Automated High-Accuracy Orthorectification and Mosaicking of PALSAR Data without Ground Control

Imagine a fully automated, highly reliable system to produce high-accuracy orthos and mosaics of radar data all over the world. Time-sensitive applications such as oil spills and flood monitoring can now access high-accuracy radar orthos as soon as the data is available. These applications and more are now possible with the successful operation of the ALOS satellite.

By Philip Cheng

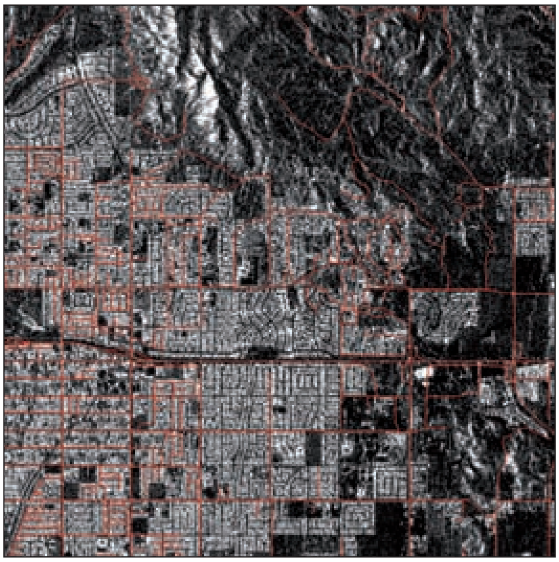

Figure 1. Orthorectified PALSAR L1.5 SGF data overlaid with USGS 1:24000 scale vectors.

The ALOS satellite was launched successfully on January 26, 2006. It has three remote-sensing instruments: the Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) for digital elevation mapping, the Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2) for precise land coverage observation, and the Phased Array type L-band Synthetic Aperture Radar (PALSAR) for day-and-night and all-weather land observation. In order to fully utilize the data obtained by these sensors, ALOS was designed with two advanced technologies. The first is the high speed and large capacity mission data handling technology and the second is the precision spacecraft position and attitude determination capability. These technologies will be essential to high-resolution remote sensing satellites in the next decade. This article will focus on the PALSAR sensor.

PALSAR Observation Modes

PALSAR provides higher performance than previous SAR sensors such as JERS-1. The high resolution mode is used most commonly in regular operation. Its maximum ground resolution of 7 meters is one of the highest among Synthetic Aperture Radar (SAR) sensors.

In addition to the conventional high resolution mode, PALSAR has a ScanSAR observation mode which enables it to switch off-nadir angles from three to five times (scan by the swath of 70 kilometers) to cover wide areas: from 250 kilometers (70x3) to 350 kilometers (70x5). For comparison, the off-nadir angle for the SAR sensor on board JERS-1 was fixed at 35 degrees, and swath width was about 75 kilometers. However, the ScanSAR resolution is inferior to high-resolution mode.

Another advantage of PALSAR is its polarimetry mode. The SAR sensor on JERS-1 was equipped only with a horizontal polarization transmission/receipt function, whereas PALSAR realizes both horizontal and vertical polarization. PALSAR can also simultaneously receive horizontal and vertical polarization for each polarized transmission - called multi-polarimetry. In addition, PALSAR can switch from horizontal to vertical polarization and vice versa at respective transmission pulse, enabling four polarizations by double simultaneous polarization - a function called full polarimetry.

PALSAR Applications

There are numerous applications for PALSAR data. Examples include: land area basin mapping, coastal area basin mapping, monitoring of the environment, and tracking of natural disasters such as oil spills. One prominent and recent example is the monitoring of an August 2006 oil spill caused by a sunken tanker off Negros Island in the Philippines. A PALSAR image taken two weeks after the initial spill showed that an expanding oil slick could be observed. This suggests that the heavy oil was still leaking from the tanker two weeks after the initial incident.

