Advancements in the Development of DORIS*

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ABSTRACT

The airborne imaging system DORIS has undergone significant advancements since its first development in 1996 at Alberta Research Council, Alberta Canada. The system, which combines a laser scanner digital elevation model with simultaneously captured digital images, is used primarily to produce highly accurate high-resolution ortho-rectified image map for Forest Inventory and Management System. Besides its primary usage, DORIS image-map and the laser scanner digital elevation model provide a complete spatial base layer in a GIS system and can virtually serve all mapping applications requiring very high resolution and accurate three dimension spatial information. The DORIS system uses GPS/INS trajectory information to obtain the exterior orientation information of the camera exposure stations to directly geo-reference the acquired imagery.

The development of the DORIS system involves integrating hardware components for data acquisition as well as developing processing software for processing the data. Whence, the DORIS system has two main components, namely, DORISia for data acquisition, and DORISpp for data pre-processing, and DORISpr for data processing. The components are integrated in a way to suite handling large data sets from the laser scanner and the digital camera. They also optimized for high performance under fully automated procedures from acquisition to image-map mosaic creation. The innovative concept of tiling is used throughout the automated scenario to speed up the overall processing of data.

The pre-processing step in the DORIS system is intended to facilitate the processing of data. In this step, the trajectory information from the INS/GPS system is utilized along with the GPS event markers for the camera firing events are used to obtain the exposure station exterior orientation information. A coarse and fine alignment process is done in the pre-processing step to bring the camera and the laser scanner to align and hence produce highest quality possible.

In this paper, advancements in the development of the DORIS system will be presented. Lab and field test results are presented to show the potential of the system.

1. INTRODUCTION

Management of Resources data is becoming increasingly complex because the objectives are dynamic in space and time. For instance, scale integration in forest resources is limited due to the limits imposed by the existing data [McNabb 2000]. Traditional vegetation mapping approaches, for instance, require extensive field reconnaissance and normally involve delineation of vegetation boundaries through interpretation of aerial photographs [Pollock 1999; Coulter et al 2000]. The inventory evolution of the resources information starts with the commodity and goes through some processes until the resource value is reached. Synergy is then achieved from integration of sensors and biophysical entities. With a synergy of tools, a platform can be built on which others can build additional applications, or is used by other management systems.

A suite of Geomatics and Remote Sensing (GRS) technologies for forest resources has been under development at Alberta Research Council since 1996 (see [Pollock 1998a, 1998b]). The focus of the new technology is on acquiring data for fundamental biophysical entities of sustainable forest eco-systems. Among the objectives of the GRS initiative is the opportunities for reducing the cost of the planning and conduct of forest operations. The ambitious objective of the GRS program is to develop tools and methodologies to enable bar-coding the trees in the Forest [McNabb 2000].

* Acronym for Differential Ortho-Rectification Imagery System

Technology drivers for change include many readily available and developed tools. In the mapping area, GPS/INS, digital cameras, laser scanners, and GIS stand as crucial tools for modern mapping systems. Many new decision support tools and spatial planning models rely on these new technologies. In fact, the modern mapping technology can improve competitiveness and compensate for extensive, relatively low productivity land-based operations. For instance, high spatial resolution digital imagery provides significant advantages over many traditional image sources. To be most useful for forestry users, any imagery products must also be properly geo-referenced [Ackermann 1996; Quackenbush et al 2000].

The need for new tree inventory system stems from the fact that Canadian and Alberta inventories are poor. The sampling strategy for the current system is extensive and labor intensive [McNabb et al 2000]. It is currently used for single purpose, wood supply. The new technology help provide critical measure of sustainability of harvest levels. As regards the landform and soil mapping, the need for new tools is driven by the fact that the current maps are poor at best and most forests have not been mapped. During the recent years, there has been increased interest in the increased value of water and other forest-related resources. Alberta Research Council GRS adds forest productivity assessment and management tool, which in turn maximizes potential for high-resolution digital elevation models, predictive landform and soil mapping, and intelligent systems and decision support approach.

The components of the GRS suites of technologies include aerial multi-sensor integration for data acquisition, tree imaging and forest inventory, landform and soil mapping under the umbrella of the integrated natural resources inventory and information system. The focus of this paper is on the development and testing of a high-resolution spatially accurate data resource system called DORIS.

2. DORIS TECHNOLOGY

DORIS represents the new trend in technology of modern mapping systems. The system relies completely on direct geo-referencing in the air from a GPS/INS system, eliminating the need for aerial triangulation. The images are acquired with a digital camera eliminating the need for film scanning. The digital elevation model is acquired through a laser terrain scanning system, which makes ortho-rectification possible without creating stereo models.

Figure 1 below shows the three enabling technologies on which the DORIS technology resets, namely, direct geo-referencing, digital imaging, and laser terrain scanning. The product of the DORIS system is high- resolution highly accurate three dimension ortho-rectified image-map and digital elevation model. DORIS image-map and the laser scanner digital elevation model provide a complete spatial base layer in a GIS system and can virtually serve all mapping applications requiring very high resolution and accurate three dimension spatial information. In addition, resource mapping and medium-scale surveys fit well within the realm of the DORIS and DORIS-like technology.

