AN OPTIMALLY INTEGRATED DIRECT GEOREFERENCING AND FLGIHT MANAGEMENT SYSTEM FOR INCREASED PRODUCTIVITY OF AIRBORNE MAPPING AND REMOTE SENSING

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ABSTRACT:

For the last decade, new methodologies in aerial mapping have emerged focusing on data collection and processing efficiency. High efficiency and productivity are demanded by niche market segments such as emergency response. Hurricane assessment, flood mapping, forest fire damage evaluation and securities planning are all examples of rapid response application segments that benefit from shorter in-field data collection and processing times to generate map products. The new technologies introduced into field operations and workflows have reduced overall costs while maintained the required quality of map products required for businesses to remain competitive. Digital sensors and direct georeferencing are leading these technology advancements and are producing quality map products that were traditionally produced from more conventional field assisted photogrammetric methods. These emerging technologies have been proven to be a cost effective approach in reducing data post-processing times and operational costs by directly calculating the exterior orientation parameters of each image capture, eliminating the need of aerial triangulation and the use of ground control points through the in-direct georeferencing approach. In addition, the use of Digital Sensor technology eliminates the expensive and time consuming film developing and scanning procedures. The resultant exterior oriented solution provides a means of generating orthophotos and orthomosaics within a seamless workflow environment. However, these efficiencies only fulfil fifty percent of the rapid temporal requirements, especially in emergency response applications when immediate mission deployment is the main criteria. This is the reason why an efficient flight planning and management system is required. Applanix's POSTrack™ system is a complete planning and mission execution package that overcomes this preparedness burden for rapid response. This paper will discuss the technical aspects of the POSTrack system and will overview the workflow of mission planning and execution. The performance of the POSTrack system is described in some detail.

1. INTRODUCTION

The Applanix POSTrack™ is the first fully integrated, real-time direct georeferencing and flight management system designed for the airborne geospatial community. It is purposely-built to resolve the challenge of flight planning and operation for both pilot and operators. The system fulfils the rapid response requirements for aerial image mission planning and execution. The embedded technology within POSTrack™ consists of POS AV™, combined with XTRACK.

Figure 1. Applanix POSTrack™

Unlike other IMU/GNSS/FMS configurations, which utilize independent components for in-flight task automation and mission planning, POSTrack has been engineered as a tightly integrated system that is compact, and easily installed on all types of aircraft.

Figure 2 shows the POSTrack system in action with flight guidance and automatic sensor control.

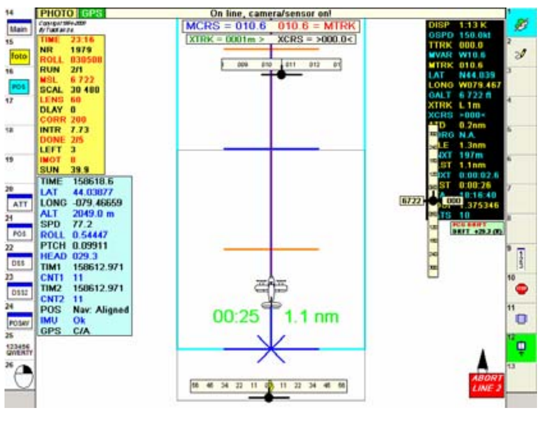

Figure 2. Flight Guidance and Automatic Sensor Control

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The POSTrack is a "single box" solution where the Flight Management Computer System (FCS) module communicates directly with the POS AV™ Computer System (PCS). A very low radiation LVDS pilot touch display, GPS antenna and IMU complete the system. The XTRACK system running on the FCS monitors the real-time position and orientation of the sensors computed by the POS AV™, then instructs it when to perform certain tasks to control the sensor. This paper first discusses the technical aspects of the POSTrack system, including hardware and software components of the system. Then, the flight planning and execution using the XTRACK system is followed. Finally, some examples and the performance of multi-sensor integration with POSTrack are discussed.

