Using RapidEye Data without Ground Control

Automated High-Speed High-Accuracy

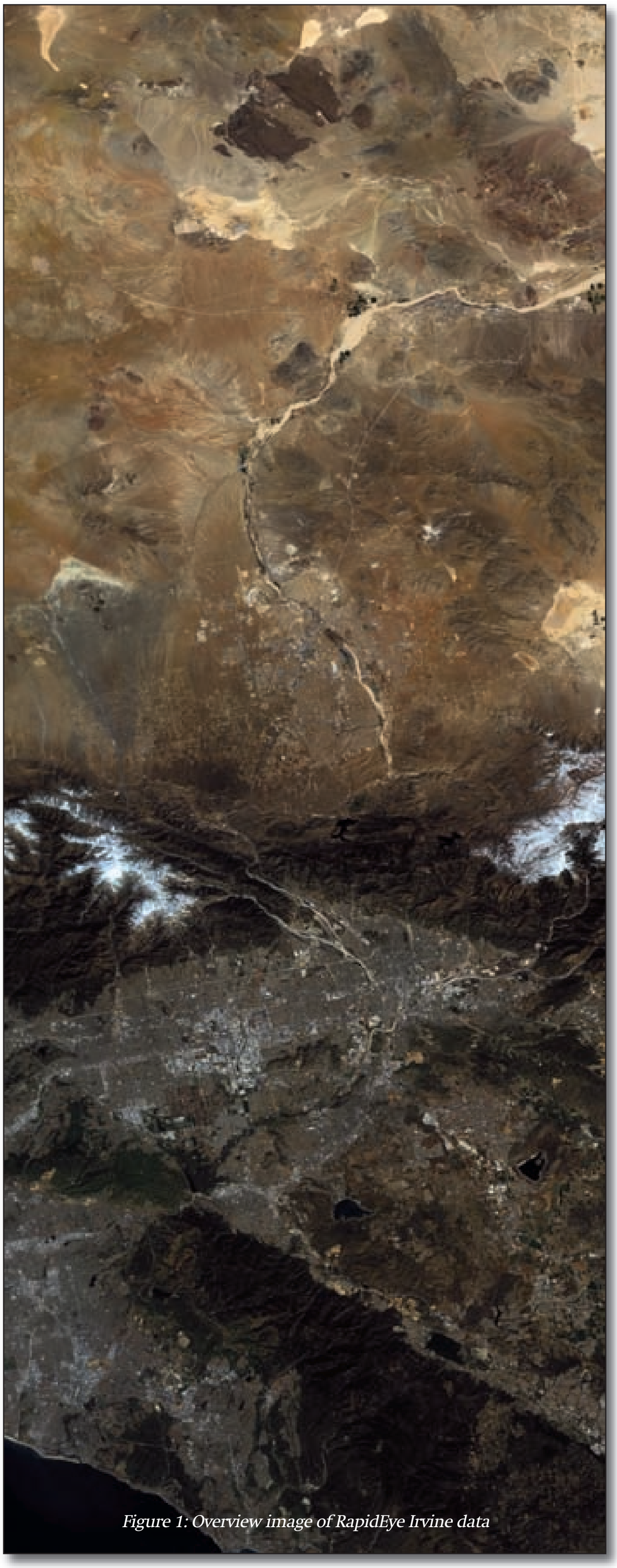

Figure 1: Overview image of RapidEye Irvine data

A fully automated high-speed system to produce high-accuracy multispectral orthos and mosaics for optical data from all over the world is now possible with the availability of RapidEye satellite data and graphic processing unit processor. Time-sensitive applications, such as agricultural or disaster management, can now access high-accuracy orthos as soon as the data is available.

By Philip Cheng and Jiri Sustera

RapidEye Satellites

RapidEye is a constellation of five satellites launched simultaneously on August 29, 2008. Each satellite measures less than one cubic meter and weighs 150 kg (bus + payload). On board digital recorders store image data until the satellite passes within range of the ground receiving station located in Svalbard, Norway. The satellites have a global revisit time in 1 day and it can image more than 4 million km2 every day.