The current advancement in the computer and Geomatics enabling industries makes the all-digital DORIS-like mapping systems possible. Lidar systems at data rates as high as 100 kHz and with multiple returns are available or will be available very soon from Lidar major manufacturers. Digital frame cameras and digital push broom line imaging systems as well as off-the-shelf low-cost digital camera systems are available from well reputable manufacturers. The all in air direct geo-referencing concept has been accepted and in place for many years after the introduction of many state-of-the-art GPS/INS systems. It is no surprise that DORIS-like technologies will dominate the mapping industry in the coming few years.

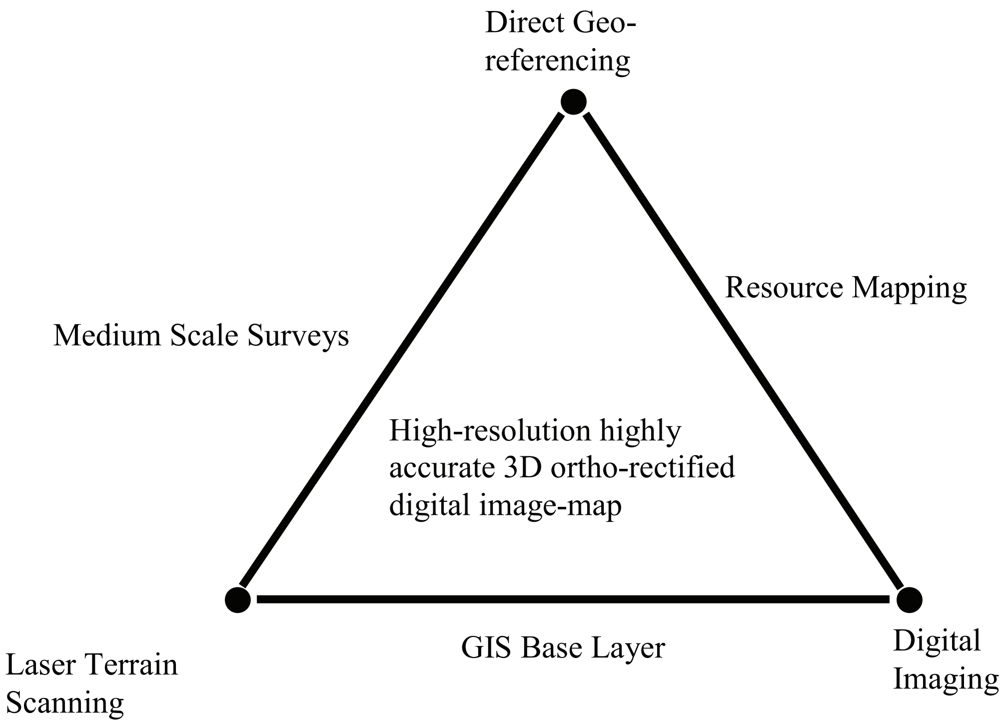


Figure 1: DORIS Technology

3. SYSTEM COMPONENTS

The major components that make the DORIS system are: in-flight acquisition, calibration and alignment procedure, data pre-processing and data processing. Hardware and software are in the heart of each of the DORIS system components. In the following, a brief description of each component is given.

3.1. In-flight Data Acquisition

Figure 2 shows the software interface between the acquisition computer and the camera and GPS system. It also illustrates, schematically, the communication between the different hardware onboard of the airplane.

The scanning-laser is an all-digital system that quickly and economically collects terrain data at high sample densities. Intelligent processing of laser data can classify the laser points as belonging to the terrain or belonging to objects near the ground, like vegetation, buildings, power lines, or other structures, see [Gutelius et. al. 1996] for more details of the laser-scanning system.

A Kodak Professional Digital Camera System is used in the proto-type of the DORIS system as an imaging sensor. The specific model DCS 520c used in the test flight is 3-color camera (RGB) with 12 bits/color and has a frame size of 1728x1152 pixels, where the actual pixel size on the CCD is 13 μm. The footprint of each frame depends on the flying height and the focal length of the used lens. In this particular test, a lens of focal length equal to 24 mm was used resulting in a ground pixel size of approximately 0.30 m at a flying height of 500 m.

A customized embedded Applanix POS/AV IMU and on-board NovAtel OEM3 Millennium GPS receiver provided the direct geo-referencing information to the DORIS system. Supplying a special pulse generator specifically designed to this purpose carried out the communication between the camera and the GPS receiver to record camera event markers. The pulse generator filters the noisy signal from the camera flash synch port and generates a clean signal to the GPS receiver. The receiver, at the reception of the camera signal, issues an event marker and stamps the marker with GPS time. An on-board strap-down industrially rugged lunch-box computer handles all the data and the camera event markers, see the schematic in Figure 2 below.

