DIGITAL LOW-COST REMOTE SENSING WITH PFIFF, THE INTEGRATED DIGITAL REMOTE SENSING SYSTEM

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ABSTRACT:

Beside high end digital imaging systems which will replace standard photogrammetric cameras in the future, a large number of "low-cost" airborne systems were developed in the last years. The system PFIFF, a digital airborne remote sensing system developed by the author, is described in detail with special respect to demonstrate the photogrammetric potential of PFIFF. The demand for current digital data of "hot spots" for various purposes is strongly increasing. in the last years several digital airborne systems were developed in the research community and for commercial use to fulfil this demand. A categorization in terms of their main components and their generated products is given. The system PFIFF, a digital airborne remote sensing system, developed by the author, is described in detail with special respect to the demands and problems of high resolution urban surveys.

1. INTRODUCTION

Urban areas undergo a continuous change; this change however doesn't take place in the whole town, but in certain developing areas such as construction sites etc. These areas are often relatively small; let's say only a few km². The user, especially local agencies, developers and private companies are interested in current data of these "developing spots" with a high level of detail. They also want the data to be delivered digitally and orthorectified within a few days after an aerial survey. The cost for data per km² from a conventional aerial survey however increases, the smaller the area of interest becomes. Due to these reasons there is a strong demand for economically priced remote sensing data for small areas.

The introduction of the high end digital imaging systems which shall replace the standard photogrammetric cameras is a slow process, why? Digital systems like the DMC, ADS 40 or Ultracam are on the market and technically well developed. But especially for smaller airborne companies a beneficial operation is hard to find, because of the high system price. On the other hand digital "low-cost" systems which provide an efficient and fully digital work flow from image acquisition to orthophotos and digital terrain models are booming. The focus of small digital imaging systems are either new markets such a precision farming or they displace the standard photogrammetric camera, e.g. to obtain additional image data during laser scanning. In general digital low cost systems may be better suited than standard photogrammetric camera in the following fields:

- Lower price per mapped area, especially for small sites of a few km² or with low ground resolution
- Short turn around time from image acquisition to the first image / final product due to an automated and fully digital work flow
- Combination of nadir an oblique viewing images.

In the last years many digital airborne "low-cost" systems were developed in the research community world wide for a large range of applications and with different technical specifications, e.g. Bäumker et al, 1999, Franke and Montgomery, 2000, Holm and Rautakorpi, 1999, Mostafa and Schwarz, 2000, Thom and Souchon, 1999, Toth, 1999. There are also integrated commercial systems available, e.g. ADAR from Positive Systems or EMERGE^{TM} from Emerge or Leica to name only two.

These systems range from "low end" systems for the acquisition of single or multiple vertical images to professional high end systems with fully automated photogrammetric workflow and direct georeferencing of single images, image strips or blocks. There are certain key components necessary, e.g. an advanced flight management system or a GPS/INS to enhance the degree of automation to produce orthoimages and digital surface models.

The efficiency of a digital system in terms data acquisition, data processing, turn around time and price for the user is always a compromise. With the use of more sophisticated technologies the photo flight and the orthorectification process may be speed up significantly. On the other side the cost for such a system raises drastically, thus requiring large areas / huge amounts of data to be processed.

In the following the system components of PFIFF a digital airborne system developed by the author will be described and some experiences with aerial surveys and direct georeferencing will be presented.

2. PFIFF

PFIFF, a digital airborne remote sensing system, was originally developed by the author to fulfil the special requirements of precision farming. Those requirements – low cost, high amount of detail and rapid delivery – are very similar to those urban users.

2.1 System components of PFIFF

The core of the system is a digital SLR colour camera, the Rollei db23. The CCD-sensor from Phase One has a resolution of 2032 * 3056 pixels, see Table 1 for the technical details of the camera. With the exposure interval of less than 2 seconds, the Rollei db23 camera enables photogrammetric aerial surveys (60% end lap) with a ground resolution of > 12 cm. The digital back works together with a Rolleiflex 6008 Integral camera body and a Zeiss distagon 4/50-lens with a min exposure time of 1/500 s. The digital camera is controlled by a laptop, which also stores all the image data via a firewire connection.