Polarimetric applications are also showing promise in fields such as forest fire monitoring, classification of vegetation (yields and

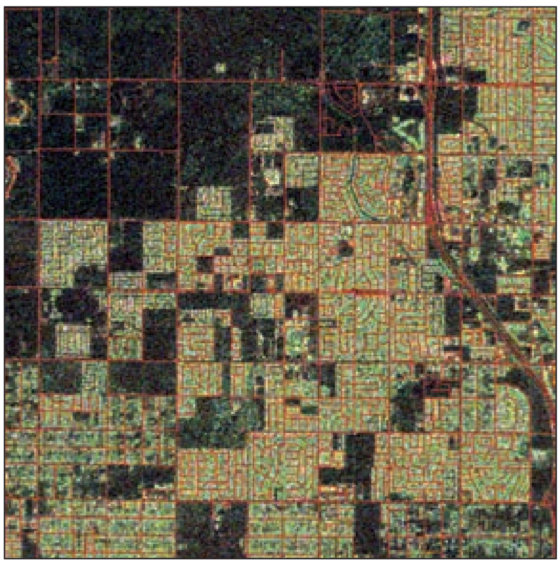

Figure 2. Orthorectified PALSAR L4.1 SGP data overlaid with USGS 1:24000 scale vectors.

Points

heights), vegetation and soil moisture studies, monitoring of snow cover, tracking of ice conditions, and flood monitoring. Another recent example was an emergency request to monitor flooding in Indonesia. Jakarta, the Indonesian capital, was heavily flooded on February 2, 2007, due to weeks of massive rainfall. The news reported that city traffic was seriously impaired and that some parts of the city were under three meters of water. Based on a request from “Sentinel Asia”, JAXA, the Japanese Aerospace Exploration Agency, decided to activate the ALOS/PALSAR sensor for rapid observation. They proceeded to image the area on February 5, 2007, using PALSAR to measure the brightness of the land and surrounding ocean. With color composites and HH-polarimetry, images were created to show detailed land surface changes due to flooding.

Orthorectification of PALSAR Data

For most SAR 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 SAR orthorectification. First, an existing source of GCPs may not be available. It is often prohibitively expensive to collect new points, especially for areas inaccessible by road. In some cases, the collection of GCPs is made almost impossible by local conditions such as floods or oil spill monitoring. Second, unlike optical satellite images, it can be very difficult to identify GCPs on the SAR image, a problem exacerbated in mountainous areas due to foreshortening and layover effects. The collection of GCPs was the main reason why it was impossible to generate high accuracy radar orthos automatically in the past.

Since the ALOS satellite has the advanced technologies of precision spacecraft position and attitude determination, this information could potentially be used to orthorectify the PALSAR data accurately to any map projection without the need for GCPs. This would be an immense benefit to a lot of applications where accurately-corrected orthos are needed as soon as possible. In this article, we will use different PALSAR data to test and explore orthorectification accuracy without the use of GCPs.

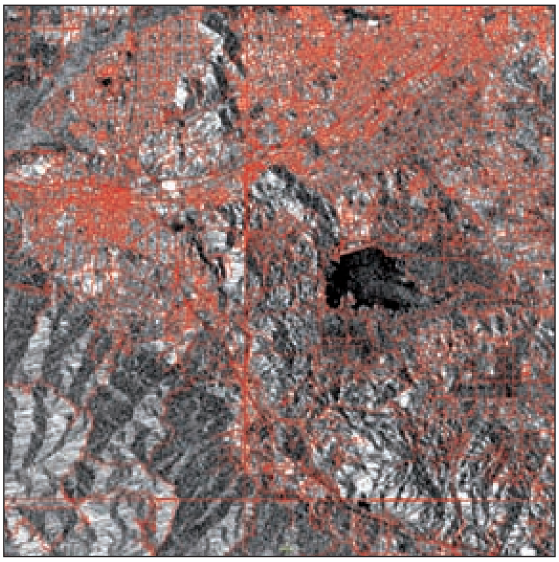

Figure 3. Orthorectified PALSAR L4.2 SCN data overlaid with USGS 1:24000 scale vectors.

PALSAR Test Data

There are two formats currently available for PALSAR data: JAXA PALSAR and ERSDAC PALSAR CEOS. The ERSDAC CEOS format data was used in this test because it is similar to the RADARSAT CEOS format, where previous testing showed a minimum effort required to support the data. The product is classified into five levels according to processing grade and observation mode. Details of these levels can be found in www.palsar.ersdac.or.jp/e/product/p_product.html. Each product can be ordered online for ¥20000 Japanese Yen.

