GEO-REFERENCING CASI IMAGERY USING DIRECT MEASUREMENT OF POSITION AND ATTITUDE

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ABSTRACT

Geo-referencing is the process of achieving correlation between airborne or spaceborne images and the Earth’s surface. Photogrammetry has been known as a tool of high geometric accuracy, but the manual interpretation of analogue stereo images restricted its use for natural resource monitoring. The need for rapid interpretation of multispectral digital images for natural resource monitoring has resulted in the use of airborne linear push broom scanners. The main drawback of these scanners is their weak geometry, as each image line is in effect an independent one-dimensional image. Resecting an individual line is an indeterminate problem, while using the whole image requires that a model of platform motion as a function of time be solved. With the development of Global Positioning System (GPS) and Inertial Measurement Units (IMU) the potential of airborne remote sensing can be further enhanced by making the direct measurement of position and attitude parameters for each scan line. This provides the potential for high quality geo-referencing of the image. A study is being undertaken at The University of Nottingham in collaboration with Institut Cartogràfic de Catalunya (ICC), in Barcelona, Spain, using the approach of directly measuring the geo-referencing parameters of a Compact Airborne Spectrographic Imager (CASI). The geo-referencing parameters for the CASI images are obtained by measurements from a GPS (Ashtech Z 12), and an IMU (Litton 101). This paper will discuss the equipment used, geo-referencing techniques, calibration method and the results obtained so far.

1 INTRODUCTION

The potential of Geographic Information Systems (GIS) for the analysis and presentation of environmental conditions has been widely accepted. Usually semantic and geographic data is used to exploit the powerful analysis and visualization tools of GIS. The spatial relationship (geographical location) of objects plays a key role in integrating the GIS data. The data collection for establishment and maintenance of GIS database is often a very expensive part of using a GIS. Therefore, the optimal tools for data collection should be fast, cost effective, area covering, kinematic, automatic, easy to handle, real time (or at least near real time), accurate, reliable and large scale (Schade, 1994). Frequently an ideal tool fulfilling all these properties for a particular application does not exist. Aerial photographs and satellite images can be a cost effective data sources for a GIS but these need to be geo-referenced before they are integrated in the database. Geo-referencing is the manual or automatic process of achieving correlation between images and the ground surface. For aerial photography this process involves the estimation of the position and attitude information for each exposure and this is commonly obtained directly or indirectly through ground control generated by aerial triangulation. It is efficiently accomplished due to the stable geometric nature of frame based imagery along with the use of ground control points in sufficient numbers, distribution and accuracy. Unfortunately the cost associated with establishing ground control points can be very high, especially in developing countries, for geo-referencing of remote sensing images which may cover large areas. Although this problem has been eased by the use of Global Positioning System (GPS) for ground control point positioning. Photogrammetry has been known as a tool of high geometric accuracy, but manual interpretation of analogue stereo images restricted its use for natural resource monitoring.

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Complementary to photogrammetry, remote sensing has been known for the automatic interpretation of multi-spectral digital images without setting much focus on high geometric accuracy.

There has become increasing interest in linear push broom imaging sensors in the last few years as a cost effective means to obtain aerial digital imagery. Linear arrays are less expensive to fabricate than area arrays and require no moving parts. Though these provide the multi-spectral images with high quality of automated interpretation capabilities, but the main drawback to the use of linear push broom sensors for accurate mapping is their weak geometry, as each image line is in effect an independent one-dimensional image. Resecting an individual line is an indeterminate problem, while using the whole image requires that a model of platform motion as a function of time be solved (McGlone, 1998). With the development of the Global Positioning System (GPS) and falling costs of Inertial Measurement Units (IMU), the potential of using linear push broom scanners for high accuracy geo-referencing has been reviewed. The direct measurement of exterior orientation parameters, which are needed for geo-referencing of acquired digital images, has resulted in a significant improvement in the quality of geo-referencing and a reduction of control points. Thus an integrated system comprising of GPS, IMU, and multi-spectral scanner such as CASI can be capable of providing a cost-time efficient data acquisition system. This paper presents an integrated sensor system developed by the Institut Cartogràfic de Catalunya (ICC), in Barcelona and the preliminary results from a flight trial.

2 SYSTEM DESCRIPTION

The integrated system is composed of the following components:

- Imaging System
    - Compact Airborne Spectrographic Imager (CASI)
- Position and orientation systems
    - Positioning system, GPS
    - Attitude system, IMU.