Each satellite carries a pushbroom multi-spectral sensor, capable of collecting image data in five distinct bands of electromagnetic spectrum at GSD 6.5 meters: Blue, Green, Red, Red-Edge, and Near-Infrared. RapidEye's satellites are the first commercial satellites to include the Red-Edge band, which is sensitive to changes in chlorophyll content. Additional research will be necessary to realize the full potential of the Red-Edge band, however, preliminary studies show that this band can assist in monitoring vegetation health, improve species separation and help in measuring protein and nitrogen content in biomass.

RapidEye Applications

There are many potential applications for RapidEye satellites: (1) Agriculture – Field boundary extraction, crop identification, acreage determination, yield forecasting, management and harvest zone mapping, damage assessment and risk management for agricultural insurances, etc. (2) Forestry – Tree species separation, stem volume estimation, infestation detection, volume estimation, harvest mapping, etc. (3) Security and emergency – Disaster management after tornadoes, hurricanes, drought, floods, landslides, hail, fires, earthquakes, etc. (4) Environment – Change detection for any environmental purpose. (5) Spatial Solutions – Background imagery services, updating road network databases, ortho-image maps, etc. (6) Energy and infrastructure – Pipeline monitoring, land cover classification, clutter mapping, etc. Further information on RapidEye applications can be found at http://www.rapideye.de.

When comparing with other optical satellites, the biggest advantage of RapidEye is the speed to provide high-resolution multispectral satellite imagery within 12-48 hours because of the constellation of five satellites. The second advantage, which will be described in this article, is the ability to generate high accuracy orthos and mosaics using no ground control information.