Four high accuracy orbit PALSAR data sets were acquired from ERSDAC, consisting of one L1.5, one L4.1 and two L4.2 data sets: the L1.5 data covers an area over California, U.S.A. and the L4.2 data covers a much larger area, including California, Nevada and Arizona. This region has an approximate elevation range of -100m to 4400m. There are two products available for each level: geo-reference and geo-code. The geo-reference product was chosen because it preserves the satellite geometry for high accuracy geometric modeling.

The L1.5 SGF (SAR Georeference Fine Beam) version is a multi-look amplitude image, generated after SAR recovery processing to the level 1.0 product, acquired in single polarization high-resolution mode. The data is equally spaced on the ground range. Pixel spacing is selectable from 5, 6.25, 12.5 and 25 meters depending on the observation mode. For these tests, L1.5 data with 6.25 meter pixel spacing was chosen.

The L4.1 SGP (SAR Georeference Polarization) data is a SAR recovery processing image rendered to the level 1.0 product observed in polarimetry mode (two or four polarizations). This is a cross product (such as HH*HH and HH*HV) value of observed multi-polarizations (HH, HV, VV and VH). Pixel spacing is selectable from 12.5, 25 and 50 meters for map geocode products in map projection coordinate systems, and pixel and line spacings of 9.37 meters and 13.96 meters for path geo-reference products in the slant range coordinate system. The L4.1 two-polarizations path product data covering 70 kilometers x 70 kilometers was chosen for these tests. The two-polarization data is composed of four integer data, i.e. two unsigned integer bands and two signed integer bands (one real and one imagery).

The L4.2 SCN data set is a SAR recovery processing image rendered to the level 1.0 product observed in ScanSAR mode (two or four polarizations). ScanSAR mode uses single polarization. The product is a row of amplitude data equally spaced on the ground range. Pixel spacing is selectable from 12.5, 25 and 50 meters. Two L4.2 SCN data sets were chosen, each with five scans covering 350 kilometers x 350 kilometers overlapping in the north and south directions with spacing of 50 meters.

Testing Software

PCI OrthoEngine V10.1 software was used for the testing. Part of the Geomatica suite of products, OrthoEngine supports reading of the data, manual or automatic GCP/tie point (TP) collection, geometric modeling of different satellites using Toutin’s rigorous model, RPC correction method, radar-specific model, automatic DEM generation and editing, orthorectification, and either manual or automatic mosaicking with different color balance methods. For these PALSAR data tests, the radar-specific modeling method was used. It allows the computation of a geometric model with or without GCPs.

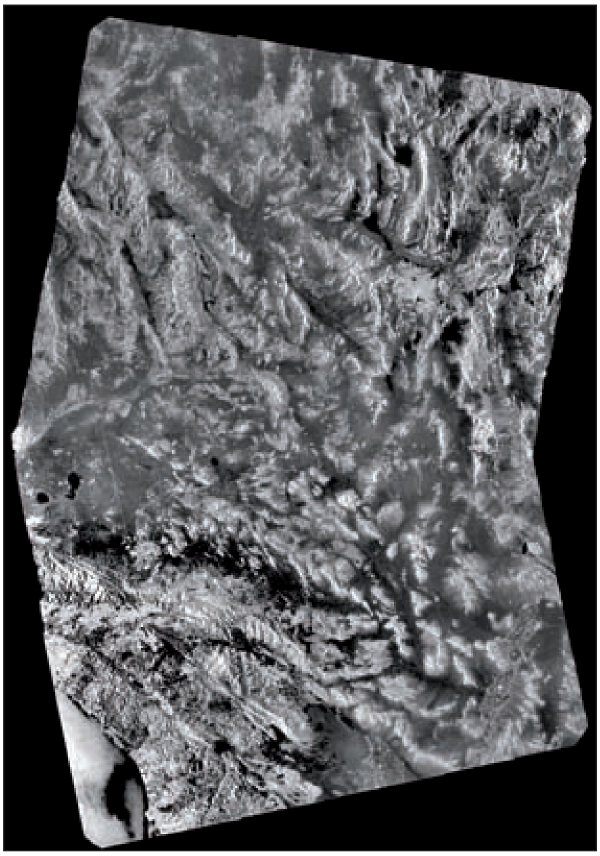

Figure 4. Automatic mosaicking of two PALSAR L4.2 SCN images.