To integrate the three components above involves establishing a physical relationship, a timing synchronization and a mathematical relationship. The physical offset between GPS antenna and CASI can be measured directly before the commencement of the flight or at the time of installation of the system. It is also important to determine the miss-orientation between the IMU and scanner, and the calibration of optical parameters of the sensor system. The timing synchronization is achieved by a dedicated system composed of hardware and software. It is a combination of electronic time tagging and interpolation to get a position and attitude at the instant of exposure of each scan line as the data output rate from each sensor is different.

2.1 Compact Airborne Spectrographic Imager (CASI)

The CASI, developed by ITRES Research Ltd, Canada, is a push broom imaging spectrometer intended for acquisition of visible and near infrared multi-spectral imagery from a light aircraft. The imaging spectrograph consists of an objective lens system designed to image a ground across track line (swath). The image passes through a slit and is recorded along one-dimension of a charge-coupled device (CCD). A diffraction grating disperses the image from the slit along the other axis of the CCD sensor spectrally (Cosandier et al. 1994). The across track resolution is defined by the platform height above ground and the optical field of view which is influenced by the focal length of the lens. The platform speed and spectrographic integration time (around 57 milliseconds) determine the instrument frame rate and define the along track resolution. It functions as a two dimensional push broom imaging spectrograph with 512 spatial pixels across swath and 288 spectral channels between 400 – 915 nm (blue – near infra red) along flight path. The number of spectral channels that can be accompanied is dependent on data acquisition rate which is a function of the flight characteristics.

2.2 Position and orientation systems

2.2.1 Positioning System. The Global Positioning System (GPS) is used to obtain the perspective centre (PC) positions of each scan line image. GPS is now a well established system with well established techniques. The GPS technique used in this application is the 'on-the-fly' kinematic technique. This allows a GPS position to be recorded at every GPS epoch. Thus the greater the GPS data capture rate the shorter the interpolation distance between GPS positions to get the PC co-ordinates which leads to a more accurate position. The rate of data capture is increasing, as new receivers are being developed, greater than 10Hz is now possible. This GPS technique requires a base station near to the 'rover' GPS receiver (GPS on the aircraft) to allow the systematic errors to be removed from the GPS observations. Careful positioning of the base station may also be useful in determining the transformation of GPS coordinates from WGS 84 in to the local mapping co-ordinate system. The locating of the antenna on the top of the fuselage facing 'skywards' and the imaging sensor on the bottom of the fuselage facing 'ground-ward' means a translation of the antenna co-ordinates is necessary to give the PC co-ordinates. This is taken in to account in the mathematical modelling.

2.2.2 Attitude System. In general attitude determination at the instant of image scanning can be obtained either by using a multi-antenna GPS or using an IMU. In this project a IMU has been used to provide the attitude information owing to its superior angular measurement, compactness and simplicity over the multi antenna GPS technique. The IMU consists of a set of gyroscopes and accelerometers fixed in a triaxis system. The output from a typical system would include angular measurements and position of the IMU. Thus if the IMU is fixed to a sensor (strap down) then the IMU will be measuring the motion of the sensor. In fixing the IMU to the sensor there will be a miss-alignment between their respective co-ordinate system axes. This miss-alignment is determined during the calibration process. The values of position and attitude from the IMU have a tendency to drift with time (Lawrence, 1993). The rate of this drift is often related to the quality and therefore the cost of the IMU. The IMU that was used in this project would introduce very little drift for the period of capturing a strip of imagery for test site discussed below. Also, only the attitude was recorded from the IMU for the trials undertaken as part of this project. So it can only be used for orientation of the scan lines and not for fully integrating with GPS. The IMU used was a Litton FLAGSHIP LTN-101.

3 GEO-REFERENCING OF AIRBORNE SCANNER IMAGES

3.1 Background

The images from airborne sensors suffer from geometric distortions, largely due to the sensing system, the instability of the platform and unstable geometry of imaging sensor. The platform instability includes variations in attitude and positions due to aircraft motion. The instrumental errors include distortions in the optical system of the sensor and, non-uniform sampling rates. The goal of geo-referencing is to precisely register the raw imagery to the earth's surface. Prior to direct measurement there were two normal methods to achieve the geo-referencing: 'image warping' and 'image acquisition modelling'.

