One Laptop, One Weekend and 4,000 UltraCamX Large Format Aerial Photo

KEY WORDS: orthophoto, mosaic, processing, software.

ABSTRACT:
Creating accurate ortho-mosaic image maps from large volumes of aerial imagery using traditional methods is a time-consuming task, even when completed using high-end hardware and software systems. This article challenges the traditional methods and requirements. Over one weekend we push a laptop computer, configured with automated production software, to the edge by attempting to process 4,000 large format UltraCamX aerial photos, from elevation model creation to the final ortho-mosaic.
We posed the following challenge: to process, in a fully automated workflow, 4054 UltracamX aerial photos (1,500GB or 1.5TB of input data) over a weekend. This processing includes utilizing stereo pairs to generate a Digital Surface Model (DSM) for the entire area of interest, filtering the DSM to a Digital Terrain Model (DTM), orthorectifying all of the images, color balancing, cutline generation and production of the final orthomosaic.

Introduction

The transition from the analogue camera to the digital camera in the past years has completely revolutionized the processing of aerial photos. The digital camera has many advantages over the analogue camera, with one of the biggest being the ability to acquire a large amount of photos within a short period of time. However, this creates a challenge in processing the photos from raw level to ortho-mosaic in an efficient manner.. The process can take many days, or even months, and that becomes critical if it needs to meet a short delivery timeline. A fast, automated system is required to solve this problem.
PCI Geomatics recently upgraded its Geomatica GXLAerial (GXL-A) high–volume photogrammetric production system to handle large (10,000+ images) aerial photo projects. A typical GXL-A system uses central network data storage with processing spread across multiple (dual or quad CPUs) servers and accelerated using Tesla GPU add-on cards. Such a system can be scaled up to achieve increased production rates.
However, modern gaming laptops incorporating high end mobile CPUs and GPU's, solid state drives, and large amounts of RAM are surprisingly powerful. Though laptop computers are limited in disk space, cheap external 2TB USB drives can be connected to USB 3.0 ports providing large amounts of easily configured disk space. This poses an interesting question: how fast can a well configured laptop process aerial photo data sets? Can a mobile platform, using commonly available and low cost hardware, do significant aerial photo production work?
To answer this question we posed the following challenge: to process, in a fully automated workflow, 4054 UltracamX aerial photos (1,500GB or 1.5TB of input data) over a weekend. This processing includes utilizing stereo pairs to generate a Digital Surface Model (DSM) for the entire area of interest, filtering the DSM to a Digital Terrain Model (DTM), orthorectifying all of the images, color balancing, cutline generation and production of the final orthomosaic.
To be kind to the laptop a 'weekend' is defined as 5pm Friday night, to 9am Monday morning, or 64 hours. On the other hand no shortcuts are allowed – from the 20cm resolution photos a highly detailed 60cm resolution DTM is to be produced and all processing must be done at full resolution yielding a final high quality 20cm ortho mosaic.

Laptop Hardware

Laptop	ASUS G75V
CPU	Intel 3610QM (4 physical cores)
GPU	Nvidia 670M
RAM	24GB (upgraded from 16GB)
Internal disk	256GB SSD drive + 480GB SSD
USB 3.0 ports	4
External disk drives	Two 2TB Western Digital My Passport Ultra
Software:	PCI Geomatica GXL 2014

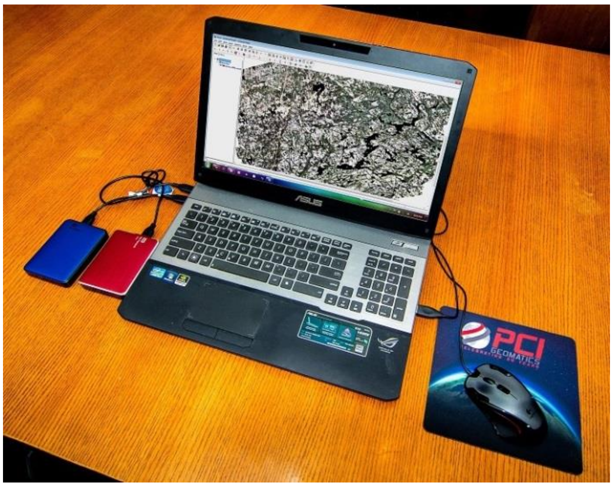

Figure 1: Laptop hardware configuration

The ASUS G75V is an older generation gaming laptop, now replaced with the more capable G750 model.

