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GPS Campaigns for Validation of InSAR Derived DEMs

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Abstract. Interferometric Synthetic Aperture Radar (InSAR) is a rapidly evolving technique. Spectacular results that are obtained in various fields, such as the monitoring of earthquakes, volcanoes, land subsidence and glacier dynamics, as well as in the construction of Digital Elevation Models (DEMs) of the Earth's surface and the classification of different land types, have demonstrated its strength.

As InSAR is a remote sensing technique, it has various error sources due to the satellite positions and attitude, atmosphere, and others, so it is important to validate its accuracy, especially for the DEM derived from SAR images before it can be used for various applications such as disaster prevention, flood mapping, and emergency map.

In this study, Real Time Kinematic (RTK) GPS positioning and Kinematic GPS positioning were chosen as tools for the validation of InSAR derived DEM. The results showed that Kinematic GPS positioning had greater coverage at field test, i.e. larger number of usable sampling points than RTK GPS. However, tracking satellites and transmitting a data between reference-rover, under trees are still pending tasks to be overcome in GPS positioning techniques. Additionally, Airborne Laser Scanning (ALS) is expected to be an alternative as an effective tool for the validation of DEMs.

Key words: Interferometric Synthetic Aperture Radar (InSAR), Digital Elevation Model (DEM), Real Time Kinematic (RTK) GPS positioning, Kinematic GPS positioning

1. Introduction

A DEM measures the height of terrain above a reference datum. DEM as a term is in widespread use and generally refers to the creation of a regular array of elevations, normally squares or hexagon pattern, over the terrain (El–Sheimy, 1999).

Nowadays DEMs can be generated with several methods such as ground surveys, photogrammetry (e.g., analytic photogrammetry and digital photogrammetry), InSAR technique and Airborne Laser Scanning (ALS).

The ground surveys (GPS positioning, levelling, etc) provide height information to a high degree of accuracy, but are time-consuming, laborious and costly, and provide information on point basis only. The point information on height may not be sufficient for conducting an engineering study on regional basis that requires dense spatial information. The spatial extent of height can be obtained from DEM.

The photogrammetric DEMs can be stereo-compilation methods, automatic collection of elevation data by digital correlation from digitized film or digital imagery, and hybrid approaches (Molander, 2004).

Recently Shuttle Radar Topography Mission (SRTM) obtained elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of the Earth. SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavor during an 11-day mission in February of 2000. This configuration produced the single-pass interferometry and during this period, SRTM mission imaged the Earth's entire land surface between 60 degrees north and 50 degrees south. The C-band SRTM data is being processed into DEMs on a continent-by-continent basis (Peltzer, 1999)

With the advent of InSAR, it may now be possible to obtain height information on regional basis thereby producing DEM up to meter level accuracy. Due to this, the technology is gaining its momentum in many application areas such as lithospheric movements in geology, crustal deformation studies in seismology, global volcano monitoring, landslide monitoring, ice and glacial studies (Arora et al, 2002).

The main aim of this paper is to provide the availability overview of GPS positioning for assessment of DEMs and to reveal the related problems.

2. Basic Concept of InSAR and GPS positioning

2.1 InSAR Overview

Synthetic Aperture Radars (SAR) produce all weather, day and night, high resolution images of the Earth's surface providing useful information about the physical characteristics of the ground and of the vegetation canopy, such as surface roughness, soil moisture, tree height and bio-mass estimates. By combining two or more SAR images of the same area, it is also possible to generate elevation maps and surface change maps with unprecedented precision and resolution. This technique is called "SAR interferometry". With the advent of spaceborne radars, SAR interferometry has been applied to the study of a number of natural processes including earthquakes, volcanoes, glacier flow, landslides, and ground subsidence (Peltzer, 1999).