Table 1: Technical parameters of the digital Rollei db23 camera

	Rollei db23
Camera type	Rolleiflex 6008 with fixed digital back
Resolution	3.056 * 2.032
Pixel size	12 µm * 12 µm
Sensor size [mm]	36.67 * 24.38
Colour depth per channel	12 Bit
min. exposure interval	ca. 1.8[1] sec.
Weight (incl. camera)	ca. 1,500 g
Connection to computer	Firewire, MS-Windows notebook
Software	Phase One 2.7

[1] value for two consecutive images, for secure image recording of a strip add 50%.

Other important components of PFIFF are the GPS-based flight management system and a navigation unit that automatically triggers the images during a flight strip according to the pre defined end lap. The navigation unit records the exposure delay of the camera as well as the approximate parameters of the exterior orientation with an attitude heading reference system (AHRF). The AHRS consists of a digital compass and a two axis inclinometer. The exposure control is coupled with the PPS-signal of the GPS-clock to ensure a perfect synchronisation with the external high accuracy L1/L2-GPS receiver.

For a photo flight the system is temporarily installed in a Cessna 172 with a small ground hole of ca. 12 cm in diameter. See Figure 1 for the system design.

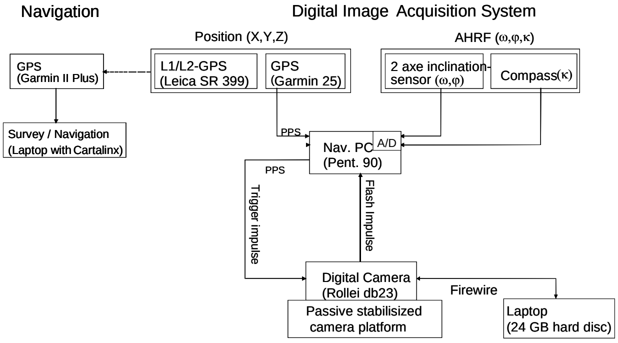


Figure 1: Low-cost remote sensing system PFIFF

For the use of a digital camera in aerial surveys not only the size of the CCD-sensor is of importance, but also many other criteria of the digital camera such as the minimum exposure interval, the external storage capacity, a continuous power source, preview options, the mechanical stability of the sensor (interior orientation), the temporal eccentricity (exposure delay), the reliability and also the radiometric properties have to be considered and determined. Therefore the system has undergone thorough geometric and radiometric calibration procedures. For photogrammetric work the interior orientation of the camera was determined. With the fixed digital back of the db23 an on-flight calibration is not necessary. The examination of the linearity, the spectral characteristics of the RGB band filters and the high signal to noise ratio revealed that the radiometric properties of the digital camera are superior to an equivalent photographic system.

2.2 Practical experiences with PFIFF

Between 1999 and 2004 single components and PFIFF as a whole was well tested in over 70 aerial surveys with more than 8.000 images recorded. The sensor system was tested in the lab as well as under airborne conditions with an additional geodetic GPS receiver and a multi antenna GPS on board of the aeroplane to explore the accuracy potential for direct georeferencing of the system.

The first photogrammetric test-flight in Nov. 2000 revealed the full geometric potential of the system, allowing sub pixel accuracy without ground control points through aerotriangulation and high accuracy GPS-receivers. Through the comparison of the exterior orientation parameters of both systems the absolute positional and angular accuracy of the GPS/AHRS-system could be determined. The accuracy assessment is complete because the residuals of the orientation parameters as well as the calibration errors of the optical system and errors of the sensor orientation are incorporated in the difference vectors to the well known ground control point co-ordinates.

Due to large number of images (> 2.000 per year) the management and archival of the image data and the meta data is quite a challenge. The meta data collection has been automated with several routines and special avenue scripts. For a convenient search and ordering of data via internet a JAVA based inquiry tool was developed.

2.3 Flight planning for high ground resolution aerial surveys

In the flight planning for urban surveys several special issues have to be considered. The surveys are generally done at low altitudes and thereby take place in a turbulent flight zone, especially during the summer when the urban heat dome introduces additional thermal turbulences. For surveys with a high ground resolution (12 – 15 cm) the minimum exposure interval at normal ground speed of the aircraft (40 – 55 m/s) becomes critical. A flight with reduced speed (30 – 40 m/s) however decreases the stability of the airplane furthermore. This causes higher deviations in the roll, pitch and heading angle. Due to the lack of an active stabilized mount a high side lap of more than 30% has to be considered in the flight planning.