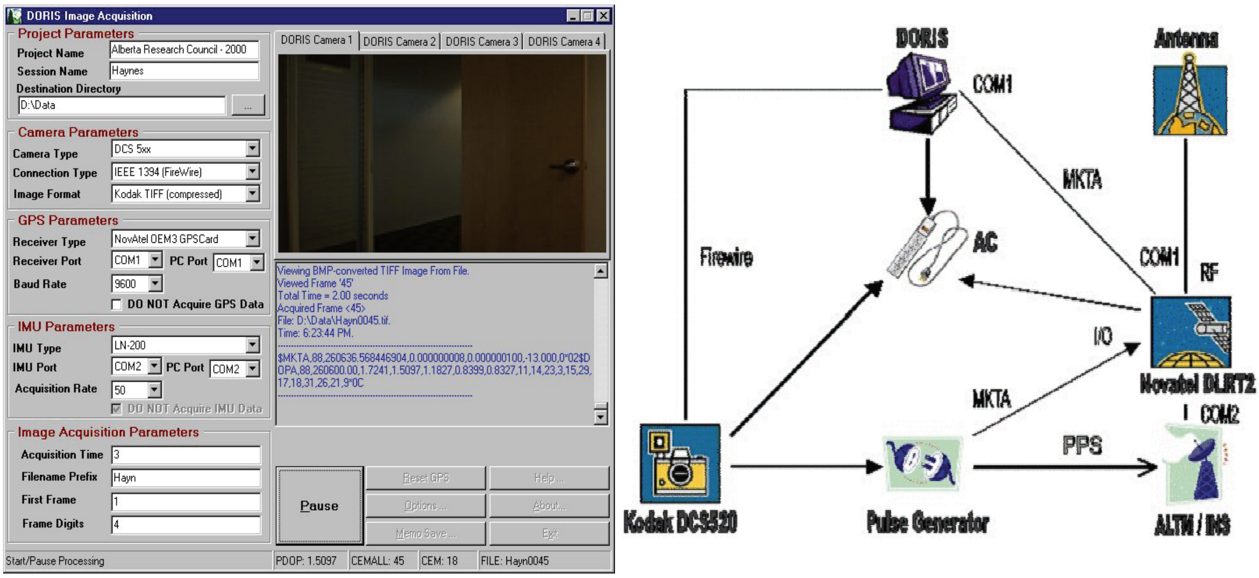


Figure 2: DORIS In-flight Data Acquisition Software and Hardware

3.2. Calibration/Alignment Laboratory Setup

For the imagery system to yield meaningful information, intrinsic and extrinsic parameters about the camera system must be known. In the particular case of the DORIS system, the intrinsic camera parameters are its calibrated focal length, the location of the image principal point and the lens distortion characteristics. The extrinsic parameters, on the other hand, determine the relationship between the camera coordinate frame and the mapping coordinate frame. While it is recommended to calibrate the system in lab conditions to yield optimum calibration results, it is possible to obtain an estimate of the calibration parameters in-flight with a well-distributed target field in a designated calibration area. For every installation of the DORIS system, at least one lab and one in-flight calibration/alignment are done. The lab calibration is also carried-out every year for maintenance purposes.

Figure 3 below shows the calibration lab setup where a 3D scattered grid of 90 highly accurate targets pre-surveyed to 0.1 mm (1σ) is used. Each side of the target grid volume is equal approximately to the minimum distance when the camera focal length is set to infinity. Three camera locations at distances approximately equal to the volume depth are chosen. At five different viewing angles in each camera location, images of the target field are taken. For each calibration setup, the overall number of images is fifteen. DORIScc, a pre-processing module for camera calibration based on Tsai technique [Tsai 1986], is used to compute the interior and exterior orientation parameters of each individual image. A simultaneous solution for the fifteen images based on a linear least-squares solution using DORISfa is sought to yield the calibration parameters. The graph in Figure 3 shows the lab calibration results based on the fifteen images solution. Only the radial lens distortion is considered in the DORIS solution since the de-centering lens distortion and imaging plane un-flatness effects (less than 0.5 pixel at most) are negligible compared to the

radial lens distortion (tens of pixels at the edge of the imaging plane). The precision of the intrinsic camera parameters from the simultaneous least squares solution is within half a pixel (1σ).
After the camera is calibrated, it is installed in its mount with the laser scanner sensor head mount. Both sensors, then, need to be aligned together. Figure 4 shows the procedure to align the camera and the laser sensor head together. In this procedure, the laser sensor and the embedded IMU are assumed aligned; errors due to misalignment between the laser sensor and the IMU will be embedded in the camera/laser alignment procedure.
In the lab coarse alignment procedure, the laser is to work in profile mode while the camera is to

