DEMS AND ORTHO-IMAGERY FOR COLOMBIA FROM DUAL-BAND SIDE-LOOKING RADAR

Mapping an Oil Pipeline

Adverse weather and terrain conditions meant the Cano-Limon oil pipeline in Colombia had never been accurately mapped until orthorectified images and digital elevation models covering an area of 94,000km2 were created using airborne dual-band interferometric IFSAR simultaneously acquired X and P-band data. The authors report on main aspects of the project.

The Cano-Limon oil pipeline extends nearly 780km from the Cano-Limon oilfield in Colombiaâ€™s Arauca region along the north-western border with Venezuela to a port in Covenas. When fully operational the pipeline can carry up to 20% of Colombian petroleum production, a major source of national revenue. In collaboration with the Colombian Government, the US National Geospatial-Intelligence Agency (NGA, formerly NIMA) took the lead in obtaining new map data. Thick cloud cover makes optical remote sensing inoperative, and ground surveys are impractical due to a combination of multi-layer tropical vegetation and rugged terrain in the Northern Andes. Therefore interferometric IFSAR was successfully used as a mapping alternative.

GeoSAR Project
The Cano-Limon pipeline mapping effort, known as the GeoSAR Latin American Demonstration Project (GLAD-P), is the first commercial use of the Geographic Synthetic Aperture Radar (GeoSAR) system by NGA, following nine years of development. GeoSAR is a dual-use development programme managed by NGA, integrated by EarthData International of Frederick, Maryland, USA and designed by the Jet Propulsion Laboratory (JPL) in California, which engineered the components of the mapping system and ground-processing segment using custom and off-the-shelf technology. EarthDataâ€™s responsibility was to transform this technology from engineering grade into an operational system. This involved mounting antenna pods on the wings of a Gulfstream II business jet, installing the radar system inside the aircraft and getting flight certification from the Federal Aviation Administration.

Penetrating Vegetation
The GeoSAR programme aimed at designing, building and deploying a commercially viable IFSAR mapping system capable of simultaneously acquiring the X and P bands. IFSAR uses two antennae, the fixed distance between them precisely known. These emit and receive radar pulses. By measuring phase differences between the reflected signals at the two antennae surface elevations can be calculated. X-band, operating at a frequency of 9,630-9,790MHz, is commonly used in airborne IFSAR mapping systems. Its rela-tively short wavelength (3cm) acquires highly detailed data from the first reflective surface encountered, such as tree canopy, man-made structures and bare ground. P-band operates in the 270 to 430MHz range. The wavelength of 1m is capable of penetrating vegetation and top layers of soil or sand in arid regions.

The simultaneous use of both short and long-wavelength radar enables mapping a variety of surface and sub-surface features in virtually any environment, regardless of the presence of vegetation. These are very beneficial properties for mapping the Cano-Limon pipeline, which passes through grassland, jungle, mountain and coastal terrain. Figure 2 shows X-band and P-band images of the same area, and the associated Digital Elevation Models (DEM) as derived products. X-band scatters off the first surfaces of vegetation, buildings and bare earth. The 3m-posted X-band image (Figure 2, top left) is rich in first-surface details. The vegetation is seen in the X-band DEM (Figure 2, top right) along rivers and fields. P-band pene-trates vegetation and scatters off substructure, showing details otherwise hidden beneath foliage. The P-band image (Figure 2, far left) reveals road networks, buildings, and features not apparent in the X-band data. Edges of features such as rivers and roads are clearer in the P-band image because the longer wavelength deeply penetrates overhanging vegetation. Absence of vegetation in the P-band DEM results in a smooth appearance that more closely follows the terrain relief. GeoSAR is the only system in the world to operate single-pass X and P-band IFSAR simultaneously from both sides of the same platform.

Dual-side Looking
Selection of the P-band was not arbitrary. Several low-frequency bands offer penetrative capabilities but the P-band is the longest that could function on a cost-effective aircraft. In airborne IFSAR the antennae pairs are separated by many wavelengths to maximise phase differences of return signals, and hence elevation measurement accuracy. Of the civilian jets that can affordably be used for mapping, the Gulfstream-II has the longest wingspan. The 20m distance between wingtips dictated that P-band was the lowest frequency that could be used without compromising interferometric performance. For this reason the P-band pods are located on the wingtips for maximum separation and the X-band antennae are contained under the wings closer to the fuselage. In each pod one antenna points to the left and the other to the right-hand side, providing simultaneous X and P-band acquisition of the same 10km-wide swath coverage on either side of the flight path. This antenna configuration is known as â€˜dual-side lookingâ€™. Redundant collection of data necessary for the creation of DEMs is obtained by overlapping flight lines covering the nadir hole of the previous flight line. Along each flight line the system looks at each ground point twice from the left and twice from the right, at a steep and a shallow angle which covers areas otherwise obscured by

radar shadow, specular reflection and foreshortening. EarthData prefers never to â€˜interpolateâ€™ ground points.

