built to describe registration algorithms, a web-based image registration toolbox, and the comparison of several image fusion techniques using data from the EO-1/ALI and Hyperion sensors.

1. INTRODUCTION

Many NASA applications, in Earth, space or exploration Science, utilize and integrate a variety of data from multiple sources, multiple viewpoints as well as multiple sensors at multiple dates, and therefore have to tackle the problem of mis-registration that introduces errors for further integration of these data. Future decision support systems, intelligent sensors and adaptive constellations will rely on real- or near-real-time interpretation of Earth observation data, both on-board and from ground-based Direct Readout stations. The more expert the system and far-reaching the application, the more important will it be to obtain accurately registered data. Because of the wide variety and the large amount of data, many commercial tools are often not general or not automatic enough to adapt to the diversity of registration requirements. The goal of our image registration project is two-fold: (1) to develop and assess image registration methodologies that will enable accurate multi-source integration, (2) to provide scientists and other data users with web-based capabilities for accurate and automatic satellite image registration. Being able to register the data on the same web site and at the same time that the data is acquired by the user would simplify the ingestion of this data into target applications and models.

Once data has been accurately registered, it can then be integrated utilizing data fusion techniques. Data fusion can be defined in several ways, such as a process that increases the quality of information contained in the data [1], or as a process dealing with the association, correlation and combination of multiple source data [2]. The goal of our project is to test multiple data fusion methods and to evaluate them by measuring the classification accuracy of the fused data compared to individual sensor data.

Results are presented using multiple sensor data from the Earth Observing 1 (EO-1)/ALI and Hyperion sensors.

2. A MODULAR APPROACH TO IMAGE REGISTRATION

Our work focuses on precision correction or automatic image registration. While navigation often refers to "systematic correction", image registration refers to "precision correction," and while systematic correction is model-based, precision correction is feature-based. In our experiments, we assume that the data has already been corrected according to a navigation model. Assuming that the results of the systematic correction are accurate within a few or a few ten's of pixels, our precision-correction algorithms utilize selected image features or control points to refine this geo-location accuracy within one pixel or a sub-pixel. Currently, there is a large quantity of potential image registration methods that have been developed for aerial or medical images and that are applicable to remote sensing images [3,4]. But there is no systematic study that enables to select the most appropriate method for a remote sensing application and predict its accuracy.

As a general definition, image registration is described as the process that aligns one image to another image of the same area that was acquired at the same or at different times by different or identical sensors. Image registration can be defined by three main steps: (1) extraction of features to be used in the matching process; (2) feature matching strategy and metrics; (3) resampling or indexing of the data. The intent of our work has been to survey, design, and develop different components of the registration process and to evaluate their performance on well-chosen multiple source data. We performed preliminary experiments looking at those different components individually [5,6], and then developed a modular image registration framework [7] that enables to perform systematic studies comparing these components and to test new components in a rigorous fashion. The concept guiding this framework is that various components of the registration process can be combined in several ways in order to reach optimum registration on a given type of data and under given circumstances. Thereby, the purpose of this framework is double-fold:

- 1. It represents a testing framework to:
 - a. Assess various combinations of components as a function of the applications,
 - b. Assess a new registration component compared to other known ones.
- 2. It is be the basis of a registration tool where a user can "schedule" a combination of components as a function of the application at hand, the available computational resources and the required registration accuracy.

Figure 1 illustrates this concept, where a registration algorithm is defined as the combination of a set of features, a similarity measure, and a matching strategy. In our current framework:

- features can be either gray levels, Low-Pass features from Simoncelli steerable filters decomposition or from a Spline decomposition, or Simoncelli Band-Pass features,

- similarity metrics can be either cross-correlation, the L2 Norm, Mutual Information or an Hausdorff distance,

- matching strategies are either based on a Fast Fourier Correlation, three different types of optimization - pure gradient descent[8], a Marquard-Levenberg approach [9] or a stocchastic gradient approach [10], and a Robust Feature Matching approach [11]. Studies using this framework are described in [7], and some of the first results are the following: - Fast Fourier correlation is very fast but limited to transformations with scales close to 1 (in the range [0.95,1.2]) and images containing very small amount of noise.

- When using a Marquart-Levenberg approach, features such as Simoncelli Band-Pass are more accurate and more robust to noise, with errors in the range of [0.032, 0.25] pixel. At the same time, Simoncelli-Low Pass features are less sensitive to the initial guess than Band-Pass features.

- An approach using a stochastic gradient approach and a Mutual Information metrics is overall the most robust to initial conditions and the most accurate with errors in the range of [0.12, 0.18] pixel.



Modular Approach to Image Registration Combining Various Choices of Feature Extraction, Similarity Metrics and Matching Strategy

3. A WEB-BASED IMAGE REGISTRATION TOOLBOX

Based on these first studies, we developed the first prototype of a web-based image registration toolbox that is depicted in Figure 2. At present, this first prototype includes 3 registration methods (implemented as JNIwrapped functions) based on the use of the wavelet-like Simoncelli representation, the use of either Mutual Information or Least Squares as a similarity measure and 2 different types of optimization for matching. These 3 methods are being extensively tested, using synthetic data representing multiple potential geometric deformations as well as radiometric deformations and noise addition. The synthetic experiments enable us to define for each method an "applicability range" that will be provided as a guidance to the users of the toolbox. At the same time, these methods are also being tested on one-band registration of a pair of images acquired by two sensors carried on the EO-1 platform, the ALI multi-spectral sensor and the Hyperion hyperspectral sensor; the pair of images is shown in Figure 3. While there have been automated procedures to orthographically correct EO1/ALI data, there is no method available to automatically register

the EO1/Hyperion data. Qualitatively, the method utilizing a stochastic gradient optimization, a mutual information metrics and Simoncelli Band-Pass features

seems to perform the best. A quantitative evaluation using manual registration is underway and will be presented at the conference.