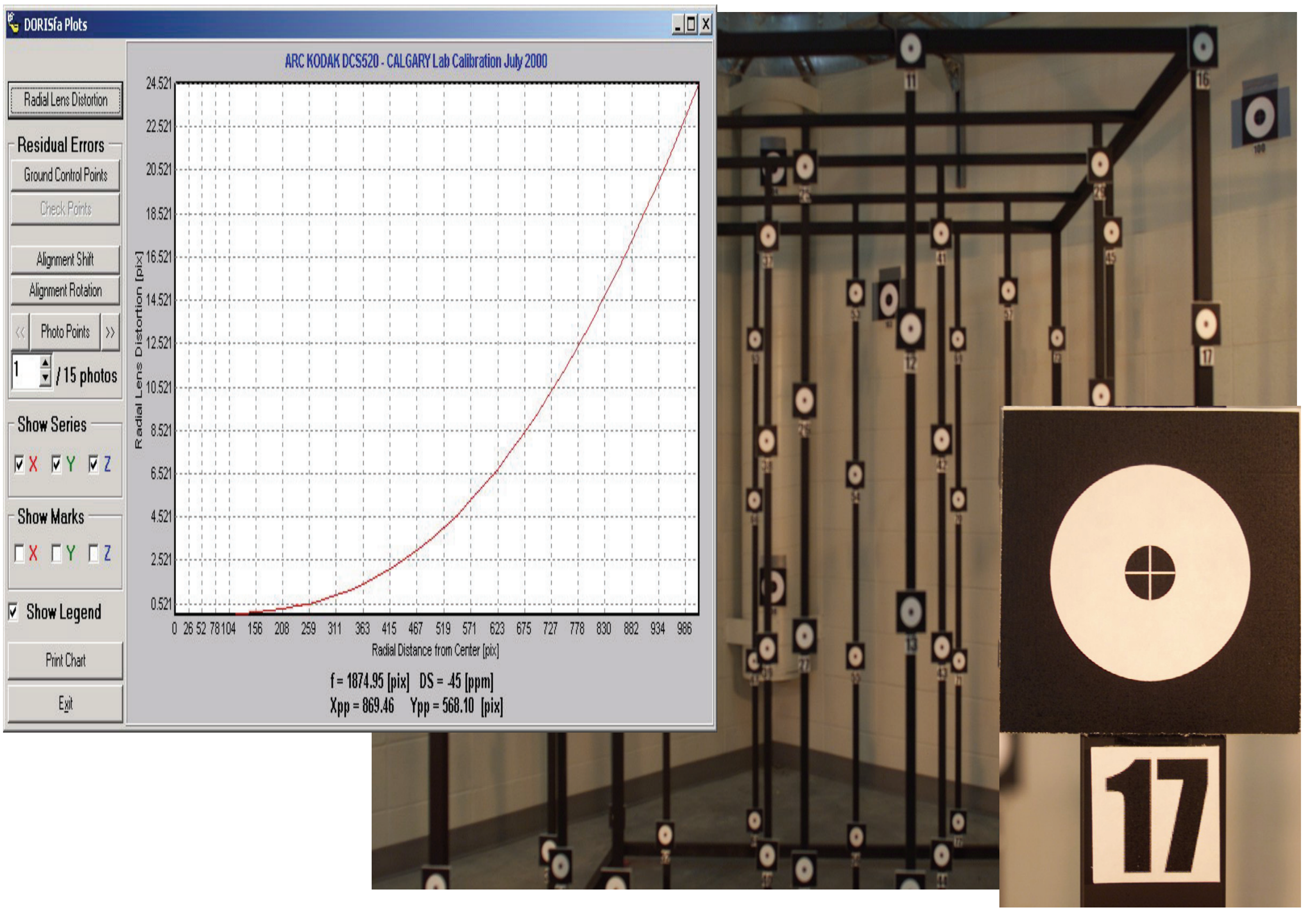


Figure 3: DORIS Camera Calibration Laboratory Setup

work in real-time mode. The laser is to profile a line of targets on a vertical wall, see Figure 4. The targets, then, are marked on the wall. With the lever-arm offset between the camera and the laser mirror center measured precisely, camera targets are marked on the wall. The camera, then, takes images of the targets. The targets are then measured on the acquired images and the camera axes are adjusted using the corresponding adjusting screws to have its axes parallel to the laser scanner axes. The same procedure is repeated once more with the camera/laser mounts set perpendicular to the original setup; the new setup is to handle the other two axes.

After all three camera axes are adjusted to coarsely align the camera with the laser scanner, a residual alignment bore-sight angles remain. From experience, the roll and pitch axes are relatively easier to align than the heading axis. However, with well-established lab setup, the remaining bore-sight angles after coarse alignment is always fraction of a degree; see Mohamed 2001 for more detailed discussion on the alignment procedure.