Image warping uses a polynomial function to model all the distortions and transform the image coordinates to the required map coordinates. Ground control points (GCPs) and tie points between strips of image are used to determine the coefficients of the polynomial function. Least squares is used when a redundancy occurs in the solution of equations. This method is popularly known as the 'polynomial technique' (Mather, 1987). The method attempts to take care of all possible sources of errors without quantifying them. Due to the difficulty of defining the function that can precisely model all the distortion present it is more popular for geo-referencing of low-resolution satellite images. Here the platform is relatively stable and also the variations in terrain elevation are small compared to satellite flying height. In the case of airborne scanners, a geometric correction method based on 'global' transformation of the image is not very effective because of the complex pattern of the distortions.

The method based on image acquisition modelling requires the modelling of the internal and external geometry of the sensing system. This process involves the modelling of sensor geometry and aircraft motion (Bernstein, 1983). The CASI sensing system consists of a linear push broom array with 512 pixels with a field of view (FOV) of 44^0, which along with flying height defines the ground pixel resolution. The ground area covered by a pixel depends on its distance from the nadir, as the fundamental image geometry is perspective in nature. The forward movement of the aircraft produces the along track image by capturing successive scan lines of ground image. Therefore, the aircraft motion directly affects the model geometry. It is thus necessary to model the aircraft motion that took place during the image capture. The time interval between successive scan line images (integration time for a scan line) is typically of the order of 1/50 to 1/100 seconds. Although this is dependent on flying height (image scale) and aircraft speed, it is normally assumed that the sensor platform is stationary for a single scan line that is then considered as a conventional photograph with perspective geometry. This means the mathematical model to represent the relationship between the image and the ground, is the well known collinearity equations.

If there is not direct measurement of the position and attitude of each scan line then a time dependent relationship must be established between all like parameters. The geometric parameters are then determined by using ground control points in a least square computation. Smith et al., (1992) attempted to compute the position and attitude parameters using the collinearity equations for a Daedelus AADS 1268 Airborne Thematic Mapper imagery, and achieved results comparable to first and second order polynomials. The basic drawback with such an approach is the difficulty to define the flight (time dependent) parameters to describe the rather unpredictable, aircraft motion. Now with the technology available described in section 2.2 there is no need to mathematically describe the motion of the aircraft.

3.1 The method using the direct measurement of position and attitude

With direct measurement of position and attitude modelling at the instant of image capture is necessary. The airborne sensor (aircraft frame) has a co-ordinate system (x^b, y^b, z^b) which changes its position and orientation with respect to the mapping frame (X^m, Y^m, Z^m) (earth surface) as a function of time. The aircraft frame has movements of pitch (ϕ), roll (ω), and yaw (κ) (heading), which are related to the mapping co-ordinate system, see figure 1. Using unit vector e the transformation from the aircraft frame to the mapping frame is of the form:

$$e^m = R^m_b \; e^b = R_3(\kappa) R_2(\phi) R_1(\omega) e^b \qquad (1)$$

Where R_1, R_2, R_3, are the elementary rotations about primary, secondary and tertiary axis respectively and the overall orthogonal rotation matrix can be written as:

$$R^m_b = \begin{bmatrix} \cos\kappa\cos\phi & -\cos\phi\ \sin\kappa & \sin\phi \\ \cos\omega\sin\kappa - \sin\omega\sin\phi\cos\kappa & \cos\omega\cos\kappa - \sin\omega\sin\phi\sin\kappa & -\sin\kappa\cos\phi \\ \sin\omega\sin\kappa - \cos\omega\sin\phi\cos\kappa & \sin\omega\cos\kappa + \cos\omega\sin\phi\sin\kappa & \cos\omega\cos\phi \end{bmatrix} \qquad (2)$$

Based on the equations by Schwarz et al. (1993) for aerial cameras, the geo-referencing of CASI image is possible if at any instant of time (t), the position of perspective centre of the camera or scanner are given in the co-ordinates of mapping frame i.e. U^m and the rotation matrix (R_b^m) has been determined. The geo-referencing equation then becomes:

$$\Delta U^m(t) = U^m(t) + s_m(t) R_b^m(t) p^b(t) \qquad (3)$$

Where, ΔU^m is the position vector in the chosen mapping system; U^m is the position of the centre of sensor; s_m (t) is the scale factor derived from the height of sensor above ground; $p^b(t)$ is the vector between perspective centre and an image point given in the frame b.