Testing Results

To test the accuracy of the orthorectification of the data without GCPs, independent check points (ICPs) were collected from USGS 1:24000 scale maps and vectors for each image. The USGS NED 1 arc second (~30m) resolution DEM was used to extract the elevation for each check point. Table 1 shows a summary of the results. It can be seen from the table that all images have root mean square (RMS) errors within two pixels (or one resolution of the sensor). Figures 1, 2 and 3 show full resolution examples of L1.5, L4.1 and L4.2 corrected data overlaid with the USGS 1:24000 vectors (in red). The reference vectors aligned almost perfectly with the orthos in all cases.

Automatic Mosaicking

The successful generation of high accuracy PALSAR orthos means that it is possible to create seamless mosaics of PALSAR data without GCPs. However, mosaicking and color balancing are usually extremely time-consuming processes. PCI OrthoEngine's tools for automatic cutline searching, mosaicking and color balancing can be used to perform the entire process automatically. No human intervention is required during the process. To test the automatic mosaicking of PALSAR data, two L4.2 ScanSAR data sets were used, one acquired in descending pass and the other acquired in ascending pass. In general, images acquired with the same passes are preferable to minimize the radiometric differences. Each image has coverage of approximately 350 kilometers in the X direction and 350 kilometers in the Y direction, with approximately 50 kilometer overlap in the Y direction. Since the images were acquired in different passes, a local adaptive contrast stretch filter was used to correct the images before mosaicking. Figure 4 shows an overview of the mosaicked image, while Figure 5 shows a full resolution subset of the mosaicked image overlaid with the cutline (in red). It can be seen from Figure 5 that the roads are aligned to each other perfectly along the cutline between the two images.

Automated Batch Processing

Since these tests prove that high-accuracy PALSAR orthos and mosaics can be generated automatically without GCPs, it is possible to integrate all the processes in a fully-automated batch system. PCI Geomatics software encompasses all the programs required to perform the necessary steps by using either Python or PCI EASI scripts. The advantages of automated processing are (1) maximizing productivity, (2) automating repetitive, time-consuming tasks while producing consistent results, (3) gaining operational efficiencies, (4) reducing labor costs, and (5) shortening 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 easily accomplished with such an automated system. As a scalable system, multiple computers can be leveraged to speed up the processing. The availability of this fully-automated process makes it easy to generate PALSAR orthos/mosaics for applications that require rapid results, such as disaster monitoring.

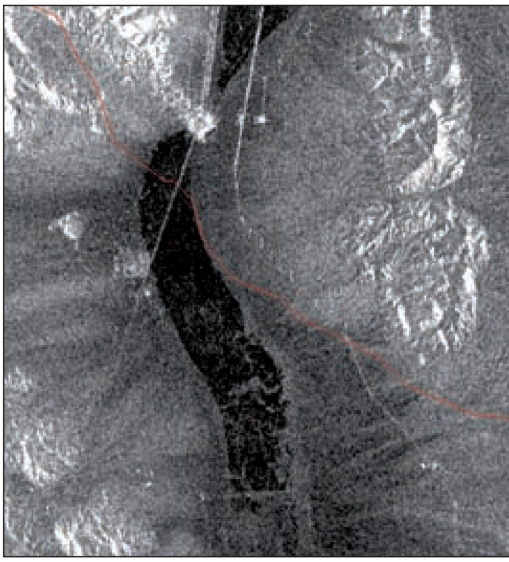

Figure 5. Full resolution mosaic of two PALSAR SCN images overlaid with cutline.

Conclusions

It is possible to generate high-accuracy orthos and mosaics of PALSAR data without ground control points. Test results show RMS errors consistently within one pixel resolution of the data. The fact the GCPs are not required for PALSAR orthorectification translates to very significant cost and time savings for the user. In addition, automated batch processing for generating a large quantity of PALSAR orthos and mosaics is now possible using single computers or multi-processor systems.

Dr. Philip Cheng (cheng@pcigeomatics.com) is a senior scientist at PCI Geomatics.

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Product	Number of ICPs	RMS Error (m)		Maximum Error (m)	
		X	Y	X	Y
L1.5 SGF	11	13.8	12.5	22.8	21.0
L4.1 SGP	8	9.6	12.6	16.0	21.3
L4.2 SCN	12	55.2	37.4	93.4	76.4

Table 1: Orthorectification accuracy results for three different PALSAR data sets using ICPs only, with elevation extracted from USGS NED DEM data.