Orthorectification and Mosaicking

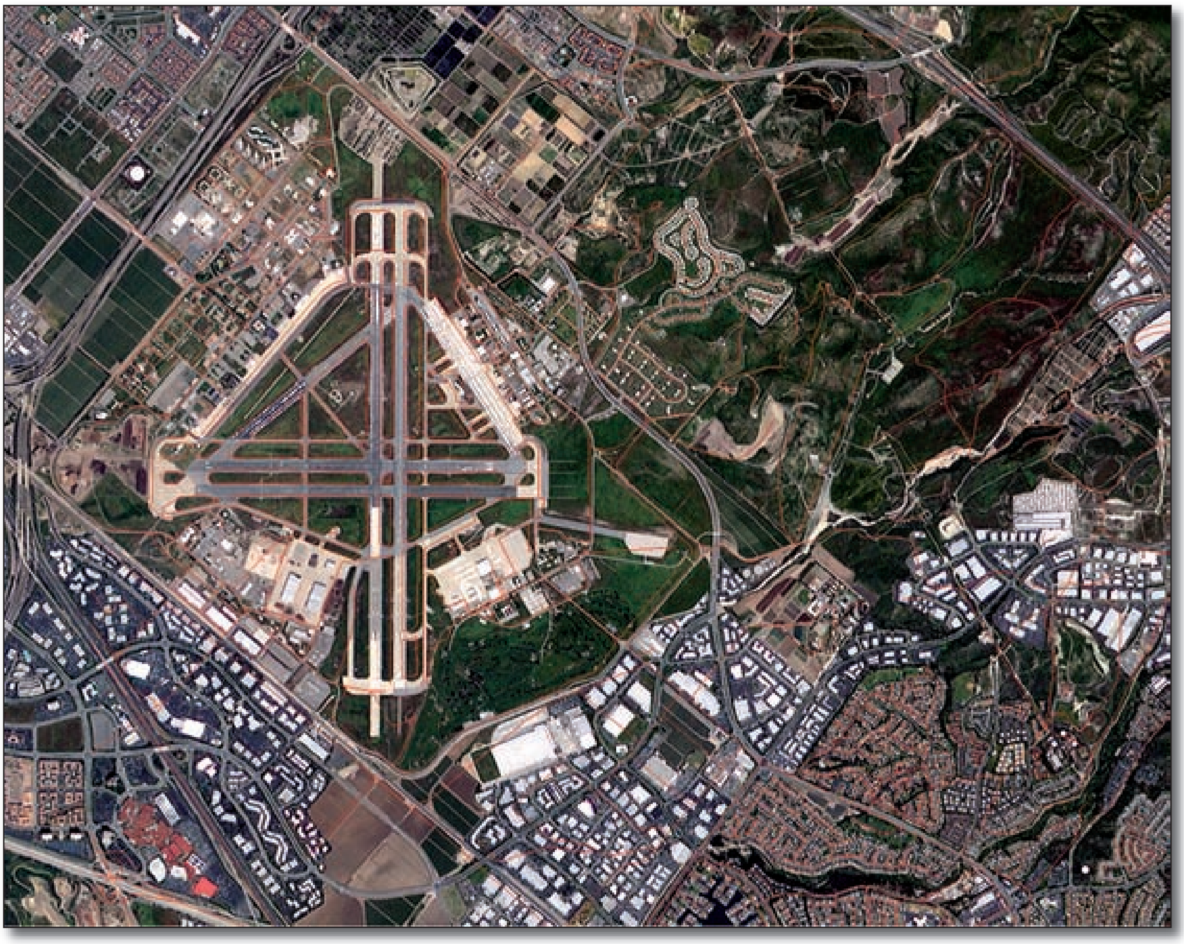

Figure 2: Full resolution orthorectified RapidEye image of Irvine corrected without GCPs overlaid with USGS 1:24000 vectors

Orthorectification of RapidEye Data

For most applications, the data must be corrected to a map projection before it becomes useful; this correction process is called orthorectification or geometric correction. The process requires the use of a rigorous geometric model, ground control points (GCPs), and a digital elevation model (DEM). The collection of GCPs presents a significant problem for orthorectification. An existing source of GCPs may not be available. It is often too expensive to collect new points, especially for areas

Figure 3: Full resolution orthorectified RapidEye image of Irvine corrected without GCPs overlaid with Google Earth

inaccessible by road. In some cases, the collection of GCPs is made almost impossible by local conditions such as floods or earthquake.

The RapidEye satellite platforms have been constructed by Surrey Satellite Technology Ltd (SSTL). Each satellite uses a star tracker known as the Altair HB. It was developed as an alternative low cost, high accuracy, spacecraft attitude determination and control sensor. The accurate attitude information could potentially help to orthorectify the RapidEye data accurately to any map projection without the need