In processing 4,054 images a large amount disk space is used for the raw data and the various intermediate products. Disk speed is critical as well as careful management of file locations. The Solid State Drives (SSDs) provide read/write speeds in the range of 400MB per second. The external USB 3.0 2TB drives are surprisingly fast, achieving read/write speeds of up to 100MB per second, and are powered through the USB cable making them extremely convenient.

Project Data

Camera	UltraCamX large format
Image Size	14430 x 9420
Project size	4,054 images (1,500GB total)
Image characteristics	8 bit, RGB, TIF format
Ground Sample Distance	20cm
Overlap	70/30
Exterior Orientation	provided
Elevation Survey Points	50 points
Projection	UTM 17 NAD83
Area covered	1,198 sq. km.

The project data was provided on loan by the North Bay-Mattawa Conservation Authority (NBMCA, North Bay, Ontario, Canada, www.nbmca.on.ca). The dataset reflects an area south of the city of North Bay. NBMCA provided pre-computed and accurate exterior orientation (EO) for the air photos as well as independently surveyed ground elevation points that could be used to check elevation accuracy. This area is partially forested, with many lakes and a few small communities.

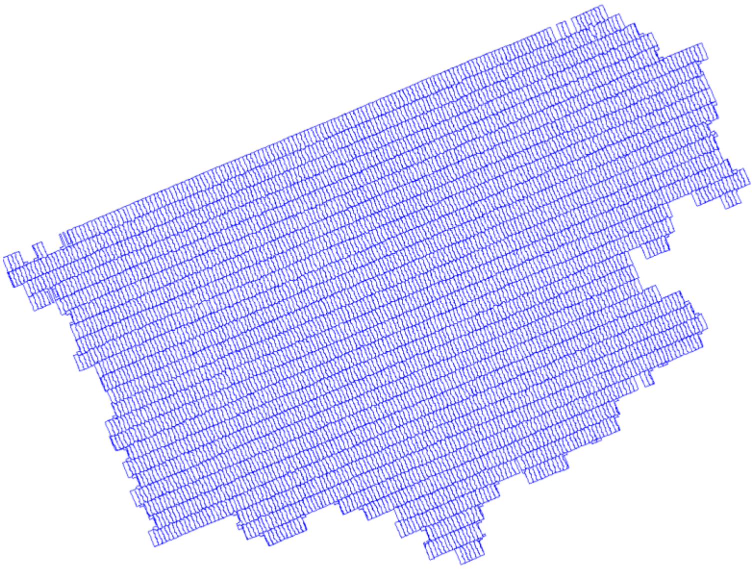

Figure 2: layout of 4,054 aerial photos in the project

Processing Steps

Table 1: Processing steps

Processing Step	Disk Space Required	Processing Time
Raw Data (4054 UltraCamX aerial photos)	1,600GB (external USB disk drive)	
Data Ingest		14m 12s
Generation of Digital Surface Model (DSM) (60cm resolution)	63GB (internal SSD Drive)	29h 51m 46s
Generation of Digital Terrain Model (DTM) (60cm resolution, filtered from DSM)	50GB (internal SSD Drive)	3h 20m 58s
Generation of ortho images (cropped to centre 30%)	460 GB (external USB disk drive)	9h 59m 16s
Colour Balancing and Cutline Generation		1h 53m 24s
Mosaic Tile Generation (172 5km x 5km tiles, 20cm resolution)	269 GB (internal SSD Drive)	7h 19m 24s
Total Time		**52h 38m 20s**

All processing was completed in less than 53 hours, under the challenge goal of 64 hours. An impressive feat for a laptop running software designed for a network of high end production servers.

Quality Assessment

However fast, automated processing of this much data does bring up questions on quality and accuracy.