A further source of inaccuracies may be caused be image motion due to the ground speed of the aircraft. Additionally image motions due to rotations and vibrations of the aircraft during image acquisition also occur. For digital images the resolving power of the lenses is generally better than the pixel resolution and therefore the image movement shall be no larger than one pixel to maintain a sharp image. The image motion may become a limiting factor for PFIFF at high ground resolutions, because the minimum exposure time of the lens is 1/500 s.

3. EXAMPLES

To demonstrate the potential for urban and agricultural applications of PFIFF two recent projects will be described in more detail. Due to different specifications of the projects the ground resolution ranged from 15 – 55 cm.

3.1 Example Poppendorf

The block "Poppendorf" realized at the 14th of April 2004 consisted of 139 images flown in 8 strips at an altitude of approx. 2.400 m, thus resulting in a ground resolution of 55 cm/pixel. The block covered an area of approx. 10 * 11.5 km, see figure 2.

The images were taken for agricultural purposes, in order to give a farmer an overview of his current crop and biomass status (precision farming). For agricultural management decisions based upon this type of imagery the turn around time between image acquisition and the delivery of orthorectified and interpreted data is crucial. Therefore the images were geocoded within three working days based upon the approach of an aerotriangulation without ground control points. The kinematic GPS-data of the geodetic receiver was extracted in postprocessing. The interpolation of the 1 Hz GPS-data onto the perspective centre was done by linear interpolation. With the precise information of the position of the perspective centre and the approximate angular information of the AHRS and the heading information of the GPS the necessary tie points were found automatically with the ERDAS LPS 8.7 software.

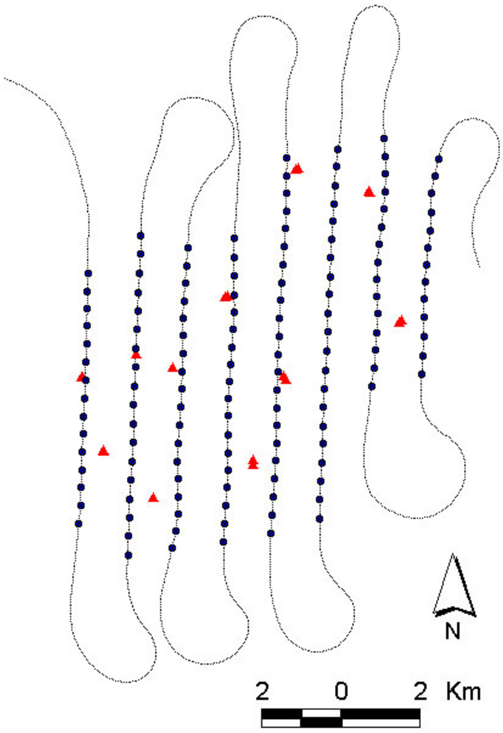


Figure 2: Photogrammetric block Poppendorf (black dots, perspective centres of images; triangles, ground control points)

For a "true" estimation of the triangulation results without ground control 16 ground control points (GCP's) were introduced first as check points and in the second step as GCP`s, see figure 2 for the spatial distribution. The GCP's were natural points, collected with a geodetic GPS receiver. Table 3 presents the results of the integration of the GCP's in order to enhance the triangulation results.

Table 2: Residuals of aerotriangulation of the block Poppendorf - with and without GCP's

Residuals [m] at 16 check points for AT without GCP	X	Y	Z
Std.	0.94	0.84	0.85
Max.	1.34	1.75	2.11
Min.	-1.61	-0.97	-1.79
Residuals at 16 control points [m] for AT			
Std.	0.26	0.28	0.06
Max.	0.40	0.81	0.07
Min.	-0.56	-0.27	-0.15

From table 2 it becomes obvious that without any GCP the overall accuracy of the block is within 1 m or roughly two pixel. This positional accuracy is well enough for the anticipated purpose of precision farming. With the full number of GCP's the accuracy is within the sub pixel range, which is also a good indicator of the overall stability of the block.

The subsequent orthorectification was based on the national DTM 25 with a height accuracy of approx. 2 m. For the mosaiking of the single images the cutlines were defined automatically and a feathering algorithm was used for a smooth radiometric transition between neighbouring images.