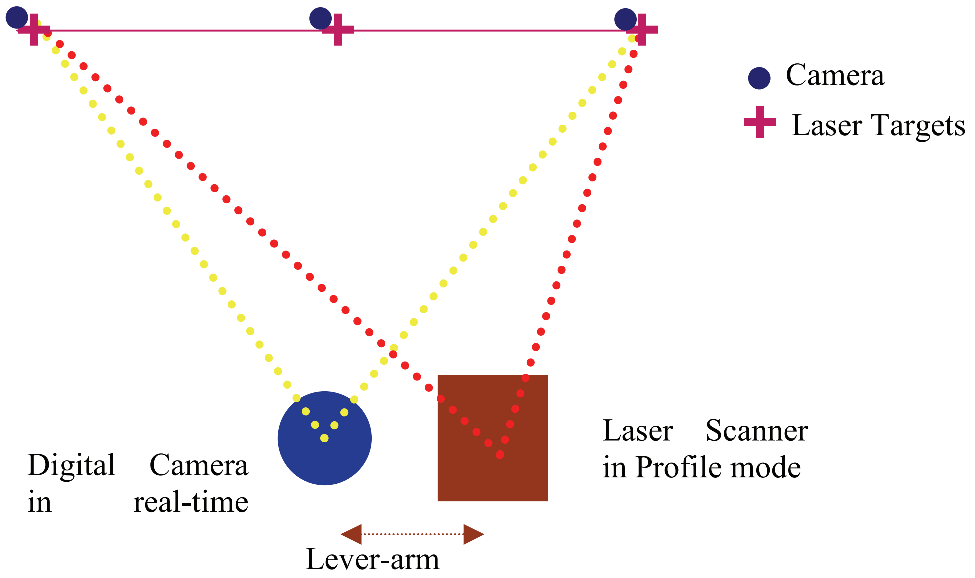


Figure 4: DORIS Camera/Laser Lab Coarse Alignment

3.3. Data Pre-processing

A number of steps are required before the acquired data is ready for processing. Figure 5 below shows the software interface to the DORIS pre-processing modules used to prepare the data for the processing step. Among the different pre-processing modules, DORISfa is considered the most important. In DORISfa, the exterior orientation parameters interpolated at the exposure stations from the 50 Hz INS/GPS using DORISti and the DORISia acquired camera event markers, are used along with the measured image coordinates using DORISic and the ground control points information for a calibration site, to refine the alignment between the camera and the laser scanner. The refined alignment parameters are then used to compute a more accurate trajectory at each exposure station for the whole operation using DORISpo. DORISfe is used to exchange image formats and manipulate the imagery if necessary. The modular structure of the DORIS pre-processing suite DORISpp is sought of as to integrate the DORIS pre-processing with other information at any pre-processing step, if necessary.

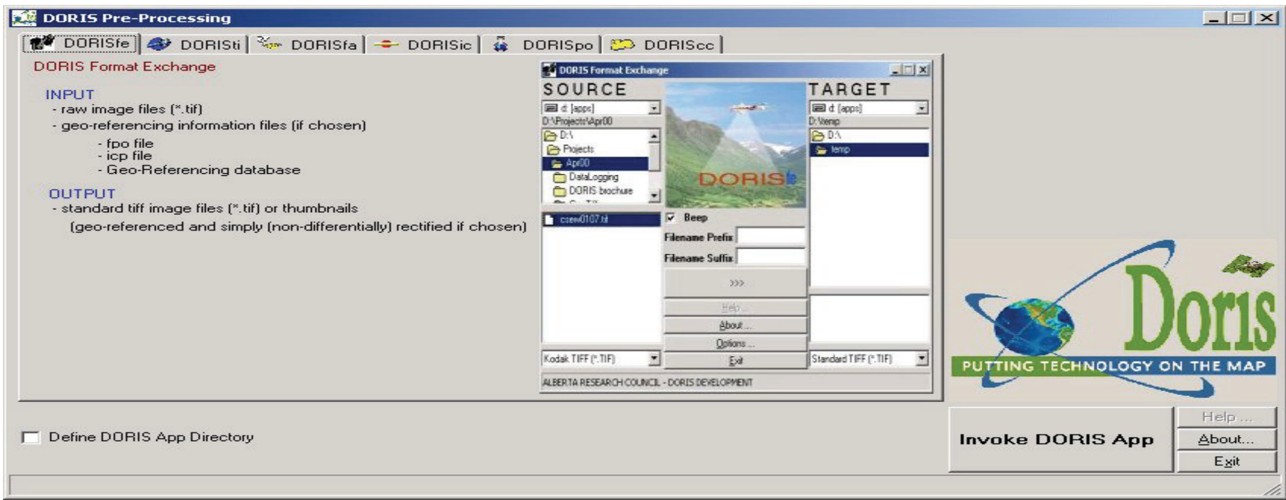


Figure 5: DORIS Data Pre-Processing Software Suite

3.4. Data Processing

The processing of DORIS data is the process of producing image-map mosaics. DORIS utilizes the concept of tiling to accelerate and modulate the processing of data. In each case a tile or tiles are created for the acquired imagery and laser data. The GenDEM module is then used to create digital elevation models for the designated tiles from the laser data. The elevation model, along with the camera orientation information, is then used to differentially ortho-rectify the acquired imagery using the Diffrect module. Rectified images for each processed tile are then composed together and color balanced in a final step inside the Mosaic module to produce image-map(s), see Figure 6 below for the DORISpr Windows software interface. Two flavors of DORISpr are available, one under Microsoft Windows 2000/NT/9x and the other under Linux Redhat operating systems. With a relatively high-speed processor (~ 1 GHz) and large fast hard drive, processing turn-around times of 1:5 to 1:10 are achievable.