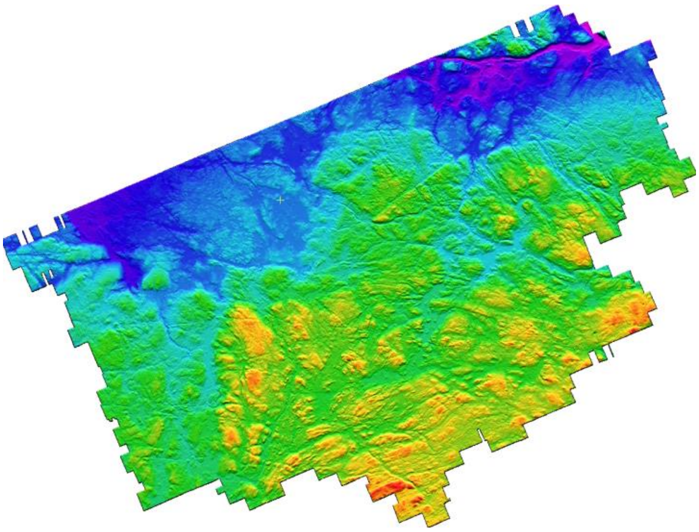

Figure 3: Overview of the 60cm resolution raster DSM produced from 4054 stereo aerial photos.

Comparing the 50 surveyed elevation points against the automatically extracted DSM yielded an average error in elevation of 4cm, an average absolute error of 18cm and an RMS error of 24cm. After automatic DTM filtering the average error was -3cm, the average absolute error 20cm and the RMS error 26cm. An RMS error approximately equal to the aerial photo resolution is considered accurate, so the results are acceptable. The quality of the automatic DSM to DTM conversion (which removes ground features such as buildings and vegetation) can be seen in figure 4a and 4b. Automatic processing invariably introduces some errors, which can be manually corrected. The GXL-A software has an innovative new method of editing digital elevation model data rapidly toa higher quality without the use of 3D stereo hardware, but for the purposes of this article the fully automated result was used with no manual editing applied.

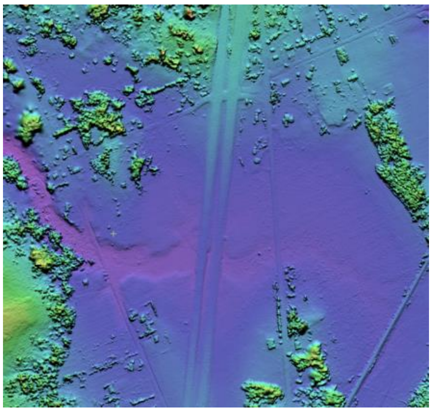

Figure 4a: small subset of original DSM

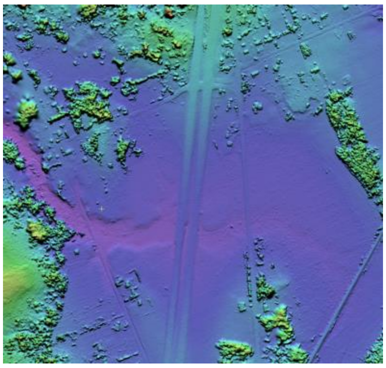

Figure 4b: DTM with buildings and trees removed

Color balancing is an important step, especially with large projects. Figure 5a below shows the 4054 images in their original raw form. The various flight lines can be clearly identified by variations in both intensity and color. At full resolution (not shown) the differences between adjacent flight lines can be dramatic. By automatically applying global balancing, localized image dodging and seam line blending, variations between images are minimized creating a pleasing final mosaic as shown in figure 5b.

Figure 5a: Ortho mosaic images without color balancing

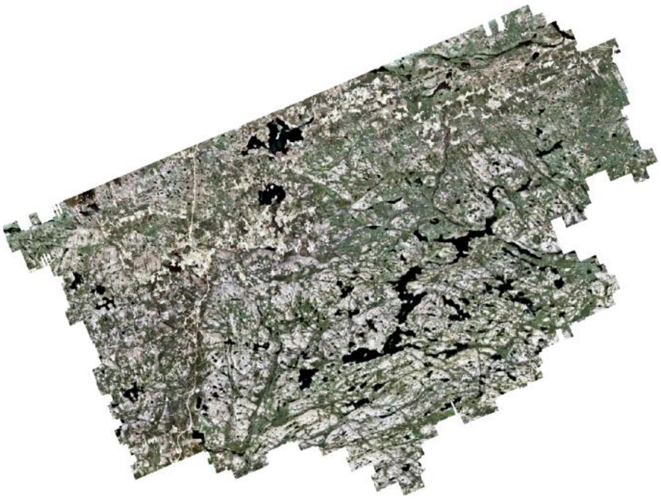

Figure 5b: Ortho mosaic images with automatic color balancing applied.