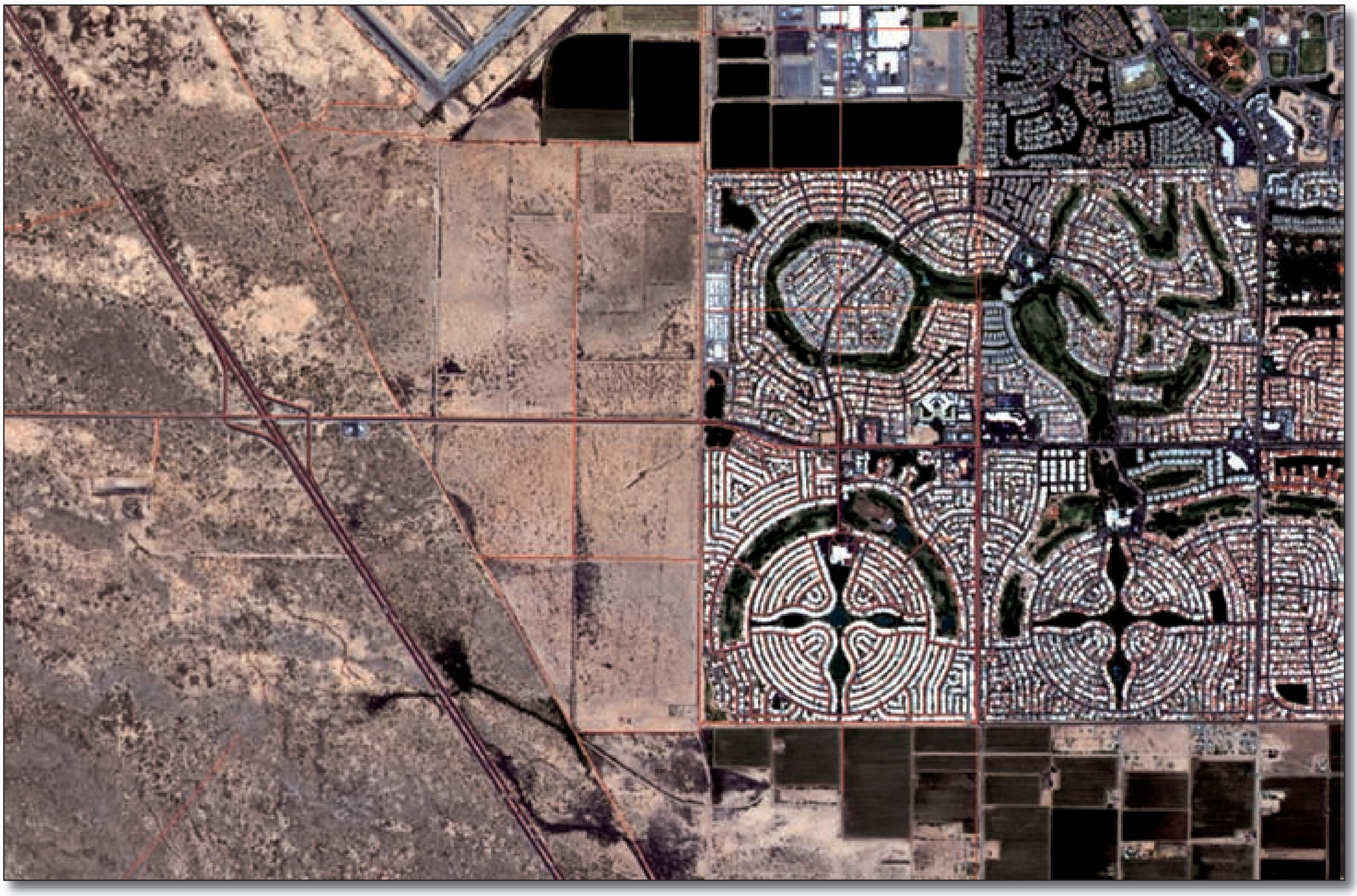

Figure 4: Full resolution orthorectified RapidEye Phoenix data corrected without GCPs overlaid with USGS 1:24000 vectors

for GCPs. This would be an immense benefit to numerous applications where accurately-corrected orthos are needed as soon as possible. In this article, we will use different RapidEye data to test and explore orthorectification accuracy without the use of GCPs.

RapidEye Test Data

RapidEye Standard Image Products can be purchased in two product levels, depending on the task at hand. (1) RapidEye Basic Product (level 1B): This data has had radiometric and sensor corrections applied to it, as well as on-board spacecraft attitude and ephemeris. (2) RapidEye Ortho Product (level 3A): Offers the highest level processing available. Radiometric, sensor and geometric corrections have been applied to the data. These have been rectified using a DTED level 1 SRTM DEM or better, and with appropriate GCPs can meet an accuracy of 6m 1-sigma (12.7 CE90). The highest accuracy that can be achieved by these products meets 1:25,000 NMAS standards.

Most users would prefer to use Level 1B data because they can use their own GCPs and DEMs to generate orthos. In this article we will test the correction accuracy of 1B data with and without GCPs. Level 1B data were obtained for the following areas: (1) Irvine, California, USA. (2) Phoenix, Arizona, USA, and (3) Zlin and Koprivnice regions, Czech Republic.