3.2 Example Laage

On 6th of September 2003 a flight of a 4 km long part of an avenue with trees on both sides was conducted with a ground resolution of approximately 12 cm. The purpose of the flight was to investigate the possibilities to obtain information of the trees, the street and the surrounding from nadir looking images as well as from oblique images. Therefore the central flight line along the street was designed to gather nadir looking data. For the oblique images the camera was turned around 90 degrees and held out the window of the airplane manually. On small aircrafts such as a Cessna 172, the wheels of the aircraft maintain outside during the flight. Due to this fact oblique images out of the window could not be taken at the anticipated 45° angle. Instead the looking angle was approximately 60° in omega. In order to get an idea of the left and right side of the street two strips with oblique images were flown, see figure 3 for the flight pattern. To become oblique stereo images with and end lap of 60% the automatic trigger control of the flight management system had to be reset accordingly.

Figure 3: Flight pattern for a combined nadir and oblique aerial survey of a street

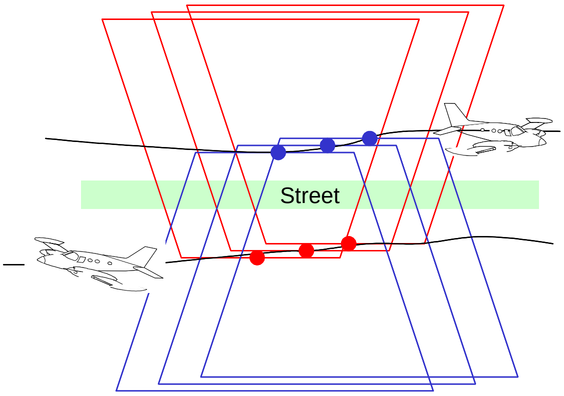
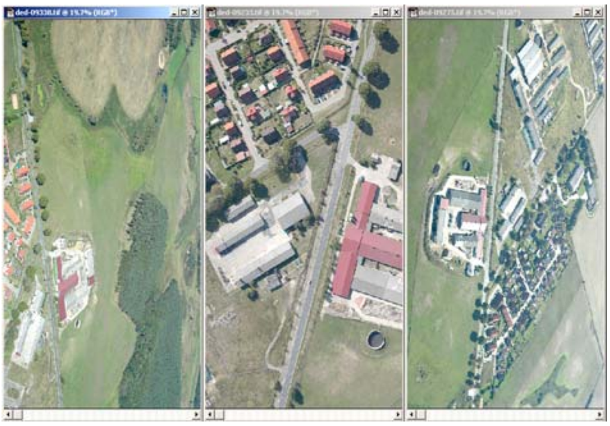


Figure 4 gives an impression of the imagery from the different viewing angles.

Figure 4: Example of nadir and oblique images



At first the nadir looking strip was processed. Since the photogrammetric orientation of a single strip requires ground control points, 18 natural GCP's were collected along the avenue after the photo flight. Table 3 presents the triangulation results of the 34 nadir looking images. The accuracy of the GCP's was set to 4 cm in X, Y, Z.

Table 3: Residuals [m] at 18 control points for AT Laage

	X	Y	Z
Std.	0.07	0.06	0.03
Max.	0.11	0.17	0.07
Min.	-0.13	-0.13	-0.06

The georeferencing of the oblique images was more complicated, because tie points in neighbouring images could not be found automatically in the first instance. This is related to the fact, that the starting values of ω and φ of the hand held images were unknown. After a manual definition of a minimum number tie points with a selected number of oblique images, a preliminary triangulation was conducted to obtain approximate angles in ω and φ. Thereafter the automatic tie point generation algorithm worked fine. Due to the apparent differences in the scale within the oblique images the precise determination of the ground control points was difficult. Nevertheless the results of the aerotriangulation of the oblique images were within 60 cm RMS at the GCP's. The most interesting aspect for the interpretation of the trees and other features along the street is the stereo view of the oblique images, because an orthorectification does not yield the full information. However the stereo interpretation with the Erdas Imagine Stereo Analyst 1.4 of the imagery was only possible for small parts of the imagery, due to a software bug.

3.3 Direct Georeferencing

The comparison illustrates that there is still quite some manual labor necessary for georeferencing with PFIFF, which could be drastically reduced with a GPS/INS. Therefore a first test flight was conducted on the 7th of April 2004. A Litton 86 IMU of the Applanix 410[1] GPS/INS of DLR, Institute for Navigation was tightly mounted on the camera, see figure 5. The airborne L1/L2-Antenna (Sensor Systems S67-1575-76) was set on top of the aircraft, approximately above the camera. The lever arms between the camera, the IMU and the GPS-antenna were determined with a total station. For the determination of the boresite angles and information of the overall accuracy a small test field with 12 signalized targets was established.

