Aerial Image Acquisition and Processing for Remote Sensing

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ABSTRACT

UAV (Unmanned Airborne Vehicle) high resolution digital image acquisition systems based on small format cameras provide a versatile alternative to the solution of environmental monitoring and remote sensing problems. Through digital image processing these small format optical and multi-spectral camera images can obtain orthomosaics that meet quality standards at a fraction of the cost of traditional heavier manned vehicle equipment. They also have higher availability, resolution and flexibility can also be obtained when compared to satellite images. This paper presents research and development undertaken to produce a computational system that can automatically process optical and multi-spectral images obtained from digital cameras mounted on a UAV aircraft. The system acquires, rectifies, mosaics and georeferences these images with minimum operator assistance. Results prove that the process can almost be fully automated and that the system can be operated by minimally trained personnel. Processed images obtained by the software can be used for pattern recognition, photo interpretation, photogrammetry, and other remote sensing applications.

1 Introduction

Teledetection and remote sensing constitute one of the preferred data harvesting methodologies for non invasive environmental modelling. [5, 6]. This technology has countless applications in different human activities, including environmental scientific research and protection, financial, social and anthropomorphic studies, among others. It is used specifically to obtain quantitative and qualitative information for decision making policies and legislation. [4].

1.1 Alternatives for remote sensing image acquisition

Remote sensing imagery have a huge potential impact in the above mentioned disciplines and have become widely accepted through specific applications such as Google Earth, ArcGis, among others. Images can be acquired by vehicles that carry instruments operating in different acquisition modes. Specifically we can mention different satellite missions and constellations, aerotransported platforms and fixed platform cameras.

Each platform and acquisition mode have specific advantages and disadvantages. Satellite imagery have high quality parameters and better spectral callibration, given the highly expensive aquisition sensors that are mounted on them, but are only freely available with low spatial and temporal resolution, and thus are many times inadequate for certain studies. Frequently they are also severely impaired by adverse meteorological and atmospheric conditions (fog, clouds, smoke, and other factors that can affect sensor measurements). High resolution satellite images are extremely expensive, making them prohibitive for most applications.

Airborne imagery taken by aero-transported platforms can overcome some of the difficulties of satellite images, mostly because they can be acquired in optimal climate and illumination conditions. Their spatial resolution can be adapted to different sensor configurations, flight plan and altitude, along with ground and atmospheric parameters. Their main disadvantage stems from high operating and deployment costs. On board image processing is not readily available and the quality of each run is only assessed after each flight. Mobile real time image verification and correction is again extremely prohibitive.

Fixed camera imagery is usually of medium or low quality due to hardware limitations and require very complex processing to be useful for precise quantitative measurements. They also usually present low acquisition ranges.

1.2 Research proposal

Modern small format cameras can be used as an alternative to overcome many of the above mentioned sensor and platform limitations. High resolution digital airborne imagery can be produced mounting such cameras on autonomous UAV airplanes. Adequately callibrated small format optical and/or multi-spectral imagery, enhanced with ground information, can produce results that rival the quality of the more advanced satellite missions and conventional aerial photography at a fraction of their cost. [8]

Our research goal is the development of a software system that can automatize many of the image processing steps required to process images acquired by optical and multi-spectral cameras mounted on a UAV vehicle. We have received collaboration from UAV manufacturers NOSTROMO S.A. (`www.nostromo-defensa.com`) who have supplied the initial test images.

The software system processes a post-flight image sequence using the GPS phrase recorded in each image by the on-board flight computer and assembles an approximate image mosaic. For each pair of neighbourhood bitmaps (determined by image georeferentiation) the algorithm computes and localizes a set of common point features extracting those that form the triangle of maximum area. These points are used to determine an affine transform to map the vertices of the triangle from one image onto the other. The same transform is then used to map all pixels of the image to produce a combined "stitched" image. When this operation introduces discontinuities on image boundaries a bilinear interpolation between bitmaps can be used to soften hard edges, making the boundary imperceptible to the human eye. Eventually, the photo-mosaic can be uploaded onto Google-Earth for its rapid dissemination and remote access by authorized users.