2. INTEGRATED FLIGHT MANAGEMENT SYSEM

2.1 POSTrack™

POSTrack is the first fully integrated real-time direct georeferencing and flight management system (FMS) designed for the airborne geospatial community. It combines the functionality of GPS-Aided Inertial Navigation, and the functionally of pilot guidance and sensor control. In comparing to other IMU/GPS/FMS configuration which utilizes independent components for in-flight task automation and mission planning, POSTrack is engineered as a single system, compact, convenient and easily installed on all type of aircraft without a complicated network of cables and connectors. The following sessions describes the technical aspects and operation workflow of the system.

2.1.1 Real-time GPS–Aided Inertial Navigation

The POS AV unit in the POSTrack system computes the navigation solution for the aerial sensor at 200 Hz or more. The quality of the IMU and GPS data being collected for direct georeferencing is display on the pilot display with immediately warning on any concern with the data. In additional, the real-time orientation data is also responsible for automated control of 3-axis gimbal mount. The orientation angles: roll, pitch and heading are calculated by the POS AV unit and fed into the mount to ensure it always remains level, and steer the azimuth of the mount to follow a desired track along the ground. This is a significant advantage as comparing to the inclinometer approach when false readings due to horizontal acceleration can cause the mount to tilt incorrectly during turbulent conditions. In addition of steering, all gimbal mount supported by POSTrack receives and the mount's motion via the gimbal encoder and logged as part of the navigation data for GNSS-inertial post-processing. This ensures lever arm parameters are always calculated with respect to the mount's center of rotation. Table 1 summaries the supported gimbal mount by POSTrack.

Manufacturer	Model	Control
Applanix	Azimuth Mount	Drift
SOMAG	GSM3000	Leveling and Drift
Z/I Imaging	T-AS	Drift
Leica	PAV30	Leveling and Drift

Table 1. POSTrack supported Gimbal Mounts

2.1.2 Compact Design and Simplified Cockpit Configuration

The POSTrack is a single box solution incorporating a POS AV computer (PCS) module and an FMS computer system (FCS) module. This is a significant difference comparing to other flight management system, when an operator is required to maintain flight guidance and sensor operation using a laptop computer. This is archived by the real-time embedded computer technology running on the FCS module with a touchscreen display. This allows the pilot to operate in full standalone mode, with complete control and awareness of the POSTrack system including the real-time GPS-Aided inertial navigation information, sensor performance and operation status. When a second crew member (navigator) is available, a single Ethernet connection can be used to connect the laptop computer with the FCS for additional flight guidance and management. The execution of the FCS module will be discussed in detail in later sessions.

2.2 XTRACK

The XTRACK is the flight management software running on the FCS module, developed by Track'air, industry's leading FMS manufacturer. It covers all the aspects of flying an airborne mission, from preparation to image acquisition. It is a complete suite including flight planning, navigation with external sensor interface for triggering and pilot display for mission guidance. The flight planning components of the XTRACK is installed on the navigation laptop, in which the operator has better access to flight preparation components such as existing vector and raster background. Ensuring generated flight plan can be easily synchronized with the XTRACK server module installed on the FCS. Either the laptop can be connected to the FCS directly to the FCS using the Ethernet connection, the Universal Serial Bus (USB) port equipped on the pilot display or the PCMCIA card read on the FCS can be used to import the flight plan using a USB flash drive or PC Card.

2.2.1 Planning

Mission planning using the XTRACK only requires two simple steps. First, a project region is defined in either vector or raster format. XTRACK supports varies vector (e.g. ASCII, DXF and SHP) and raster formats (USGS, DRG, GeoTIFF / TFW and JGW). In the case when existing planning region is not available, TerraServer USA can be used to download seamless coverage of the entire United States. Furthermore, digitalization can be used to prepare raster background in conjunction with publicly available raster pictures. All of these features are to simply the project definition. Then the remaining flight parameter required by XTRACK is the map scale / ground sample distance, endlap and sidelap percentage. The remaining is automatically calculated by XTRACK when varies camera sensors are supported in the XTRACK database, and custom camera definition is also allowed to support other sensor platform, such as small format digital cameras. Once these two criteria are fulfilled, XTRACK can calculate the optimal flight pattern using any user defined direction of flight. Figure 3 shows an example of flight planning using Digital Orthophoto Quadrangle (DOQ) as project area and optimized flight pattern using a heading of 220 degree.