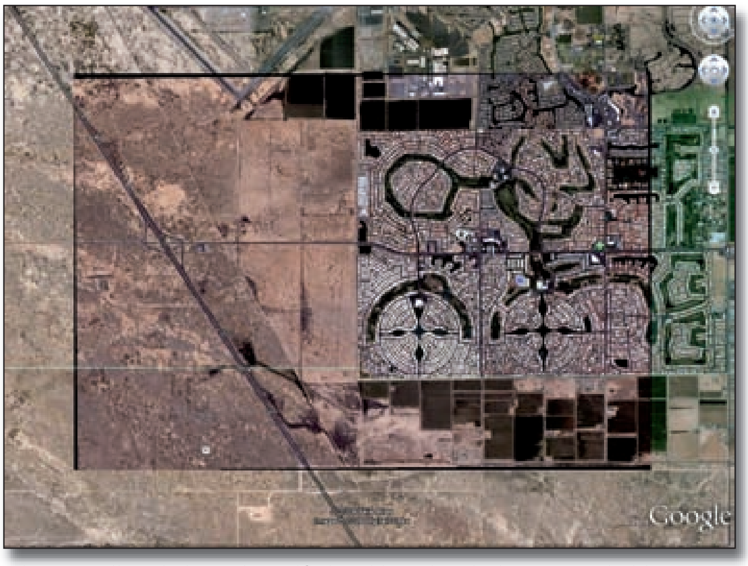

Figure 5: Full resolution orthorectified RapidEye Phoenix data corrected without GCPs overlaid with Google Earth

Geometric Correction Method and Software

Each RapidEye 1B data is supplied with 5 bands in NITF format. In addition, rational polynomial coefficients (RPC) are provided with the data, which enables the use of RPC model to orthorectify the data. More details about the RPC model can be found in the paper written by Grodecki and Dial (Block Adjustment of High-Resolution Satellite Images Described by Rational Functions - PE &RS January, 2003). Since biases or errors still exist in the RPCs, the results can be post-processed with a polynomial adjustment and several accurate GCPs.

The latest version of PCI Geomatics' OrthoEngine software was used for this testing. This software supports reading of the data, manual or automatic GCP/tie point (TP) collection, geometric modeling of different satellites using Toutin's rigorous model or the RPC model, automatic DEM generation and editing, orthorectification, and either manual or automatic mosaicking.

Figure 6: Full resolution orthorectified RapidEye Zlin data corrected without GCPs overlaid with Google Earth

Irvine, California

The data has a coverage of approximately 76 km by 230 km. Figure 1 shows an overview of the image. 14 GCPs were collected from USGS 1:24000 scale maps and 0 order RPC adjustment was used. The root means square (RMS) GCP residuals were about 3.6m in X and 7.0m in Y with a maximum residual of 6.5m in X and 11.5m in Y. The results were similar when using 1st order RPC adjustment. When all the GCPs were changed to independent check points (ICPs), the RMS ICP errors were about 5.7m in X and 7.5m in Y with a maximum error of 11.7m in X and 13.6m in Y. Although the errors are slightly higher when no GCPs were used, the RMS errors are still close to the resolution of the sensor, i.e., 6.5m. The accuracy of the GCPs using 1:24000 scale maps could also contribute the errors in the result. Figure 2 and 3 show examples of the orthorectified image corrected without GCPs overlaid with 1:24000 USGS vectors and Google Earth, respectively.

Phoenix, Arizona

A block of three 1B RapidEye data set with overlaps was tested in this case. Each image has a coverage of approximately 76 km by 162 km. 14 DGPS GCPs with sub-meter accuracy were collected from the data set. The RMS GCP residuals were about 2.3m in X and 2.1m in Y with a maximum residual of 3.3m in X and 4.7m in Y. When all the GCPs were changed as ICPs, the RMS ICP errors were 3.5m in X and 4.2m in Y with a maximum error of 6.3m in X and 6.5m in Y. Hence, RMS errors when no GCPs were used are within the resolution (6.5m) of the sensor in this case. Figure 4 and 5 show examples of the orthorectified image corrected without GCPs overlaid with 1:24000 USGS vectors and Google Earth, respectively.

Figure 7: Full resolution orthorectified RapidEye Koprivnice data corrected without GCPs overlaid with Google Earth

Czech, Republic

RapidEye 1B data set of Zlin and Koprivnice regions were acquired on June 14, 2009. The size of each scene was around 76 km by 60 km. The GCPs were collected from 0.5m aerial orthophotos and elevations of GCPs were extracted from DEM that was generated using 2m contours originated from 1:10 000 topographic maps. For testing purposes more than 30 GCPs were prepared for each scene. The 1st order of RPC adjustment was used for all scenes. In the case of scene acquired over Zlin region 34 GCPs were collected.