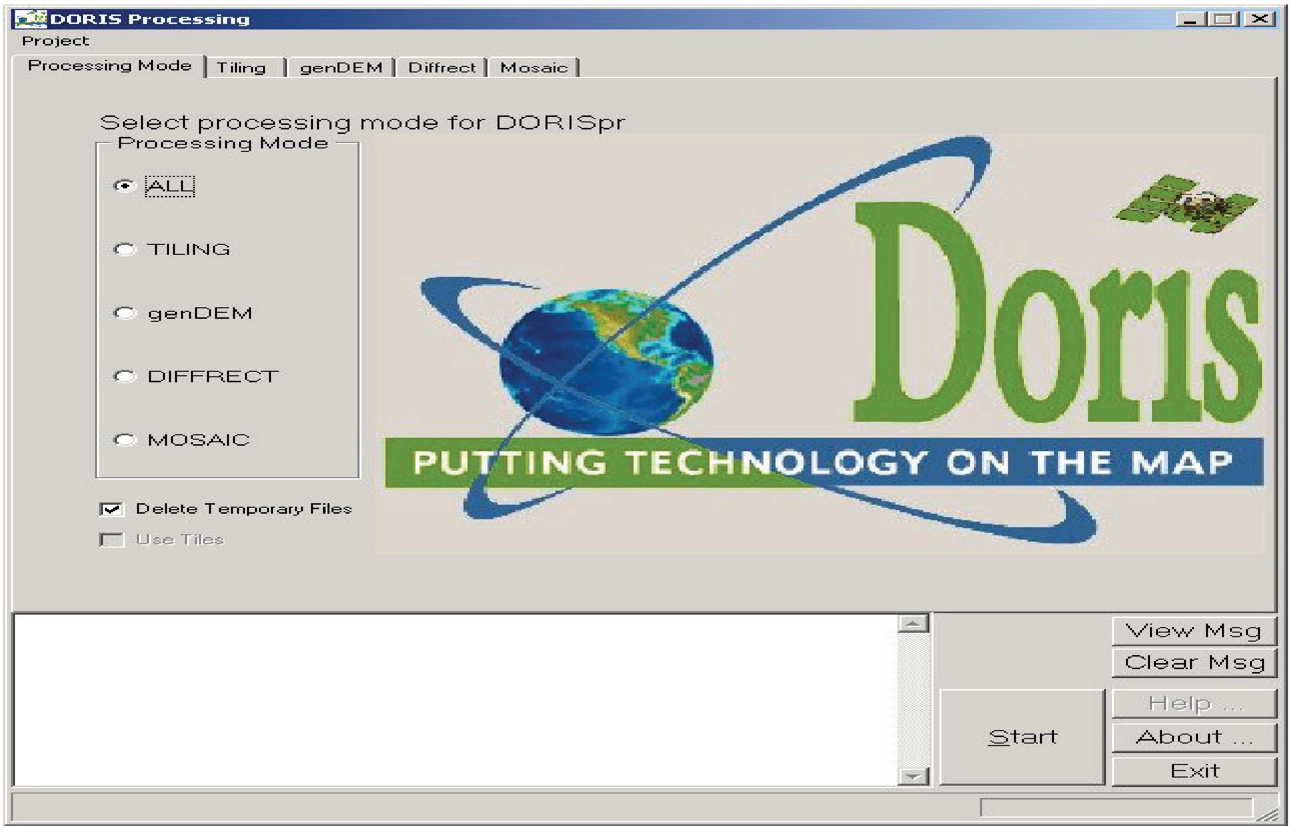


Figure 6: DORIS Data Processing Software

4. TEST FLIGHTS AND RESULTS

Many flight tests were conducted to test and concept-proof the DORIS system, see Mohamed et al 2000 for results from another flight test. The test presented here was carried out last October in two cities of Alberta, Canada. The system was first calibrated and coarsely aligned in the lab. Then, a calibration site in the city of Edmonton was flown to refine the calibration/alignment parameters. To ground truth the alignment/calibration procedure, the system was flown to another calibration site in the city of Calgary, about 300 km south of Edmonton. The Calgary calibration site was flown for ground truthing purposes and hence its ground control information was not used in the refinement of the alignment/calibration parameters. Instead, the ground control targets were recalculated and compared to the pre-surveyed values.