The next section of this paper describes the employed methodology, specifically those aspects in reference to image acquisition and processing with their metadata and the image mosaic algorithms that have been developed. Section 3 provides results obtained on test images and section 4 concludes this work with a discussion on these results and future work proposals.

2 Methodology

The possibility of incorporating small platforms with sensors and cameras in UAV (Unmanned Aircraft Vehicles) has fostered a wide range of remote sensing civil applications. These sensors range from conventional digital cameras modified to accept shutter control from the flight computer, to lasers, GPS, infrared and multi-spectral equipment. These devices, along with the specific flight control avionics for the UAV, are driven by the autopilot or flight control computer. The autopilot is pre-flight programmed in accordance to the required mission parameters (flight path, altitude, speed, etc.). The aircraft takes off and lands under human control but the major part of the flight plan is flown with the aircraft controlled by the autopilot. Using the GPS signal the flight computer positions the aircraft and triggers the camera shutter or sensor capture circuits. A flight datalogger registers relevant data during the whole mission. The acquired images and the information from the datalogger are written to a digital memory that is downloaded after the flight.

2.1 Acquisition and image processing

The images acquired for this paper have been obtained with a multi-spectral TETRACAM camera. This camera has been specifically designed to be mounted on ultra-light aerial platforms. The TETRACAM has an electronic shutter that can be fired by the flight computer and can access a GPS device to register a time and position phrase that is recorded along with the image data. This information is stored in a proprietary RAW data format. We developed a specific reader and data decoder to disassemble the GPS header and the image bitmap. A linear deBayering algorithm was also developed to convert the raw bitmap image into standard digital format.

Experimental flights with conventional digital camera photography were also performed. These acquired images do not contain positional or flight attitude information. To be able to process them, GPS data also recorded by the flight computer can be used to produce an approximate georeferenced image.

2.2 Image mosaicking

Image mosaicking can be achieved through the use of different software packages (Autopano, Autostich, Photostich, and Photoshop among others) though none of these packages have good performance with the aerial images we have tested. They also require complete human interaction in each processing step. The mosaic can be built on a pair matching correspondence but this would lead to a highly complex computational algorithm. This complexity can be reduced using an image pre-ordering algorithm based on the GPS geographic data that facilitates subsequent processing steps.

The image mosaic is built with a pre-ordered image sequence by matching contiguous image pairs. To achieve this, an affine transform between each pair of images must be found which allows reprojection of the pixels from one image onto the other's reference system. This processing can be based on one of two strategies [1, 7]. The first strategy is based on notable points or "features" that appear in overlapping common areas of both images. Ideally in this "feature based" approach it should be possible to calculate a specific optimal transform for each pixel that is inside the the overlap. In practice only a small number of points are used to produce a unique transform that is later applied to the whole image. This approach is similar to the one typically used to georeference satellite images.

The second strategy is "pixel based" in the sense that it processes small blocks of pixels pertaining to each image seeking a transform that will minimize the accumulated squared difference between corresponding pixels. The major problem with this strategy is that the search space is huge and each quadratic difference calculation is processor intensive.

In our implementation we utilize a mixed strategy that combines the advantages of the feature and pixel based algorithms. Our first step is to find pairs of matching characteristic feature points which we determine a first affine transform to produce an approximate solution. Later, we apply a quadratic difference minimization algorithm seeking to determine an optimized transform in a small neighbourhood of the previous solution.

Characteristic feature points are detected using an open source C++ implementation of the SURF (Speeded Up Robust Features) [2] algorithm. SURF evaluates a set of image descriptors (features) for each pixel of an image and extracts a subset of pixel coordinates for those that present the most prominent features.

GPS geographic positioning information and spatial resolution can then be used to find correspondence between notable features pertaining to the two images that are to be registered. When this criterion is not sufficiently precise (for example when many features are located close to each other) we adopt a second one based on a distance measure defined directly in descriptor space and searching for points that are nearest together. For our implementation a Manhattan distance measure (i.e. the sum of the absolute value of the differences of corresponding descriptor values) has been used. The second criterion proved to be significant in reducing the combinatorial feature matching search space between images.