Equation (3) is the simplest form of geo-referencing equation to define the perspective geometry. It relates points in the image plane to the points on the ground in the defined mapping frame. It implies that the co-ordinates of the perspective centre of the imaging sensor can be directly determined. It is usually not the case because the positioning GPS antenna has to be on the upper surface of the fuselage. If the vector between the two centres (e.g. GPS and imaging sensor) is given in the aircraft frame as a^b, equation (3) can be written as:

$$\Delta U^m(t) = U^m(t) + R_b^m(t)\,(s_m(t)\,p^b(t) - a^b) \tag{4}$$

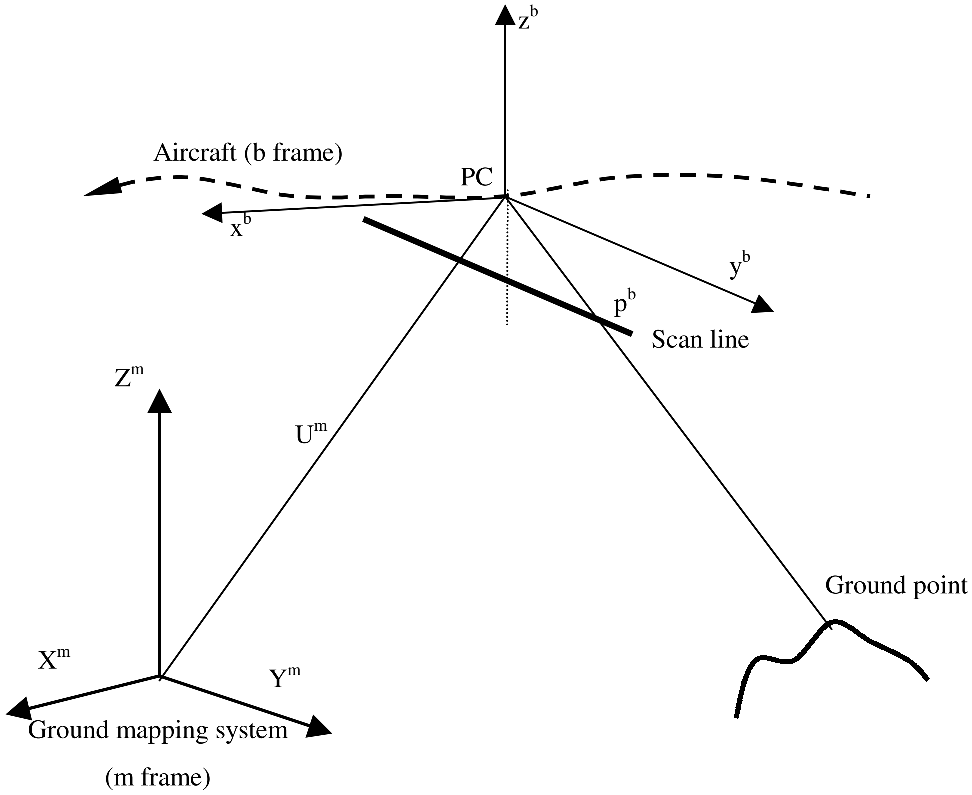

Figure 1. Concept of geo-referencing

The vector a^b (camera - GPS offset) can be determined before the start of mission by direct measurement using for example theodolite intersection techniques. Similarly the IMU may not be completely aligned with the imaging sensor; and this will introduce a constant miss-alignment dR in to the rotation matrix. The resulting equation then takes the form:

$$\Delta U^m(t) = U^m(t) + (R_b^m(t).\,dR)\,(s_m(t)\,p^b(t) - a^b) \tag{5}$$

A convenient way to determine this miss-alignment matrix (dR) is to fly over a test field with precisely known ground control co-ordinates. This should be done at the start of the flight mission. The matrix can then be determined using the collinearity equations.

4 TEST SITE AND TRIALS

A test site has been established at Bellmunt in Spain and data has been acquired for the present study. Seven strips of image were captured over the area with a ground pixel size ranging from 1m to 1.5m. Two base stations consisting of TRIMBLE 4000 SSE GPS receivers were used to facilitate the differential processing of GPS data. The data rate from GPS being 1 Hz, while the rate from the IMU is 50 Hz and this requires synchronization to match the CASI imagery which was captured at about 60Hz. This synchronization was achieved by an integrated System of Airborne Sensors (SISA), developed by ICC for this kind of applications and provides the time tagging for each scan line in GPS time frame (Alamús et al., 1999). Therefore after GPS processing cubic spline interpolation as proposed by Fisher (1995), was applied to obtain the GPS positions corresponding to each scan line. The attitude data (ω,ϕ,κ) was recorded using a LITTON 101 and was linearly interpolated for attitudes of the platform at the mean scan instant for each line. At present the analysis and processing has been carried out for the first five strips flown nominally from north to south. A set of ground control data has been used to determine the angular miss-alignments and some optical parameters. The general flight parameters are as follows:

Focal Length 9.33 mm	Field of View 44.7^0	Average Terrain Height 740 m.
Average Flying Height	1450 m (first two strips)	1900 m (other 3 strips)
Average Ground Pixel Size	1.0 × 1.0 m (First 2 strips)	1.5 × 1.5 m (other 3 strips)

The algorithms have been developed so far for geometric processing of the images. An accuracy assessment has been carried out not only by comparing the absolute co-ordinates with ground control points but also by comparing the co-ordinates of common points in the different strips of image.

5 RESULTS

The calibration of the attitude measurement must take in to account the miss-alignment between the image coordinate system and the IMU as well as between the IMU and the mapping frame. The computation to determine the miss-alignment is based on equation (5). Further elements of calibration can be introduced, in particular the position of the principal point and the principal distance. High correlation was expected between certain parameters and early results showed this to be the case. To deal with this problem the determination of the calibration parameters was carried out in two different ways. Firstly, by splitting the parameters into two groups and solving for the rotations then the optical parameters. Secondly the calibration was performed solving for all parameters except dx.

Strip No	No of C.P	Total No of Points	RMSE at Control Points		RMSE at Check Points	
			X m	Y m	X m	Y m
1	16	20	2.35	1.46	1.64	0.87
2	14	19	1.80	1.03	2.45	0.79
3	19	24	2.60	1.80	1.51	1.73
4	17	23	2.96	2.30	2.33	1.60
5	18	24	1.91	1.40	2.04	1.10
Mean			2.32	1.60	1.99	1.22

5.1 Residuals at control and check points with the adjustment for angular and linear variables in different stages

The results from the calibration are presented in tables 1 – 4 as root mean square errors (RMSE) at control points (points used in the calibration computation) and check points (points not used in the calibration computation). Table 1 and table 3 show each strip calibrated separately. Table 2 and table 4 show a comparison between check point coordinates that are common between adjoining strips. The RMSE values at check points are indicative of the results expected from geo-referencing the image including the use of digital elevation model (DEM). Results are showing accuracy in the order of sub pixel to 1.5 pixels is being achieved by these techniques

Strip Nos.	common Points	Individual strips RMSE at Common Points X m	Individual strips RMSE at Common Points Y m
1 & 2	3	1.08	0.89
2 & 3	3	1.81	1.79
3 & 4	3	3.56	1.37
4 & 5	5	1.15	1.33
Mean		1.90	1.35

5.2 Residuals at common points between strips with the adjustment for angular and linear variables in different stages

Strip No	No of C.P	Total No of Points	RMSE at Control Points X m	RMSE at Control Points Y m	RMSE at Check Points X m	RMSE at Check Points Y m
1	16	20	1.50	1.46	1.08	0.85
2	14	19	2.21	1.03	2.21	0.79
3	19	24	2.29	1.77	2.82	1.73
4	17	23	1.47	2.33	1.85	1.59
5	18	24	1.61	1.40	1.71	1.12
Mean			1.82	1.60	1.93	1.22

5.3 Residuals at control and check points with the adjustment for angular and linear variables at the same stage

Strip Nos.	common Points	Individual strips RMSE at Common Points X m	Individual strips RMSE at Common Points Y m
1 & 2	3	0.28	1.03
2 & 3	3	0.97	1.73
3 & 4	3	1.70	1.29
4 & 5	5	1.79	1.33
Mean		1.19	1.35

5.4 Residuals at common points with the adjustment for angular and linear variables at the same stage

Further tests are to be carried out to explore a number of other calibration issues. The correlation between parameters needs further investigation along with the calibration of all strips together. Since there will be a significant time taken to fly all the strips any drift in the IMU measurements must be taken into account. Preliminary investigations into using all strips show this is likely to be the case. Further investigations will take place into reducing the number of control points for the calibration to find the economical optimum number.

6 CONCLUSIONS

The results so far are encouraging with results from sub-pixel to 1.5 pixels being achieved and it is expected that a number of refinements will improve the quality of results. This technology shows the potential for geometric processing of airborne scanner data for monitoring the rapid changes in the environment is an efficient and cost effective way. It will further enhance the potential of airborne scanner technology to find its due place in the real world of development planning.

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