A feature in development over the XTRACK planning is DTM support, which becomes an important factor in aerial mapping over rapidly changing terrain, especially in remote and coastline area. While terrain variation can be changed along a single flightline, the pilot is required to adjust the elevation of the flightline in order to maintain the proper overlapping percentage and map / ground sample distance.

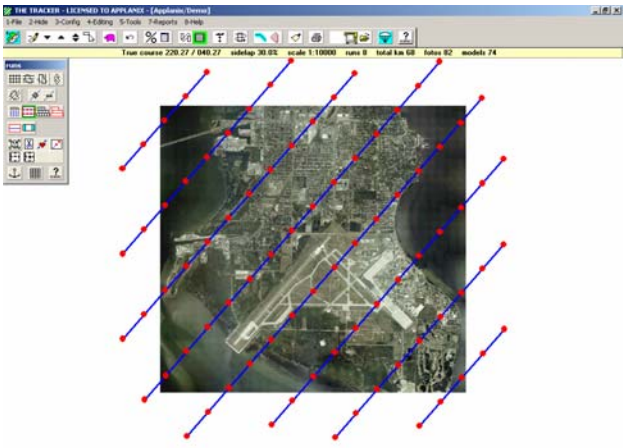

Figure 3. Flight planning example using XTRACK

Although some user might not realize the influence of terrain variation (dt) towards the effective overlapping percentage (P_e), it is a function of the flying height (h) and the designed overlapping percentage (P), presented the equation (1)

$$P_e = \frac{h(\frac{h-dt}{h} - 1 + P)}{h - dt} \qquad (1)$$

On the other hand, the flying height (h) is a function Ground Sample Distance (GSD), focal length and pixel size (p) (for digital camera) or scan resolution (for film camera), as shown in Equation (2). This relationship depends purely on the camera type and format.

$$h = \frac{GSD \times f}{p} \qquad (2)$$

Table 2 shows a list of parameter for the Applanix DSS, Vexcel UltraCamX, Intergraph DMC and Traditional Film Camera. These parameters are used to calculate the effective overlapping percentage during terrain variation, from a designed 60% endlap collection (stereo collection) flight with a ground sample distance of 10 centimeter, as shown in Figure 4. Similarly, Figure 5 shows the scenario for a 30% sidelap at the same ground sample distance. In order to apply equation (2) onto the film camera, scan resolution of 12.5 micron is used.

Camera Type	Focal Length (mm)	Scan Resolution / Pixel Size (microns)
Applanix DSS	60	6.8
Vexcel UltraCamX	100	7.2
Intergraph DMC	120	12
Film Camera	152	12.5

Table 2. Camera Configuration for Equation (1) and (2)

From Figure 4, it clearly shows that stereo collection will be lost when terrain variation is approximately 175m or more, up to 275m depending on the camera selection. On the other hand, Figure 5 shows a 100m of terrain variation causes sidelap to decrease by 10%. This represents a strong correlation between terrain variation and flight plan with reduced overlapping percentage for rapid response application. In a rapid response scenario, the system performance can be further enhanced without the stereo collection, such as a minimal of 30% endlap for orthophoto and orthomosaic generation. From Figure 5 and 6, the magnitude of such terrain variation is very common in remote area. Therefore, terrain variation must be serious considered in flight planning. Also note that equation (1) assumes a vertical collection with zero drift. In the case when 3-axis or drift only stabilization platform is not used, the influence of terrain variation is significantly increased. This emphasis the importance of a fully integrated flight management system including all aspect of in-flight device control, including the exact position of image capture, stabilization mount control and other sensor integration.

