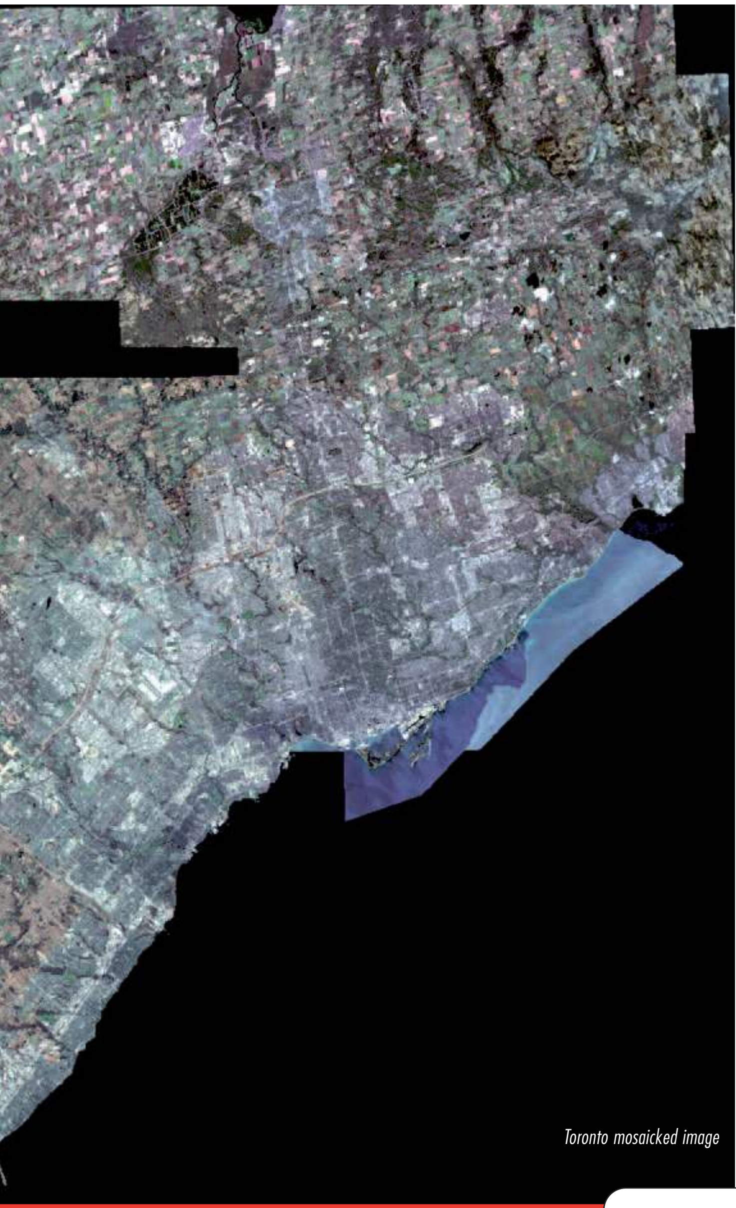
Article

The increased availability of imagery from a growing number of sub-meter resolution earth observation satellites has made it easier to create detailed image maps over large areas. When mapping large areas using high resolution satellite imagery, the biggest challenges are the processing of the high volumes of imagery and the requirement to generate accurate ortho-mosaic images efficiently and economically. This article will describe which satellite imagery are most suitable to meet these requirements and how to obtain maximum performance by leveraging the latest computer software and hardware advancements.

By Philip Cheng

Mapping Large Areas

Satellite Imageries with Limited Ground Control



Toronto mosaicked image

Since the breakthrough of the first sub-meter resolution commercial earth observation satellite IKO-NOS in 1999, many additional high resolution satellites have been launched. In addition, more countries now have their own high resolution satellites. Different applications have been using high resolution satellite imagery such as mapping, digital elevation extraction, and most notably, consumer level mapping over large areas on platforms that are used by hundreds of millions of people everyday such as Google maps and Bing maps.

Currently the three highest resolution commercial satellites: GeoEye-1, WorldView-1 and WorldView-2, are owned by U.S. commercial operator, DigitalGlobe, of Longmont, Colorado. GeoEye-1 provides 0.41 m panchromatic and 1.65 m multispectral images in 15.2 km swaths. The spacecraft is intended for a sun-synchronous orbit at an altitude of 681 km and an inclination of 98 degrees, with a 10:30 a.m. equator crossing time. GeoEye-1 can image up to 60 degrees off nadir. WorldView-1 is a high-capacity, panchromatic imaging system featuring 0.46 m resolution imagery. With a nominal swath width of 17.6 km at nadir and an average revisit time of 1.7 days, WorldView-1 is capable of collecting up to 750,000 square kilometers (290,000 square miles) per day of 0.46 m imagery. WorldView-1 is equipped with state-of-the-art geo-location accuracy capability and exhibits unprecedented agility with rapid targeting and efficient in-track stereo collection. The most recent satellite in the DigitalGlobe constellation, WorldView-2, was launched in 2009 and has a panchromatic band with 0.46 m resolution and eight multispectral bands with 1.84 m resolution, introducing new opportunities for high resolution thematic mapping.