Once a list of matching characteristic feature points in both images has been determined, the points that form the vertices of the triangle with maximum area are selected. With these points an affine transform is obtained and applied to all the pixels of the image. This criterion tends to reduce the effect of selecting three points that are not well distributed, too close together, or are collinear as the basis for the affine transformation parameter calculation. In turn, this will reduce the geometric error introduced in the numeric calculations of the transform coefficients and that is amplified when this transform is applied to the pixels farthest away from the vertices of the triangle. Fig. 1 shows a pair of images to be registered, matching characteristic points are located in each image and are joined by a green line. The triangle of maximum area is shown in blue.

Once the optimum feature based transform has been determined a pixel based method is applied to calculate a local transform that minimizes the quadratic accumulated error in the superposition area of both images. If necessary, a linear interpolation (blending) algorithm can also be applied to soften edge visualization of overlaid images. Fig. 2 shows a blow-up of a three image overlay

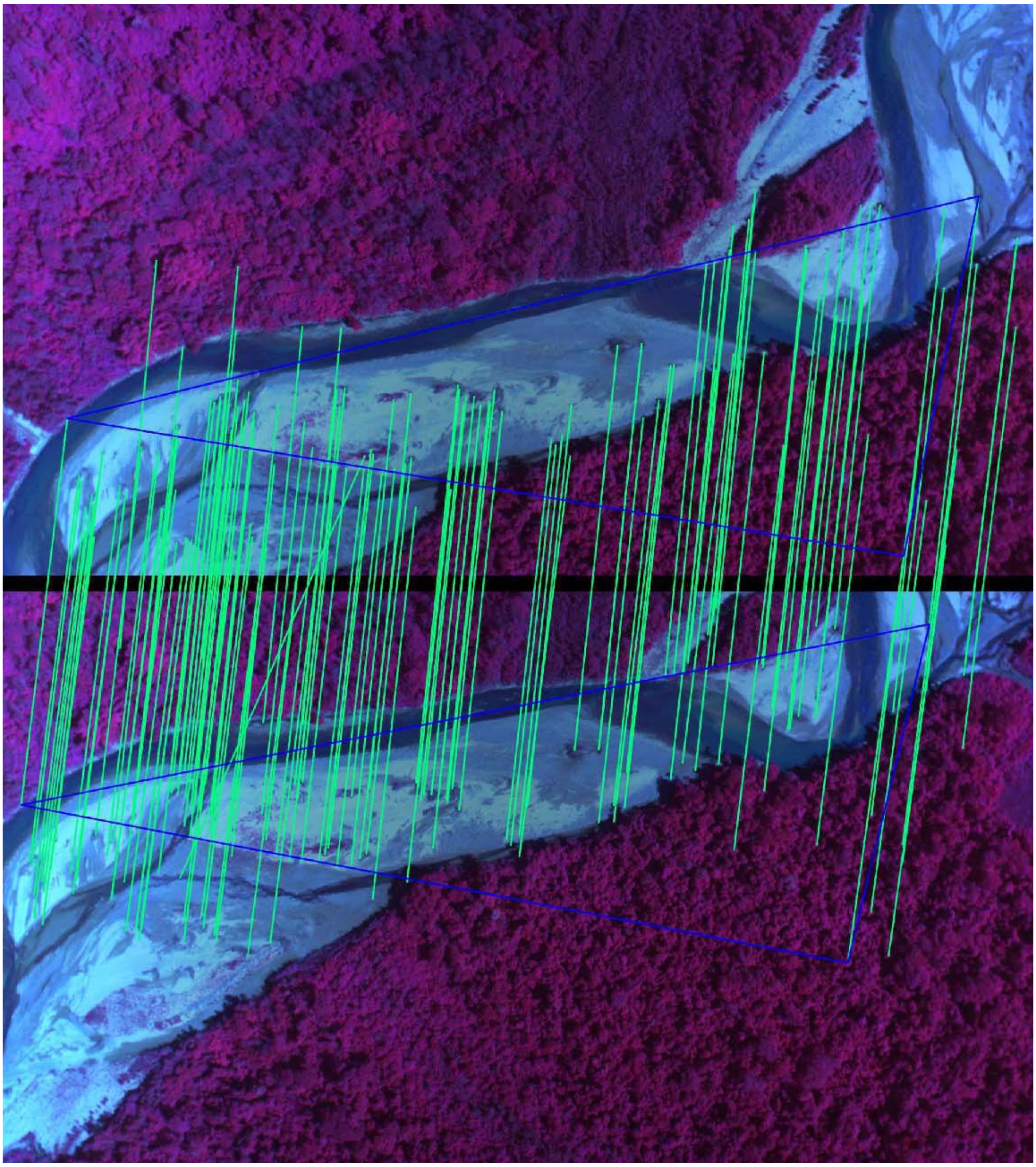

Figure 1: Two images to be registered. Pairs of corresponding feature points are joined by green lines. The triangle of maximum area is in blue.