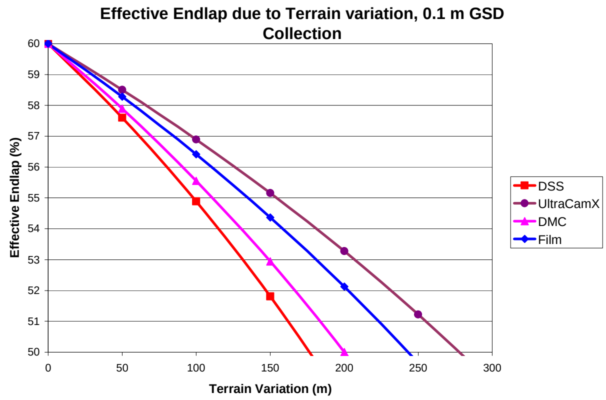

Figure 4. Effective Overlapping Percentage over a 60% Endlap

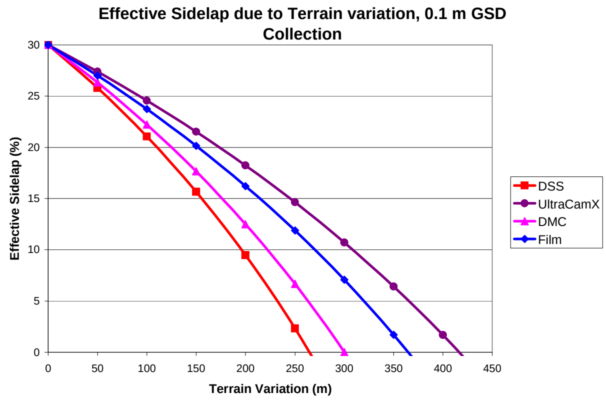

Figure 5. Effective Overlapping Percentage over a 30% Sidelap

2.2.2 Execution

Mission execution using the XTRACK is very simple, especially with the touchscreen capability on the pilot display. In standalone operation, flight plan selection and even flight line sequence can be pre-selected prior to takeoff to ensure minimal pilot interaction is required. As mentioned in previous session, the Real-time GPS-Aided Navigation provides all the navigation information to the pilot. Figure 6 shows an example of the flight guidance through the turn circle. This is a optimization feature in XTRACK to provide the most cost-effective flight pattern to minimize project cost.

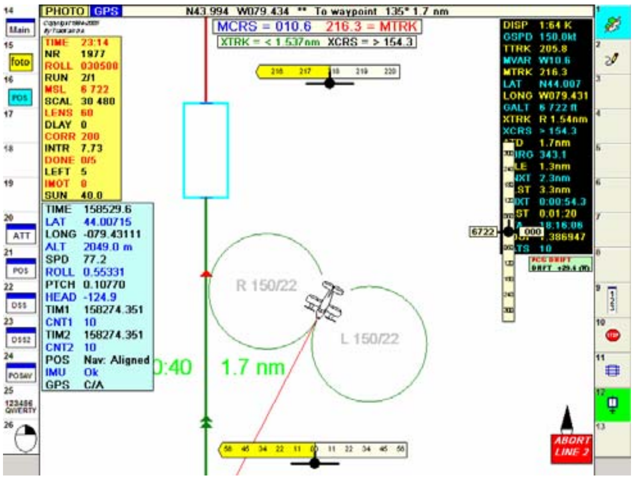

Figure 6. Turn Circle for flight guidance

When the navigation crew connects the laptop computer to assist the pilot to perform in-flight operation, the laptop shows similar information as the pilot display. It is also designed to have minimal interference to the pilot. Independent viewing option (e.g. pan and zoom) is available between the two display modes and the pilot mode on the FCS can operate on its own whenever the operator disconnects at any point of time.

2.2.3 Sensor Automation

The POSTrack system monitors the real-time position and orientation of the imaging sensor then performs certain control to the sensors based upon a pre-planned mission. Such in-flight operation includes automatic triggering of frame cameras, automatic on/off control of LiDAR and push-broom scanners, and the automatic on/off control of 3-axis mount stabilization. Figure 7 shows an example of Applanix DSS / LiDAR using the POSTrack system, providing exact control and coverage between the imagery and point cloud data in a single pass over a corridor mission.