User Interface of the Prototype Web-Based Image Registration Toolbox

4. IMAGE FUSION STUDIES

Once the data is accurately registered, it can be integrated using an image fusion method. In our studies, we compare several methods to perform the fusion of the ALI and the Hyperion data. The three methods being compared are:

- Principal Component Analysis (PCA)
- Wavelet-Based Fusion
- Cokriging

In our application, both datasets have the same spatial resolution but very different spectral resolutions. The image fusion attempts to take advantage of this spectral difference. In the PCA method, images are stacked together as one multi-spectral image and PCA is performed on all of the concatenated data. In the wavelet-based fusion method, high- and low-resolution data are independently decomposed using a Multiresolution Analysis wavelet decomposition and reconstruction schemes. Then, components from both decompositions are combined during the reconstruction phase to create the new fused data.

Cokriging is an interpolation method that has been traditionally used in mining and geostatistics applications. In a recent paper [12], we proposed cokriging as a novel fusion method, where image fusion is considered as an interpolation problem used to estimate frequencies at missing points of the low spectral resolution data using high spectral resolution data. This enables to create data at any spectral resolution.

Results shown in [12] were evaluated using variance of co-occurrence matrices and correlation as a new fusion quality metric. Fusion results based on PCA and wavelets show that texture, measured through variance, can be improved through fusion, while preserving almost all of the input original information, measured through correlation. Using the dataset shown in Figure 3, the new fusion approach based on cokriging was utilized to improve the spectral resolution of ALI using Hyperion. Results show that new fused ALI bands can be created and mimic the spectral behavior of the Hyperion spectral signature. Validation using ground truth will be presented at the conference.

5. CONCLUSION

Studies involving image registration and fusion of multisensor data are being performed. In particular, registration and fusion of datasets including hyperspectral data have been presented. Future extensions of the toolbox will include enhanced capabilities, such as applicability to multiple types of data and data formats, addition of new registration modules, generalization to multi-band registration (especially for hyperspectral data), and interfaces to several end-users, such as the National Applications/ Invasive Species and the NASA Goddard EOS MODIS Validation Core Sites projects. Our future work will also include the generalization of the cokriging fusion method to both spatial and spectral fusions.

6. REFERENCES

[1] C. Pohl, and J.V. Genderen, "Multisensor Image Fusion in Remote Sensing: Concepts, Methods and Applications," *Remote Sensing*, vol. 19, no. 5, pp. 823-854, 1998.

[2] D.L. Hall, and J.Llinas, *Handbook of Multisensor Data Fusion*, CRC Press LLC+, 2001.

[3] L. Brown, "A Survey of Image Registration Techniques," *ACM Computing Surveys*, vol. 24, no.4, 1992.

[4] J. Le Moigne, W.J. Campbell, and R.F. Cromp, 2002, "An Automated Parallel Image Registration Technique of Multiple Source Remote Sensing Data," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 40, no. 8, pp. 1849-1864, August 2002.

[5] H.S. Stone, J. Le Moigne, and M. McGuire, "Image Registration Using Wavelet Techniques," IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 21, no. 10, Oct. 1999.

[6] I. Zavorin, and J. Le Moigne, "Use of Multiresolution Wavelet Feature Pyramids for Automatic Registration of Multisensor Imagery," IEEE Transactions on Image Processing, vol. 14, no. 6, pp. 770-782, June 2005.

[7] J. Le Moigne et al, "Registration of Multiple Sensor Earth Science Data," Earth Science Technology Conference, Palo Alto, CA, June 22-24, 2004.

[8] R.D. Eastman, and J. Le Moigne, "Gradient-Descent Techniques for Multi-Temporal and Multi-Sensor Image Registration of Remotely Sensed Imagery," *FUSION'2001, 4-th Int. Conf. Info. Fusion*, CA, August 2001.

[9] P. Thévenaz et al, "A Pyramid Approach to Subpixel Registration Based on Intensity", *IEEE Trans. on Image Processing*, Vol. 7, No. 1, .1998

[10] A. Cole-Rhodes et al, "Multiresolution Registration of Remote Sensing Imagery by Optimization of Mutual Information Using a Stocchastic Gradient," *IEEE Transactions on Image Processing*, vol. 12, no. 12, 1495-1511, December 2003.

[11] N. Netanyahu et al, "Georegistration of Landsat Data via Robust Matching of Multiresolution Features," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 42, no. 7, pp. 1586-1600, July 2004.

[12] N. Memarsadeghi et al, "A New Approach to Image Fusion Based on Cokriging," *FUSION 2005 Conference*, Philadelphia, PA, July 2005.



Figure 3 Corresponding ALI and Hyperion datasets