However, all of the imagery provided by the satellites discussed above have been resampled to 0.5 m panchromatic and 2.0 m multispectral for commercial use due to US government maximum resolution restriction. DigitalGlobe formally asked the U.S. National Oceanic and Atmospheric Administration (NOAA), the licensing authority for the industry, for permission to sell 0.25 m imagery in 2013. Company officials say the current restrictions are outdated and hinder their commercial opportunities and competitiveness. Although the National Geo-Spatial Intelligence Agency (NGA) is DigitalGlobe's biggest customer, the company is looking to broaden its non-U.S. government business and has said it could better compete with the aerial photography market if allowed to provide higher-resolution imagery commercially. According to DigitalGlobe, aerial photography with 0.3 m resolution is widely available. DigitalGlobe currently operates a fleet of five satellites. The company's WorldView-3 satellite, currently scheduled to launch in August, will be able to capture panchromatic imagery with 0.31 m resolution. On June 11, 2014, the U.S. Department of Commerce approved DigitalGlobe's application. Effectively immediately, DigitalGlobe will be permitted to offer customers the highest resolution imagery available from their current constellation. Additionally, the updated approvals will permit DigitalGlobe to sell imagery to all of its customers at up to 0.25 m panchromatic and 1.0 m multispectral ground sample distance (GSD) beginning six months after its next satellite WorldView-3 is operational.

Mapping large areas using satellite imagery

Given that there is an increased availability of high resolution commercial satellite imagery from multiple providers, it is now common for governments and commercial organizations to map large areas, or even entire countries, using high resolution satellite imagery. There are two big challenges when mapping large areas. The first challenge is the requirement of accurate ground control points (GCPs) to compute the geometric model for the imagery, which is essential for the creation of accurate image maps. An existing source of GCPs may not be available, especially for areas where it is prohibitively expensive or impractical to collect new points, such as areas inaccessible by road. The questions of which high resolution satellite imagery are most suitable for mapping large areas, especially when GCPs are limited or not available at all, will be explored in this article by looking at the satellite geometric modeling method required to process the satellite imagery.

The second challenge is the processing of high volumes of satellite imagery to generate ortho-mosaic images, as the size of the high resolution imagery is very large. For example, a single WorldView-2 panchromatic image can be up to 10 Gigabytes. The size will become eight times larger when performing pansharpening using both panchromatic and 8 bands multispectral imagery. A system which can utilize the latest computer hardware and software advancements to gain the maximum processing performance is required. This article will present a system which can be used to perform the processing tasks both economically and efficiently.

Satellite Geometric model – RPC method

To create accurate image maps using satellite imagery, the imagery must be corrected to a map projection. This correction process is called orthorectification or geometric correction. The process requires the use of a rigorous geometric model, GCPs, and a digital elevation model (DEM). Since the introduction of rational polynomial coefficients (RPC) method to correct IKONOS data, this method has become the most popular method to correct satellite data as it requires only a small number of GCPs, and in some cases, no GCPs at all. Most current commercial satellite imagery are distributed with RPCs. The RPC method uses an empirical/statistical model developed by Space Imaging (now DigitalGlobe), which approximates the 3D physical sensor model of a satellite. This method is useful as it eliminates the requirement of 3D physical model, enabling users having little familiarity with the satellite sensor to perform a geometric correction without GCPs; only a DEM is required. Since biases or errors still exist in the RPCs, the original RPCs can be refined in most cases together with a zero or first order polynomial adjustment computed from several accurate GCPs. Zero and first order polynomial adjustment require a minimum of 1 and 3 GCPs, respectively. A zero order polynomial adjustment, which only computes the translation in the horizontal and vertical direction is always preferable because the GCPs can be collected anywhere on the image. A first order polynomial adjustment, which warps an image as opposed to a simple horizontal and vertical translation, requires GCPs to be collected uniformly throughout the image in order to get the best accuracy for the entire image. To the knowledge of the author, only IKONOS, GeoEye-1, WorldView-1 and WorldView-2 ortho-ready level images can achieve accurate results with only zero order polynomial adjustment especially for large areas. Most other satellite images require first order polynomial adjustment, with some requiring even second order polynomial adjustment, are not recommended when only a limited number of GCPs are available.