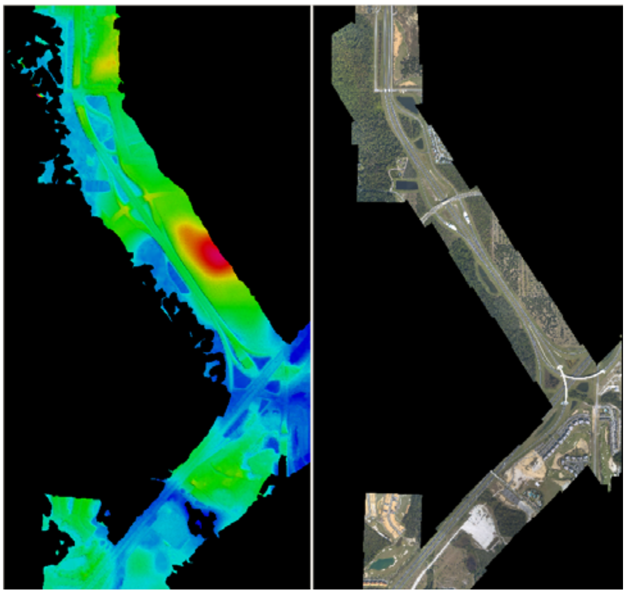

Figure 7. Example of DSS / LiDAR integration with POSTrack (Courtesy of Tuck Mapping)

This exact control of image ground coverage minimizes both the amount of sensor data logged, and the amount of time the sensor is turned-on. This translates into minimizing the time to fly and post-process the mission, while increasing in the life-span of the airborne sensors, ensuring the most economical and efficient aerial surveying capability.

3. DIRECT GEOREFERENCING

3.1 What is A Direct Georeferencing System

A direct Georeferencing (DG) system provides the ability to directly relate the data collected by a remote sensing device to the Earth, by accurately measuring the geographic position and orientation of the device without the use of traditional ground-based control points. Over the last decade, the Applanix's direct georeferencing system (POS AV^{TM}), has been widely used in the airborne mapping industry, including LiDAR, Inteferometric Synthetic Aperture Radar systems (INSAR), multispectral and hyperspectral scanners, large format digital line scanners, film cameras and large and medium format digital frame cameras. The key component of the POS AV^{TM} is the GNSS-Aided Inertial Navigation software which runs in real time on the POS Computer System. In post mission, its post-processing version, POSPac™ Air software suite, performs the integration of the GNSS and the inertial data. In order to produce the best possible accuracy of the trajectory of the remote sensing device, for accurate map production, post-processing (PP) is typically used. Post processing combines the forward and backward solution, generating the Smoothed Best Estimated of Trajectory (SBET). A summary of the POS AV performance is presented in Table 3.

	Model 410			
	C/A* GPS	DGPS**	RTK***	PP****
Position (m)	4 – 6	0.5 – 2	0.1 – 0.3	0.05 – 0.3
Velocity (m/s)	0.05	0.05	0.01	0.005
Roll & Pitch (deg)	0.015	0.015	0.015	0.008
True Heading (deg)	0.08	0.05	0.04	0.015
	Model 510			
Position (m)	4 – 6	0.5 – 2	0.1 – 0.3	0.05 – 0.3
Velocity (m/s)	0.05	0.05	0.01	0.005
Roll & Pitch (deg)	0.008	0.008	0.008	0.005
True Heading (deg)	0.07	0.05	0.04	0.008
	Model 610			
Position (m)	4 – 6	0.5 – 2	0.1 – 0.3	0.05 – 0.3
Velocity (m/s)	0.03	0.02	0.01	0.005
Roll & Pitch (deg)	0.005	0.005	0.005	0.0025
True Heading (deg)	0.03	0.03	0.02	0.005

*Coarse/Acquisition Code
** Differential GPS
***Real Time Kinematic
****Post processing

Table 3. POS AV^{TM} Absolute Accuracy Specifications (RMS)

For emergency response applications in which time constraints do not allow a complete post-processing activities, the POS AV™ unit supports all Satellite Based Augmentation Services (SBAS). Figure 8 represents the SBAS scenario and examples of SBAS services supported by the POS AV unit are OmniSTAR and NavCom StarFIRE™.