Forbidden Area

The two-sided raw-collection rate at nominal acquisition altitude of 10km is 240km2 per minute per band. In comparison to a standard single-sided IFSAR, dual-side-looking IFSAR collects more looking angles, so that surface elevation values can be calculated more accur-ately. The distance between two subsequent flight paths is usually 5km, or half the swath width. The multiple and oppos-ite â€˜looksâ€™ of each point on the ground much improves elevation calculation and reduces the number of ground surfaces hidden behind tree shadows, hills and mountain peaks in rugged terrain. Dual-side-looking IFSAR also makes it possible to cover twice as much terrain on one pass as covered by a standard, single-side-look system. The elevation varied by 5,000m from the coastal area through the Andes along the pipeline route, with ground cover varying just as drastically. Nevertheless, the system was operated at standard altitude and power throughout the project. Airspace restrictions, however, required many modifications to normal flight-path planning. The aircraft was not permitted to fly over neighbouring Venezuela, creating the risk of voids resulting from mountain peaks shadowing lower terrain from radar illumination. To minimise data voids the flight path spacing was tightened, increasing the number of â€˜lookâ€™ angles and swath overlaps.

Radar Notching

Use of the P-band potentially introduces frequency interference. This is because the P-band transmits in the UHF (Ultra-High Frequency) part of the electromagnetic spectrum: the part dedicated to many government radio communications, including air traffic control, aviation instrument-landing systems and emergency locator beacons. In the US many UHF bands are reserved for military communications. To avoid interference the radar emission in government-specified segments has to be significantly reduced (notching). Close co-operation with the National Telecommunications and Information Agency (NTIA) was necessary. NTIA facilitates co-ordination with local communications users to determine where notching should occur in each flight path. The frequencies are programmed for automatic notching during data acquisition. Fortunately, there were few stationary UHF systems operating in the region, so notching was not needed. However, there was occasional interference, probably from mobile communications devices in the jungle. The impact of such interference on data quality was minimal thanks to the acquisition redundancy and adaptive filtering technology that is a unique feature of the system.

Twisting Wingtips

IFSAR requires that the baseline, that is the distance between the two antennas, be precisely known. However, during flight wing flexure causes antennae positions to continually shift with respect to the fuselage. Therefore a motion-measurement device was mounted on the fuselage centreline between the wings. This device, the first of its kind deployed in commercial IFSAR, uses lasers and optical cameras to measure to a fraction of a millimetre the attitude of the antennae pods with respect to the body of the aircraft. The measurements were transmitted daily, together with onboard-collected GPS data, by internet to EarthDataâ€™s Maryland (USA) headquarters, where the datasets were analysed to ensure that excessive turbulence had not ruined the data. On the rare occasions when this occurred re-flights could be planned for the next day, before the aircraft left the area.

End Products

The entire project included 187 flight paths. Stored on Sony 19mm data cartridges with 100-gigabyte capacity, the IFSAR data was processed by a SGI 2400 computer at the Maryland facility. Six months after acquisition the end products were ready for delivery. They included 3m-resolution X-band and 5m P-band orthorectified radar imagery and DEM of the same spatial resolution. Comparison of the X and P-band images illustrates the advantages of simultaneous acquisition of the bands. The X-band image readily shows the pipeline, holding tanks, smaller pipes and other infrastructure not obscured by vegetation. By comparison, P-band peaks beneath the foliage and reveals topographic structure, homes, streets and paths barely visible in the X-band. Linear features such as fences and field boundaries pop out of the P-band data. Together these complementary images provide a complete picture of natural and manmade features.
Comparing the dual-side-looking imagery to standard single-side IFSAR, a striking difference was the low level of speckling. Filtering reduces speckle noise but also reduces the resolution or sharpness of the imagery. Dual-side-looking imagery enables averaging of the different â€˜looksâ€™, which decreases the level of speckle noise. All GLAD-P deliverables received first-time acceptance from NGA.

Two Upgrades

The Cano-Limon project provided an opportunity to identify system features that could be refined to improve operational efficiency, resulting in two upgrades. Firstly, there was installation of a solid-state digital data-storage system capable of storing 4,000 gigabytes (four terabytes). The 100-gigabyte capacity of the onboard data storage cartridges limited flight lines to 22 minutes, which necessitated changing in-flight tapes. Now the path lengths are no longer limited, yielding greater cost-effectiveness. Secondly, there was addition of nadir-looking profiling Lidar for generating accurate bald-earth profiles for ground-control purposes. The placement of multiple radar reflectors used earlier for this purpose proved dangerous when operating in a jungle, and at least one disappeared before the flight mission began. These upgrades have been completed and tested and are operational.
As a result of this project and the upgrades, NGA has contracted EarthData to deploy GeoSAR for other mapping efforts in other parts of South America where accurate, up-to-date map data has up until now been lacking.

Further Reading

- Scott Hensley, Riadh Munjy, andÂ Paul Rosen, 2001, Interferometric Synthetic Aperture Radar in Digital Elevation Model Technologies and Applications: The DEM Users Manual, editor: David F. Maune, Chapter 6, ASPRS.