An Approach for Automated Registration of Hyperspectral Images for Boresight Calibration

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Abstract: Parametric geocoding is a standard procedure for orthorectification of hyperspectral airborne scanner data. Boresight parameters are estimated by using the image coordinates of precisely known ground reference points. To fully automate the processing of the recorded hyperspectral data ground reference points should be selected and matched by an algorithm without user interaction. In this article a two-step procedure is presented. First, direct geocoding of the data is done without ground reference points. This step is solely based on the data of the inertial measurement unit with differential GPS. Next, the hyperspectral data is normalized and pixels are clustered with an unsupervised method. Image blocks of an edge image of the resulting regions are matched with a high resolution edge image of a digital orthophoto of the calibration site. The found correspondences are used as ground control points in the second geocoding step.

1 Introduction

In this paper a robust algorithm for automated matching of low resolution hyperspectral and high resolution RGB orthophotos is presented. The matching results are used as ground control points for parametric geocoding of hyperspectral images. This automates the boresight calibration of the camera system. This is an important task for fast generation of geospatial data products based on remotely sensed data because it eliminates the need for user interaction.

Different approaches for automatic point selection exist. Automatic tie point generation for aerial triangulation is used for the registration of stereo images (SCHENK, 1997). As in (SKALOUD, 2007) described, the roofs of buildings can be detected in LiDAR images and matched across different flight tracks as a substitute for using precisely known ground reference points. Different tie point suitability indices and validation parameters for hyperspectral satellite images have been investigated in (MARCAL, 2007). In (XIONG, 2009) a super point detection algorithm based on interest point detection for matching of control points in satellite stereo image pairs has been presented.

For our photo mission flights the runway and the facilities of the base station airport were chosen as calibration targets. High resolution digital orthophotos are matched with short wave infrared (SWIR) hyperspectral images to find optimal boresight parameters. However, matching of images from different spectral ranges taken at different times is a challenging task. In (KNAPP, 2012) a method for automatic tie point selection for the fusion of hyperspectral and LiDAR images is presented which uses features in the overlapping spectral regions of different spectrometers. Their method cannot be applied for our datasets because such an overlap does not exist for a single sensor.

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Instead, the use of edge and line features seems to be adequate because they are potentially visible in the reference RGB image and the SWIR hyperspectral image as they typically belong to material boundaries. Edge detection in the hyperspectral image is based on unsupervised clustering of the spectral data while the aerial photo is transformed with a traditional gradient based algorithm. By this, the method benefits both from the high resolution of current aerial photography and the high spectral resolution of current hyperspectral imaging devices. The calibration procedure consists of two steps. First, a coarse geocoding is done which is based on the positioning data of the inertial measurement unit only. Using the flat ground assumption with an average ground level for the observed region seems to be sufficient. Second, the algorithm searches corresponding ground control points. These are used to repeat geocoding. Then, a real digital elevation model is used to model the terrain. First results for the boresight calibration of five recent flights using the same calibration site are given.

2 Methods and Datasets

The Biosystems Engineering Group at Fraunhofer IFF operates an airborne hyperspectral SWIR imager from Norsk Elektro Optikk (NEO). For orthorectification of the hyperspectral images the software PARGE is used. This toolkit has been developed and is distributed by the company ReSe Applications Schläpfer. To fully automate the process workflow of PARGE a set of ground control points and their coordinates within the hyperspectral datacube must be provided.

2.1 Data Acquisition

The hyperspectral imager is operated in different airplanes using a stabilized mount (GSM3000) and an inertial measurement unit (Novatel SPAN-CPT with DGPS receiver). Hyperspectral images are recorded on solid state disks by the data acquisition unit from NEO. This device also performs the simultaneous recording of the IMU data. The lever arm to DGPS antenna is measured for each setup before flight.

2.2 Parametric Geocoding

According to the PARGE manual the standard workflow of geocoding consists of the following steps (Schläpfer, 2011):

- Data preparation
  - Define image data
  - Define sensor model
  - Load IMU/DGPS data
- Preparing Digital Elevation Model (DEM)
- Import of ground control points (GCP)
- Estimation and setting of offsets
  - Roll and pitch, heading, FOV, height, …
- Main Processing
Calculation of the Image Geometry Map
• Scan Angles for ATCOR
• Final Processing
  o Geocoded data cube
  o Geocoded RGB

Typically, this workflow is processed manually by selecting and configuring the parameters of each step within the user interface of the PARGE software. Additionally, PARGE offers an API for automation of the workflow. This interface and PARGE itself are based on the IDL programming language.