Test Imagery and software

To test image mapping for large areas with limited number of GCPs, eight WorldView-2 and six GeoEye-1 ortho-ready images covering Toronto, Canada and the surrounding area were obtained from DigitalGlobe. The images were acquired in different seasons and years with a coverage of approximately 7500 square km. The author would like to thank DigitalGlobe for providing the test imagery. The latest release of PCI's software, Geomatica 2014, was used to perform the testing. The Optical Satellite Ortho Suite within OrthoEngine software was specifically used since it supports reading of the imagery, manual and automatic GCP/tie poinit (TP) collection, geometric modeling using different methods including Toutin's rigorous model and the RPC model. In addition the software provides automatic DEM generation, orthorectification and either manual or automatic mosaicking with multiple color balance methods.

Testing results

To evaluate the results using different GCPs and TPs, 81 measured points were obtained from 0.25 m aerial photos and 10 m spacing DEM together with 657 tie points collected automatically. The following cases were tested by changing the measured points to GCPs and independent check points (ICPs): (1) no GCPs and no TPs, (2) TPs only with no GCPs, (3) 1 GCP with TPs, (4) 3 GCPs collected near the center of the block with TPs, (5) 3 GCPs collected at each edge of the block with TPs, and (6) case 5 with one additional GCP near the center of the block. Table 1 shows a summary of the results for each case.

From the table we can draw the following conclusions when using large block of imagery with only limited number of GCPs: (1) the geometric accuracy of the image block is within approximately 5 m with no GCPs and no TPs, (2) TPs can improve the geometric accuracy of the image block to approximately 3 m, (3) A single GCP can improve the accuracy to within 3 m, (4) GCPs should be collected near each edge of the block if possible to provide the best accuracy,

Case	No. of GCPs	No. of ICPs	No. of TPs	RMS Error X	RMS Error Y	Maximum Error X	Maximum Error Y
1	0	81	0	2.5	1.6	5.2	4.8
2	0	81	657	1.9	1.3	3.3	2.8
3	1	80	657	1.5	1.2	2.8	2.9
4	3	78	657	1.4	0.8	2.1	2.3
5	3	78	657	1.1	0.8	2.2	2.2
6	4	77	657	1.0	0.8	2.1	2.1

Table 1: Comparisons of geometric accuracy results using different GCPs and ICPs

(5) The best case is GCPs collected near each edge of the block with a GCP near the centre of the block, and (6) Only a minimum of 3 GCPs with TPs can produce geometric accuracy approximately within 2 m. Figure 1 shows the mosaic result of the 14 images.

GXL System

The second challenge of mapping large areas is the processing of such high volumes of imagery An advanced system is required to utilize the latest computer hardware and software to gain the maximum performance. One significant hardware improvement is the graphic processing unit (GPU). This is a specialized electronic circuit designed to rapidly manipulate and alter memory to accelerate the creation of images in a frame buffer intended for output to a display. GPUs are used in embedded systems, mobile phones, personal computers, workstations, and gaming consoles. Modern GPUs are very efficient at manipulating computer graphics, and their highly parallel structure makes them more effective than general-purpose CPUs for algorithms where processing of large blocks of imagery is done in parallel. Another hardware improvement is the increase in the multi-core processors. This is a single computing component with two or more independent processing units (called "cores"), which are the units that read and execute program instructions. Multiple cores can run multiple instructions simultaneously, increasing overall speed for software programs amenable to parallel computing. Combining these two pieces of hardware together with computer distributed system nodes can improve the processing speed significantly when compared to a single processing machine. The GXL system, developed by PCI Geomatics, uses proprietary algorithms which are uniquely suited to leverage multi-core CPUs and GPUs to deliver incredible increases in speed on a multi-node system.

As an example, using the GXL system, the total orthorectification and mosaicking time of the 14 images in this article was approximately 12 hours and 3 hours respectively (15 hours total), when running on a single desktop system with 8 CPUs. The time was shortened to only 2 hours and 45 minutes respectively (2 hours and 45 minutes total), when using a GXL system equipped with 2 nodes.

The real benefit of working with GXL system is its scalability – adding additional nodes to the system enables load balancing, and proper allocation of processing to multiple nodes – this provides even greater time savings and is critical for these types of high volume processing projects. The GXL system has been successfully deployed to different environments, including the Cloud, where machine virtualization can be further explored, and the system can expand and contract based on the image processing need and throughout requirements.

Conclusions

To map large areas using high volumes of high resolution satellite images and limited number of GCPs, it is recommended to use GeoEye-1 or WorldView-1 or WorldView-2 satellites because they only require zero order RPC polynomial adjustment to get the highest accuracy. A minimum of 3 GCPs collected near each edge of an image block together with tie points could generate geometric accuracy within 2m. To speed up the process of mapping of large areas, a system which utilizes GPUs and CPUs together with multiple-processing nodes, which is highly scalable and flexible, could be deployed.

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