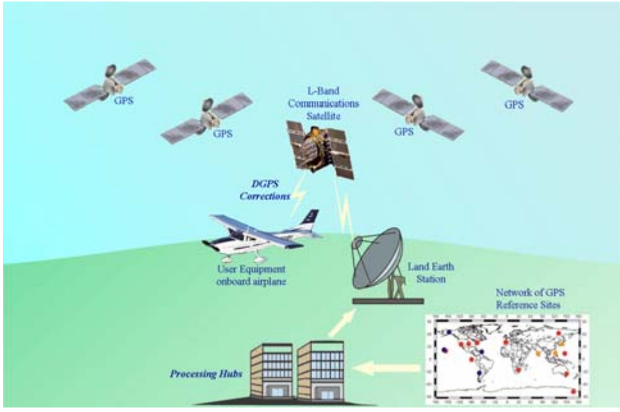

Figure 8. Satellite Based Augmentation Services

3.2 Benefits of Direct Georeferencing

The direct georeferencing technology has made a difference in the mapping industry and allowed for producing a variety of mapping products that never existed before the advent of direct georeferencing. One of the direct benefits of Direct Georeferencing is that Aerial Triangulation is not needed in most of the mapping applications, except for large scale mapping resulting in enormous savings in data acquisition and processing time. On the other hand, other sensor system such as LiDAR, INSAR, multispectral and hyperspectral scanners has been using the DG systems as an enabling technology and they would never exist if it were not for the DG systems providing the position and orientation of each sensor measurement..

3.2.1 Large and Medium Format Digital Camera

The use of DG system on these cameras is fully realized while the turnaround time for project delivery has been significantly reduced. Combining the benefits of a digital camera and direct Georeferencing, the time constraint of orthomosaic delivery is further reduced when rapid response imagery is needed within 24 hours after data collection. This cannot be achieved with digital camera alone when GPS-assisted aerial-triangulation requires extensive image processing on every single image collected, in order to derive the exterior orientation parameters for each image. In addition, rapid response imagery is mainly collected over remote areas such as coastline and disaster area.. As a result, only a fully integrated digital camera with direct georeferencing technology is capable to perform such tasks.
Table 4 shows an example of The average time to generate a complete set of orthomosaic (including image development) with full colour balancing is about 13 hours after landing in a rapid response mission using the DSS (Ip et al, 2007)

The results show that the DSS RapidOrtho system, even on a relatively slow computer such as a laptop, can produce a complete set of orthophotos to support initial damage assessment and recovery efforts within the same 7 hour period as the flight. In fact even the complete orthomosaics can be produced within the same 16 hours of flying a typical rapid response mission. This easily exceeds the goal of 24 hours.

Date	Flight		#	Area	Ortho	Mosaic	
dd/mm	#	hrs	Images	km^2	Hrs	hrs	# Tiles
30/08	1	3.3	355	340	3.7	16.4	54
31/08	3	8.1	1220	218	11.8	61.1	164
01/09	3	8.4	1050	1037	11.1	29.3	250
02/09	2	6.3	1042	927	10.6	40.2	153
03/09	3	6.7	1037	1112	13.7	32.7	201
04/09	4	8.2	1317	1103	15.6	38.8	165
05/09	1	3.0	182	121	1.8	4.3	34
07/09	1	3.3	537	426	5.5	11.9	54
08/09	1	3.5	794	558	6.8	14.1	47
Total	**19**	**52.6**	**7534**	**5842**	**79.5**	**248.9**	**1122**
Ave. / Flight	**2.7**		**397**	**308**	**4.2**	**13.1**	**59**

Table 4. DSS RapidOrtho Performance
(Orthomosaic times include time to develop orthophotos)

3.2.2 Film Camera

The theoretical analysis and implementation of DG system on film camera has been started since early nineties (Schwarz et al, 1993) followed with extensive testing by the OEEPE group in 2001 (Heipke et al, 2001).
Table 5 presents the performance of the POS AV 510 system comparing with the GPS-assisted AT approach (Mostafa et al, 2001a). The results are consistent with the system specifications listed in Table 3.