that illustrates superior quality of the final images obtained from the blending step.

3 Results

The previously mentioned research concepts were implemented and tested on pairs of aerial images to fine tune the algorithms and optimise the final output. These programs were also tested on standard digital camera photographs. These images are usually of poor quality because of non-constant focus, vignetting, and barrel distortion effects that distort the images, and make them lose luminance near the corners. The resulting image shown in Fig. 3 is reasonably acceptable, even though the original images are of low quality and definition. When applied to high defini-

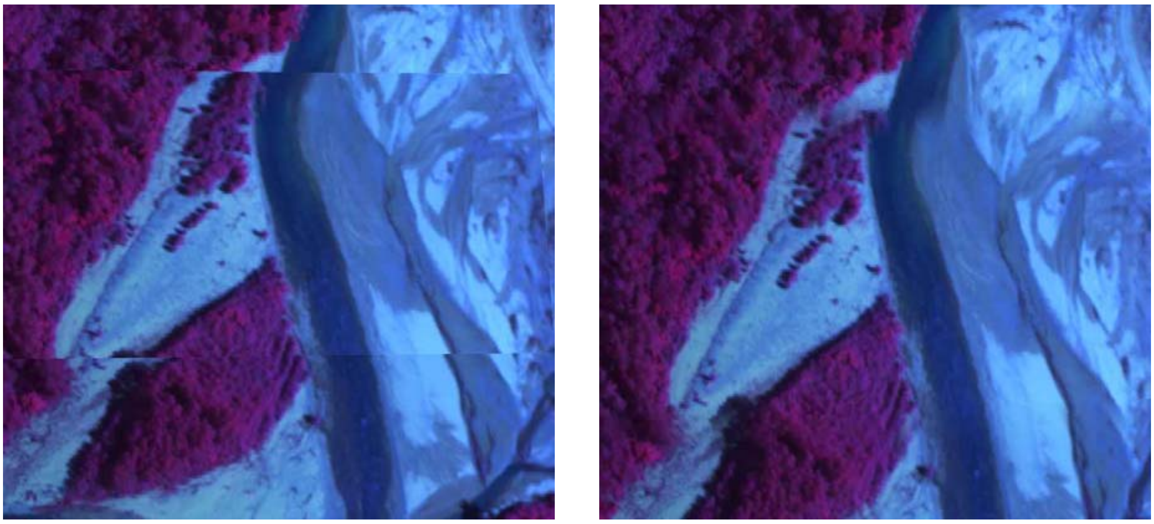

Figure 2: Blowup of the intersection of three overlaid images: (a) No blending (b) With blending

tion images, such as some trials ran using tiles of IKONOS satellite images, the resulting mosaic was excellent (Fig. 4).

Our software is now prepared to receive a complete set of TETRACAM images acquired from an UAV flight mission and automatically separate the raw pixel data from the GPS phrase in each image, convert the RAW pixel map using a linear deBayering filter to a standard computer image format, and use a combination of pixel and feature based registering strategies with edge smoothing to produce a final mosaic with minimal operator assistance. An example of a generated mosaic using this algorithm can be seen in Fig. 5.