Figure 5: Litton 86-IMU mounted on Rollei db23

The weather conditions of that day were miserable, with a cloudy sky and sporadic rainfall. Nevertheless a photo flight at altitudes of max. 650 m above ground could be realized, yielding a ground resolution of approx. 15 cm/pixel. The 1.5 h test flight consisted of two starts to obtain information of the stability of the GPS/INS solution. Therefore the test field was flown two times. Additionally to the test site a photogrammetric block with four strips and a total of 86 images was acquired. Also a strip of oblique stereo images was made. The flight took place within a 12 km range of the airport, where the GPS reference station was build up. In the first step an aerotriangulation of the test blocks was conducted to determine the bore site angles between the camera and the IMU. Based upon the initial values of the GPS/INS the tie points between the images were found automatically. With the position of the perspective centers set to be fixed, differences between the GPS/INS angles and the aerotriangulation were determined. To estimate the triangulation results without ground control 12 signalised points were introduced first as check points and in the second step as GCP`s. Table 4 presents the results of the first flight over the calibration site.

Table 4: Residuals of aerotriangulation of the calibration site - with and without GCP's

Residuals [m] at 12 check points for AT without GCP			
	X	Y	Z
Avg.	0.094	-0.014	0.630
Std.	0.066	0.043	0.305
Max.	0.223	0.041	1.408
Min.	0.016	-0.114	0.019
Residuals at 12 control points [m] for AT			
Std.	0.050	0.061	0.022
Max.	0.105	0.089	0.060
Min.	-0.068	-0.108	-0.007

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[1] http://www.applanix.com/html/products/prod_airborn_tech_410.html

Thereby it became obvious that there are systematic shifts depending upon the flight direction between the angles of the GPS/INS solution and the outcome of the aerial triangulation. The shifts of +/- 0.1° in ω and +/- 0.45° in φ are most probably related to the different definition of the rotations matrices of the Applanix system and the ERDAS LPS Software, Cramer & Stallmann, 2002. The recalculation of the rotations is currently under way.

Additionally the GPS/INS data provide valuable information to compare them to the common approach of PFIFF, based solely on the GPS-information with linear interpolation to the perspective centres. The time delay between the trigger impulse and the image exposure is 71 ms, ± 0.5 ms. The GPS data was processed with the Leica Ski Pro 3.0 software. A comparison with the integrated GPS/INS data was done at 133 recorded events. Thereby the positions at the full GPS-second prior to the recorded trigger event and the XYZ-position at the event itself were compared, see table 5a. Table 5b shows the influx (residuals) of the linear interpolation onto the perspective centres between two GPS-seconds, compared to the GPS/INS positions.

Table 5a: Differences between GPS and GPS/INS (n = 133).

	X	Y	Z
Avg.	-0.006	-0.003	-0.553
Std.	0.106	0.061	0.109
Max.	0.177	0.135	-0.258
Min.	-0.139	-0.119	-0.697

Table 5b: Residuals between GPS and GPS/INS at the interpolated perspective centres (n = 133).

Avg.	-0.001	0.000	0.000
Std.	0.012	0.017	0.007
Max.	-0.019	-0.038	-0.023
Min.	0.028	0.060	0.018

The standard deviation of X and Y in table 5a is due to the fact that the GPS-antenna on top of aircraft was not placed exactly above the camera. The differences in Z are still under investigation. The very small residuals in table 5b demonstrate, that a simple linear interpolation yield precise information of the perspective centres.

4. CONCLUSIONS AND OUTLOOK

The most important factor for aerial image acquisition is the reliability of all components, especially for larger projects or for commercial use. This is some what in contradiction to a university development where every now and then new components are added or changed. Nevertheless PFIFF has been proven to be a reliable system for digital airborne data acquisition. Currently the bottleneck for high resolution surveys is the number of images with a total of several gigabytes which have to be processed and geocoded in a timely manner. This may be overcome with direct georeferencing. The test flight revealed that direct georeferencing does not only work high end photogrammetetric systems but also with digital SLR-cameras. For low cost systems the direct georeferencing provides additional flexibility for image acquisition, especially for a combination of nadir looking and oblique images.

With direct geocoding small digital systems such as PFIFF will become a competitive alternative due to some special advances compared to large digital systems such as the DMC or ADS 40.

An important goal for future hardware developments is the construction of an active mount, which compensates the difference between the true heading and navigated direction of the aircraft. The active mount will also reduce the need for large side laps in urban areas and make the photo flights even smoother than today.

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