For this particular data set and exterior orientation an error of 80cm in elevation translates into a 20cm error horizontally (shift on the ground). Given a 24cm RMS error in the automatically extracted elevation and the high density of the DTM this implies that pixels in the ortho imagery should have an average error around ¼ of a pixel (5cm) on the ground. This means that within the ortho-mosaic we shouldn't be able to see the seams between images in the vast majority of cases. An examination of the seam lines confirms this. Figures 6 and 7 show examples of the accuracy along cutlines.

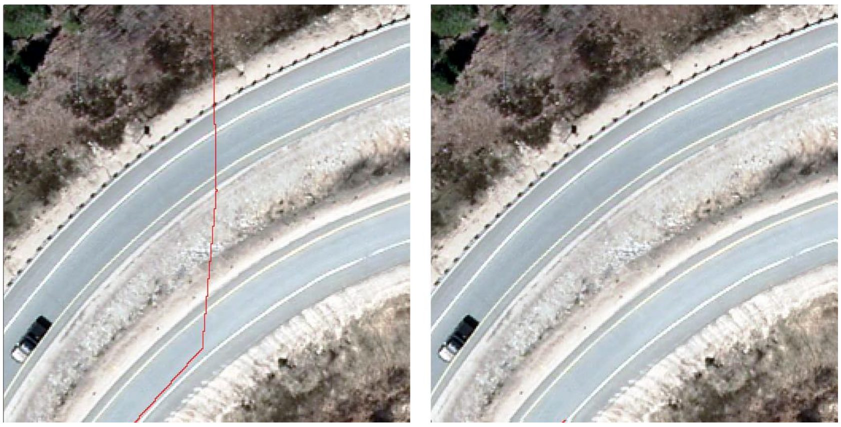

Figure 6: Ortho-mosaic subset (zoomed in) showing cutline in red and alignment between ortho images.

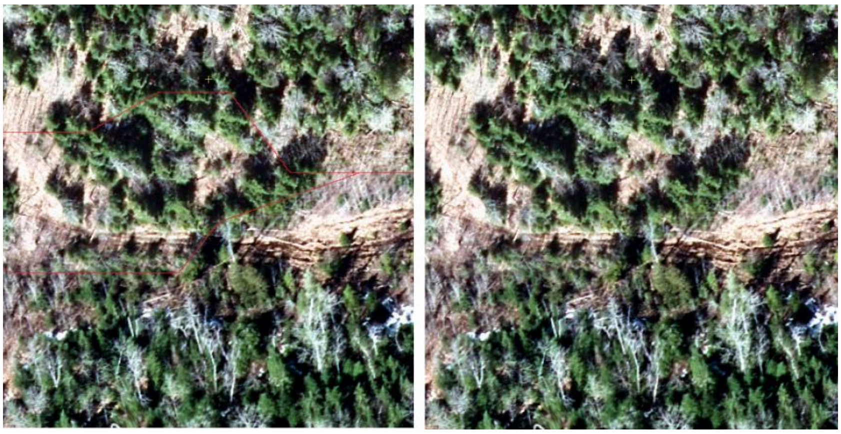

Figure 7: Ortho mosaic subset with cutline (in green) showing excellent alignment even in forested areas.

Conclusion and Future Possibilities

Clearly a high-end laptop, configured with large amounts of RAM and solid state drives, is able to process large format aerial photos at surprisingly high rates. This includes the entire workflow - from DSM extraction to final ortho-mosaic tiles at a throughput of 1,800 images per day in fully automatic mode. Yet even this rate can easily be bettered. The newest generation laptops are about 15% faster than the one used in this project and PCI Geomatics DSM extraction speeds (via a software update) are expected to double again. By late 2014 we expect that this entire project could be re-run in around 32 hours, for a throughput of around 3,000 photos per day. By the end of 2015, with high end mobile processors expected to increase from 4 to 6 CPU cores, faster GPU's, cheaper SSD drives and the new USB 3.1 and SATA express interface standards, processing speeds of over 4,000 large format UltracamX photos per day, and over 6,000 per day for smaller format cameras, should be achievable.

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