Stats.	Min	Max	Mean	Std Dev	RMS
dX (m)	-0.064	0.040	-0.004	0.026	0.03
dY (m)	-0.029	0.031	0.000	0.017	0.02
dZ (m)	-0.034	0.070	0.000	0.023	0.02
dOmega (ArcSec)	-39.2	33.1	-1.4	19.1	19.2
dPhi (ArcSec)	-22.7	25.2	-0.3	11.9	11.9
dKappa (ArcSec)	-68	61	0.4	33.1	33.1

Table 5. POS AV 510 on film camera vs. GPS-assisted AT

The use of DG system on film camera continues to grow until the digital camera sensors gets into user attention with their radiometric and fast turnaround performance as discussed in the pervious session. Although the film camera requires significant time on image post-processing than the digital cameras, the squared film size provides more ground coverage than digital camera sensors at the same mapping scale / ground sample resolution (GSD). Therefore it continues to be widely used for large area mapping. However, the rapidly improving computer performance confuses film camera users about the actual benefit of DG system on film camera, when large area projects usually contain a block of imagery and the processing time of AT has been significantly reduced. The comparison between DG and AT is continuously revisited, mainly focused on the processing time and accuracy. But, as mentioned in previous session, the benefit of DG is not limited to the elimination of AT. The ability of direct acquisition of the EO parameters allows film camera user to enter the rapidly growing market segment including corridor mapping and single photo orientation. It is cost inefficient to collect adjacent strips for corridor mapping or collect a block of imagery for a single orthophoto production. These types of project can only be achieved using a direct georeferencing system, regardless of the sensor being used. Figure 9shows an example of corridor mapping using the POSTrack system. Without the collection of adjacent strip, flight time and project cost is significantly reduced.

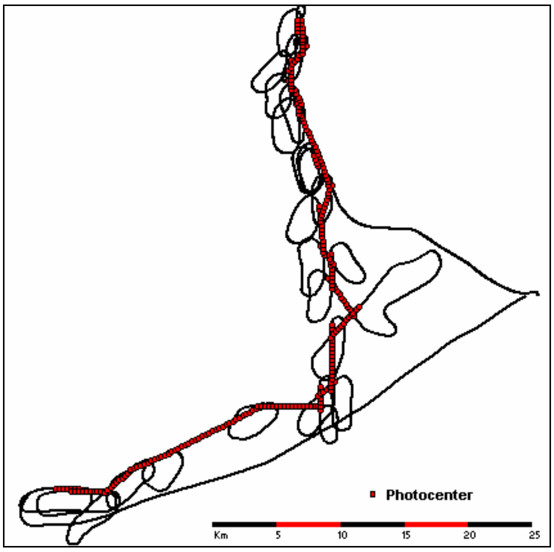

Figure 9. Example of Corridor Mapping
(Courtesy of Tuck Mapping)

4. CONCLUSIONS

This paper reviews the technical and operation aspects of the POSTrack system. It is a fully integrated, real-time direct georeferencing and flight management system designed for the airborne geospatial community from planning to execution in a user friendly interface. Having a variety of sensor support and dedicated interface, flight plan generation with multiple sensors is a simple task, eliminating multiple hardware configurations from different software vendors. In order to support large area mapping over remote area, the support of existing digital elevation model for flight planning is in development in the XTRACK planning module. This ensures terrain variation will not influence the overlapping percentage in orthophoto and orthomosaic generation. As for the flight plan execution, the single box solution is specially designed for single pilot operation with minimal user operation. This is an important feature for emergency response application when immediate deployment is necessary. While fully integrated with GPS-Aided Inertial technology, XTRACK provides all around navigation information and flight guidance to the pilot, minimizing flight time for cost-effective project completion. At the same time, the exact control of the sensors increases the life-span of the airborne sensors, ensuring the most economical and efficient aerial surveying capability. Finally, the Direct Georeferencing in the POSTrack system enables fast turnaround solution in varies application, such as corridor and coastline mapping. This allows different imaging sensor user to emerge further market segments

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