4.1. In-flight Calibration/Alignment

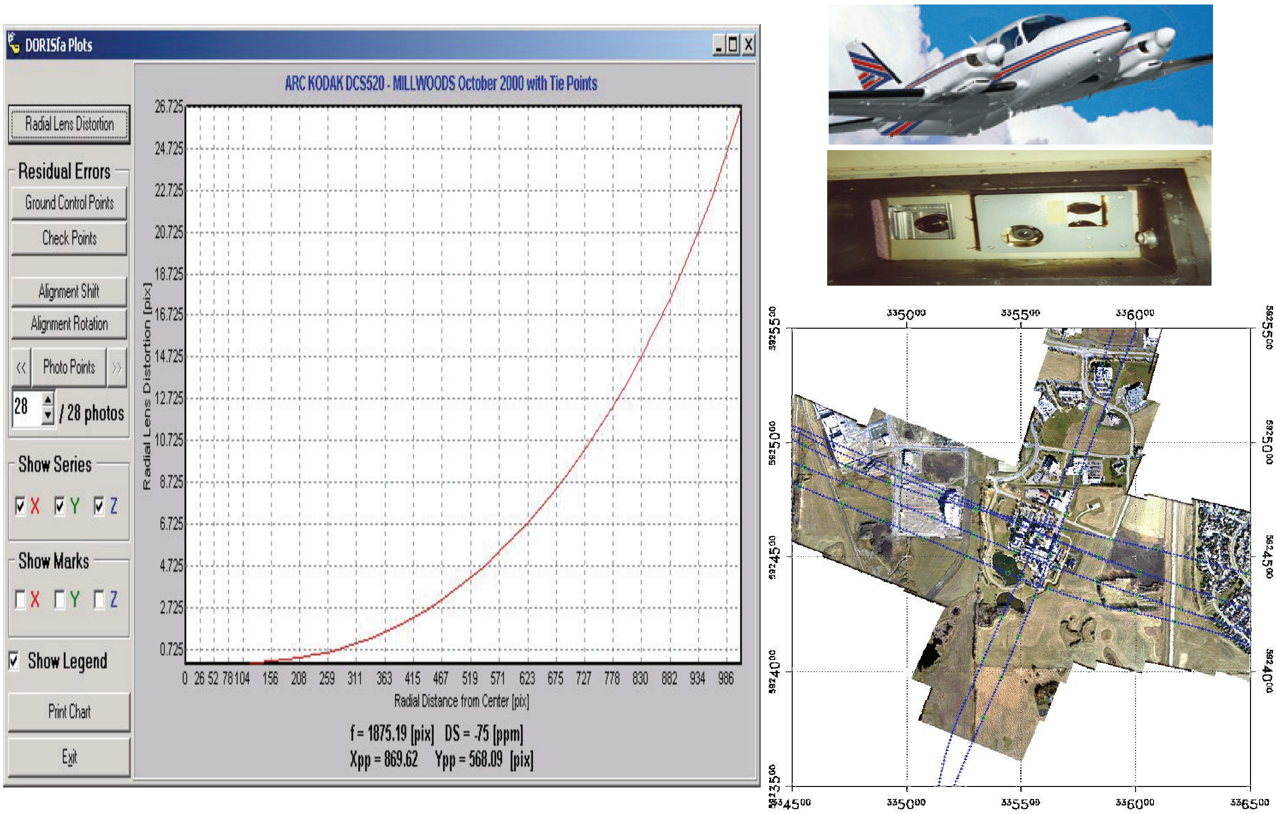


Figure 7: DORIS Camera/Laser in-flight Calibration/Alignment – Edmonton Site

After the acquisition system has been calibrated and aligned in the lab, as discussed in section 3.2, it was installed on-board of a twin-engine six-seat Navajo fixed wing aircraft. A calibration field of 30 pre-surveyed targets was then flown in Edmonton at two flying altitudes of 500 and 750 meters resulting in ground pixel resolutions of 0.30 and 0.45 m, respectively. The acquired data was then used to refine the lab calibration parameters.

The chart in Figure 7 above shows the in-flight calibration results, which are closely related to the lab calibration results, see the chart in Figure 3. The focal length and principal point agreed within half a pixel, while the lens distortion characteristics differ by two to three pixels. The latter can be explained in the light of the distribution of the targets inside of the calibration images. While it is easy to have calibration images with relatively evenly distributed targets all over the image plane, it is very difficult to get the same distribution from air. Consequently, the corners of the air images will not be properly modeled for lens distortion see [Wolf et al 2000] for models. Luckily, overlap in the form of end-lap and side-lap are used to tackle such modeling problems and ensure full coverage of the flown area.

The DORIS image-map in Figure 7 above shows the flight lines over the calibration site; the small green circles over the blue flight lines are the locations of the exposure stations. Two flight directions in cross pattern were flown to de-correlate direction-dependent errors. Twenty-eight images, in total, were used to refine the lab calibration and alignment. The ground control and check point results, not shown above, indicated that the ground control survey errors were within the noise level of the used GPS system. However, few ground control targets of the thirty pre-surveyed targets were problematic/erroneous and were removed from the adjustment. The adjustment of the blunder-free ground control target set resulted in standard deviation value of about 0.1 m (1σ 1D). The relatively low GPS static accuracy was due to the high ionosphere activity and the relatively long DGPS baseline. The standard deviation on the lever-arm offset between the camera and the laser scanner mirror center, however, was approximately 0.05 m. The standard deviation of the bore-sight angles was approximately 10 milli-degrees. Both standard deviations were well within the noise levels of the used INS/GP system indicating that the overall adjustment was blunder free.

4.2. Test Results Discussion

The system was then flown over the ground truthing site in Calgary that has twenty-two ground-surveyed targets. The refined calibration/alignment parameters calculated from the Edmonton calibration site were used to ortho-rectify and produce a mosaic image-map of the Calgary site, shown in Figure 8 below. The coordinates of the ground control targets were then measured from the mosaic image-map and compared to their corresponding pre-surveyed values; the difference is recorded as errors in the table of Figure 8 below.