These mosaics can be submitted to subsequent traditional digital image processing techniques to obtain valuable domain specific remote sensing information that will vary according to need. The geographic information embedded in the mosaic could be used with Google Earth's digital interface to create interactive websites that might facilitate the rapid dissemination of the image data. A feature highly pondered by environmental and natural disaster decision makers.

4 Conclusions and Future Work

A software system was developed to automatically carry out the traditionally human intensive labour of processing images acquired by lightweight optical and multi-spectra cameras mounted on UAV platforms required to build and image mosaic. The system uses GPS metadata recorded with the RAW image data when the camera is triggered. If the acquisition sensor does not have the required GPS inputs, geographic information can be obtained directly from the flight computer datalogger. This information is used to preorder the images in the correct sequence. RAW pixel data is deBayered to obtain standard digital images and matching characteristic feature points are searched for in contiguous images. The matching points that conform the maximum area triangle in both images are used to determine the affine transform that is required to map one image onto the other.

The parameters of this transform are later refined using a pixel based local minimum algorithm with an acumulative quadratic error measure applied to the intersection of both images. The optimized transform is applied later to all the pixels in the image to produce the complete coregistered image. If this operation introduces visual discontinuities it is possible to apply a bilineal blending interpolation that blurs the edges of both images and produces a less perceptible image overlay. In the future a mash up of these images with Google Earth can be uploaded to restricted websites for access by only authorized users.

The results presented in this paper can be used as a basis for civil applications such as crop monitoring, natural disaster relief, wildfire fire fighting, precision agriculture, to name just a few. These applications will also demand the devel-

Figure 3: Mosaic formed with two standard digital camera pictures

Figure 4: Mosaic built from tiles of an IKONOS satellite image

opment of specific algorithms for each problem domain, adapting the image processing to their specific needs.

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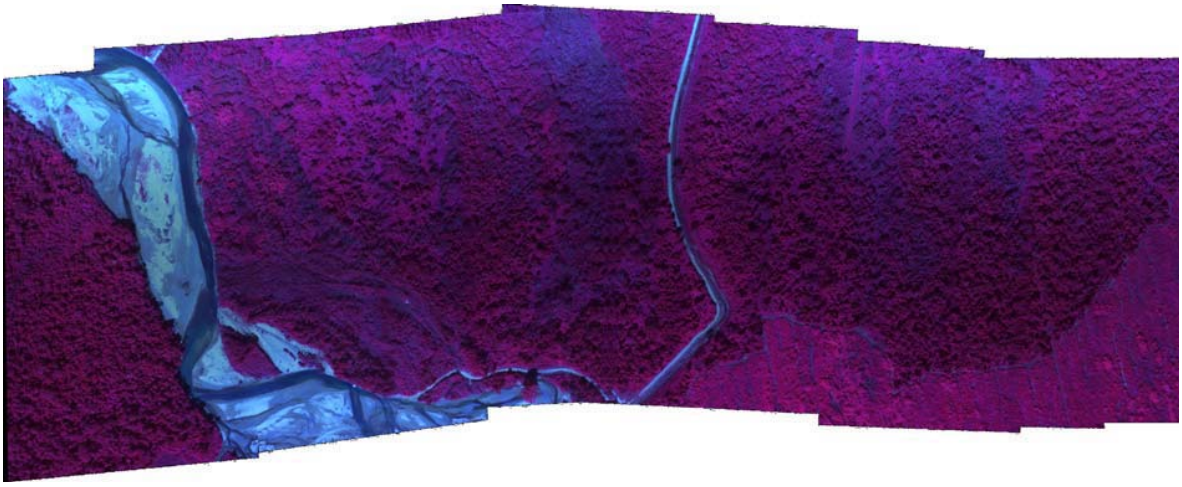

Figure 5: Automated mosaic obtained from a sequence of TETRACAM images

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