2.3 Automated Selection and Matching of Ground Control Points
First, the PARGE workflow runs without GCPs. This provides a rough estimate of the orthorectified image. Second, the coordinates of candidate control points are randomly selected. This selection is done in the coordinate system of the unaligned image. Hence, the coordinates are the line number and the pixel number. They are projected to UTM coordinates using the image geometry map which is the result of the first main processing step. Fig. 1 shows a set of candidate points and their projection onto the georeferenced orthophoto.

Fig. 1: Randomly chosen candidate control points in raw coordinate system (top) and projected to UTM coordinates with PARGE (bottom)

Next, the hyperspectral data is clustered using the k-means algorithm \( \text{(Lloyd, 1982)} \). However, before clustering a normalization of illumination is done. Normalization is not a complete ATCOR procedure, but estimates the spectra of sunlight and corrects the overall intensity. Then, all pixels are classified to belong to one of the resulting k classes. The boundaries of the connected regions in the resulting label map are extracted to be used for matching with the edge
image from a RGB reference image. To suppress small regions, k is set to a small value (e.g. k=6) and only the largest regions are used for edge extraction.

The edge map of the RGB reference is generated with a gradient based algorithm. However, the parameters of the so called Canny edge detector (Canny, 1986) are adapted to the gradients of the current image. Adaptation is controlled by the number of edge pixels in the hyperspectral edge map as shown in Fig. 2.

Fig. 2: Flowchart with feedback loop for selection of edge detection parameters

Fig. 3 shows a typical result of edge detection for the reference image and the hyperspectral image. The matching between the RGB based edge map and the hyperspectral edge map is done by two dimensional correlation between image patches centered on the randomly chosen candidate points.

Finally, the number of reference points is reduced based on the appearance of the edge maps as well as based on outlier detection for the estimated translation vectors between the RGB image patches and the hyperspectral edge map patches.

Fig. 3: Edge images generated from RGB reference orthophoto (left) and from the label image of the clustered hyperspectral image (right)
### 2.4 Datasets

A hyperspectral image of the airfield was recorded as part of each photo mission. For testing the automated boresight calibration approach five of these recordings are analyzed.

The reference image is a digital orthophoto of the base station airport with a ground resolution of 20 cm per pixel.

![Fig. 4: Results of clustering the hyperspectral data of the calibration track for different flight missions](image)

**3 Results and Discussion**

The objective of unsupervised clustering of the hyperspectral data is to derive a high quality edge image of the observed area. Therefore, it is important to extract the boundaries of ground structures such as the runway and streets. On the other hand, edges which are related to the vegetation should be treated as irrelevant. Fig. 4 shows the segmentation results based on unsupervised clustering for five flights over the calibration site. For compactness of presentation the not rectified images are show. The results show that boundaries of the ground structures can be successfully segmented for all flights and hence can be used for matching.

Fig. 5 visualizes the distributions of the length of translation vectors between matching pairs of ground control points for flights #3 and #5. Translation vectors are used to update the UTM coordinates of the reference points in the hyperspectral image. The vectors length is a measure for the error of direct geocoding with PARGE using IMU/DGPS data only. However, also errors made by the proposed matching algorithm contribute to the shown distributions and require an outlier detection. The results show clearly that quality of direct geocoding is different for all flight missions.
Finally, the calculated correspondences are used as ground control points in the PARGE workflow. Now, the boresight parameters for each flight can be estimated and later be used as offset values for the direct geocoding of all the other flight tracks. In Fig. 6 results of geocoding without ground control points are compared with geocoding using the proposed algorithm.
Fig. 6: Before (left column) and after (right column) matching of ground reference points
4 Conclusion

A fully automated geocoding procedure is needed in applications which require fast generation of maps based on remotely sensed data. When a final data product has to be provided shortly after landing to allow a decision making for instance in agriculture, forestry, or security applications a trade-off between the highest possible accuracy and the use of fast but less accurate methods exists. We presented such a robust algorithm for automated matching of randomly chosen ground control points in low resolution hyperspectral data and high resolution RGB orthophotos. The results show that the approach provides a satisfying level of accuracy compared to the error which is made by using direct geocoding based on the IMU/DGPS data only. However, the article describes work in progress. Therefore, modifications of the algorithm as well as different metrics for performance evaluation have to be investigated.

5 References