The Calgary site was flown at an altitude of 500 m resulting in pixel spatial resolution of 0.30 m. Results are shown in the table of Figure 8 below. The overall spatial accuracy of the DORIS system, as shown in the table below, is within one pixel. The large bias in the solution of the north-south direction is thought to be due to the time delay offset between the camera fire event and the GPS time stamp; a time delay of one-millisecond results in a systematic shift of 0.075 m in the direction of flight when flying at speed of 150 knots. The orientation angles are also affected by the time delay in a random fashion; in the particular case of one-millisecond delay, the orientation angles fluctuate within 3 milli degrees. Measuring the actual time delay and correcting its effect is still under investigation. When the large blunders (like C9) were removed from the results, the overall accuracy of the system improved to two-thirds of a pixel; this in fact the sought accuracy of the DORIS system after resolving the residual systematic error effects.

5. SUMMARY AND CONCLUSIONS

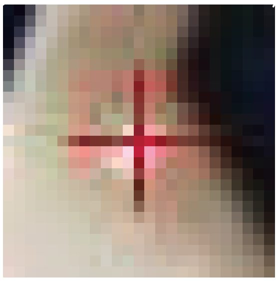
The aim of the suite of Geomatics and Remote Sensing (GRS) technologies for forest resources is to reduce the cost of the planning and conduct of forest operations. The initiative also includes building tools for tree inventory and better management of the forest resources. . With a synergy of tools, a platform can be built on which others can build additional applications, or is used by other management systems.

An airborne multi-sensor mapping system has been under development for years at Alberta Research Council under the GRS initiative. DORIS technology represents the new trend in the modern mapping system which utilize all in air direct geo-referencing, laser terrain scanning, and digital imaging to produce high-resolution and highly accurate ortho-rectified image-map. DORIS provides a complete spatial base layer in a GIS system and can virtually serve all mapping applications requiring very high resolution and accurate 3D spatial information. The DORIS system is all digital and highly automated because of its inherent structure. It uses state-of-the-art direct geo-referencing provided by a highly accurate GPS/INS system. Very fast turn-around time is possible with the DORIS system due to its digital nature and high automation.

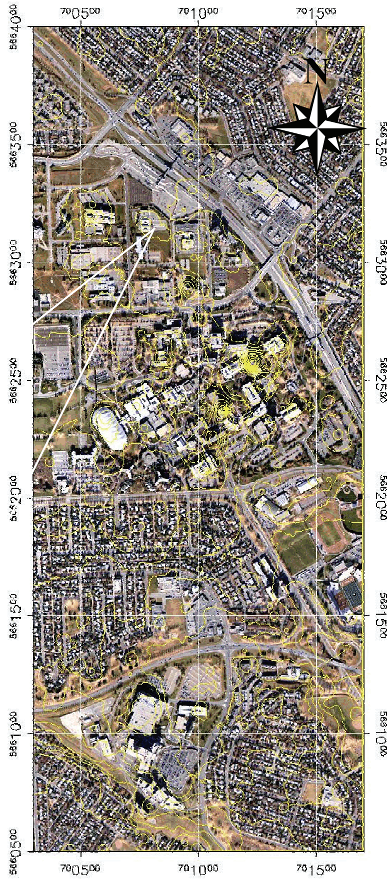
The overall error budget shows promising results of the system due to the highly accurate hardware and software components and procedures. Test results show sub-pixel accuracy (1Drms) within the mosaic map. Systematic errors and biases due to atmospheric and calibration effects contribute to the overall system accuracy. Errors due to poor modeling, misalignment between the imaging system and the laser-scanning system contribute considerably to the overall system accuracy. When these errors are modeled correctly or compensated for, sub-pixel accuracy is possible.

The high-resolution capability of the DORIS system and its high accuracy and fast turn-around time make it an ideal system for forest resources and other mapping applications that require such capabilities. It also provides short wave length information that, when combined with high-resolution satellite imagery, can provide a very economic and feasible solution.

GCP	**ΔE**	**ΔN**
C1	-0.01	-0.21
C2	-0.08	-0.20
C3	0.10	-0.37
C4	0.22	-0.69
C5	0.16	-0.20
C6	0.16	-0.24
C7	0.15	-0.62
C8	0.26	-0.76
C9	0.30	-0.79
C10	0.03	-0.60
C11	-0.05	-0.55
C12	0.39	-0.51
C13	0.33	-0.64
C14	-0.02	-0.44
C15	-0.02	-0.52
C16	-0.16	-0.33
C17	0.11	-0.41
C18	0.12	-0.31
C19	0.09	-0.33
C20	0.03	-0.13
C21	-0.09	0.03
C22	0.04	0.05
mean error	0.09	-0.40
stdev	0.14	0.24
rmse	0.17	0.46
1Drmse	0.32	
2Drmse	0.49	



Ground Target



This DORIS quick mosaic product of the Alberta Research Council Calgary office in the University of Calgary Research Park has a pixel spatial resolution of 3m and 10m contours (in yellow). The mosaic combines 130 images and 670 of 6 million laser spot elevations and cover an area of 490 ha.

Figure 8: Ground Truthing Results [in m] – Calgary Site

6. ACKNOWLEDGEMENTS

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