The RMS GCP residuals were about 2.0m in X and 1.9m in Y with a maximum residual of 5.4m in X and 4.4m in Y. When all the GCPs were changed to ICPs, the RMS ICP errors were about 3.7m in X and 4.6 m in Y with a maximum error of 6.6m in X and 9.5m in Y.

In the case of scene acquired over Koprivnice region 30 GCPs were collected. The RMS GCP residuals were about 2.6m in X and 2.3m in Y with a maximum residual of 5.8m in X and 5.4m in Y. When all the GCPs were changed to ICPs, the RMS ICP errors were about 5.1m in X and 3.9m in Y with a maximum error of 10.5m in X and 8.6m in Y.

Figure 8: Automatic mosaicked RapidEye image of Phoenix

Hence, both data have RMS error within the resolution of the sensor when no GCPs were used. Figure 6 and 7 show the orthorectified images using no GCPs overlaid with Google Earth.

Automatic Mosaicking

The successful generation of high accuracy RapidEye orthos means that it is possible to create seamless mosaics of RapidEye data without GCPs. However, mosaicking and color balancing are usually extremely time consuming processes. The PCI automatic cutline searching, mosaicking and color balance tools could be used to perform the entire process automatically. No human intervention would be required during the process. To test the automatic mosaicking of RapidEye data, the block of three Phoenix data were used. The mosaic file has a size of approximately 5.6 Gigabytes. Figure 8 shows the overview of the mosaic image and figure 9 shows a full resolution of the mosaic image overlaid with the cutline in red color. It can be seen from figure 9 that the roads are aligned to each other perfectly at the cutline between the two images.

Automated Batch Processing using GPU

Since high accuracy RapidEye orthos and mosaics can be generated automatically without GCPs, it is possible to integrate all the processes in a fully automated batch system. The batch programs required to perform all the steps are available inside PCI software. It can be run through python or PCI EASI scripts. The advantages of automated processing are that it will: (1) maximize production, (2) automate repetitive time-consuming tasks to produce consistent results, (3) improve operating efficiencies, (4) reduce labor costs, and (5) shorten throughput time for the delivery cycle. The generation of a large quantity of high accuracy orthos or mosaics, such as a mosaic of an entire country, can be generated easily with the automated system. Multiple computers can also be used to speed up the processes. The fully automated process means that it is easy to generate RapidEye orthos/mosaics for many critical applications for quick turnaround.

Figure 9: Full resolution automatic mosaicked RapidEye image of Phoenix overlaid with cutlines

Modern computer hardware such as multi-core processors and graphical processing units (GPU) have been found to improve the speed of computation-bound processes. The model for GPU computing is to use a CPU and GPU together in a heterogeneous computing model. The sequential part of the application runs on the CPU and the computationally-intensive part runs on the GPU. From the user's perspective, the application simply runs faster because it is using the high-performance of the GPU to boost performance. PCI GeoImaging Accelerator (GXL) has taken advantage of this modern computer hardware by integrating the use of GPU computing to perform intense computation tasks such as pansharpening, orthorectification and automatic mosaicking. It provides speed improvements of approximately 6 times for pansharpening, 10 times for orthorectification and 5 times for automatic mosaicking. These improvements in processing speed will help the user to obtain results much faster without any change in accuracy.

Conclusions

It is possible to generate high accuracy orthos and mosaics of Rapideye data without ground control points for quick turnaround. The test results show RMS errors consistently around one resolution of the data. The fact the GCPs are not required for RapidEye geometric correction translates to very significant cost and time savings for the user. In addition, automated batch processing to generate a large quantity of RapidEye orthos/mosaics is now possible using single or multiple computers. The use of GPU computing can improve the speed of orthorectification to 10 times faster and automatic mosaicking up to 5 times faster.

Dr. Philip Cheng cheng@pcigeomatics.com is a senior scientist at PCI Geomatics.
Mr. Jiri Sustera jiri.sustera@gisat.gz is remote sensing expert at GISAT.

The authors would like to acknowledge RapidEye Company and JRC European Commission for providing the test data.