Fig.1 presents imaging geometry for a repeat-pass interferometer. One interferogram is formed with images acquired from positions A1 and A2. Assume two identical antennas, A1 and A2, are receiving radar echo signals from a single source. The path length difference, $\Delta\rho$, of the signals received by the two antennas is approximately given by

$$\Delta\rho = |\vec{\rho}_2| - |\vec{\rho}_1| \approx B\sin(\theta - \alpha) \qquad (1)$$

where $\vec{\rho}_i$ indicates the vector from antenna i to the target, B is the length of the baseline vector which is the vector pointing from antenna 1 to antenna 2, θ is the desired elevation (or) look angle and the baseline orientation angle, α is the angle the baseline vector makes with respect to the horizontal. If a ground resolution element scatters identically for each observation, then the difference of the two phases depends only on the path length difference. The range difference, $\Delta\rho$, may be obtained by measuring, ϕ , the phase between two interferometer signals, using the relation

$$\phi = -\frac{2\pi m\Delta\rho}{\lambda}, \; m = 1, 2 \qquad (2)$$

where λ is the radar wavelength and m equals to 1 when the path length difference is associated with one way difference, or 2 for the two-way path difference. Using the simplified geometry of Fig. 1, the height of a target, h_t is given by

$$h_t = h - \rho\cos(\theta) \qquad (3)$$

where h is the altitude of the radar antenna and ρ is the slant range from the antenna to the target. Generation of accurate topographic maps using radar interferometry places stringent requirements on the knowledge of the platform and baseline vectors (Hensley et al., 2001).

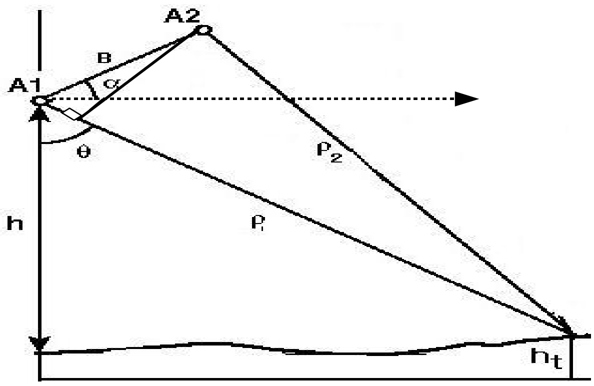


Fig. 1 Radar Interferometric geometry

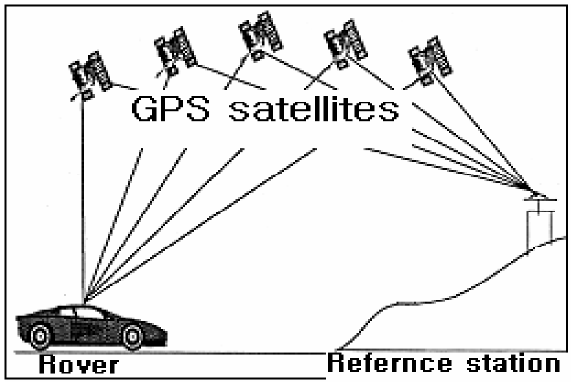


Fig. 2 Overview of Kinematic GPS positioning

2.2 GPS positioning techniques

Kinematic GPS positioning is productive in that the greatest number of points can be determined in the least time. In kinematic GPS positioning, the unknown rover was positioned 'relative' to a reference station that occupied a point of known 3-D coordinates. Fig. 2 presents the graphic presentation of Kinematic GPS positioning.

The Kinematic technique requires the resolution of the phase ambiguities. There are lots of ambiguity resolution techniques for the kinematic case. One of them is called On the Fly (OTF).This solution required an instantaneous positioning (i.e., for a single epoch). The main problem is to find the positions as fast and accurate as possible. This is achieved by starting with approximations for the positions and improving them using least squares adjustments or search techniques (Hoff-mann et al, 1997).

RTK GPS is the dynamic GPS positioning technique available. Using short observation times, this system provides precise results instantaneously whenever continuous four-satellite tracking is available. Nowadays kinematic carrier phase-based positioning can be carried out in real-time if an appropriate communications link is provided over which the carrier phase data collected at a static base receiver can be made available to the rover receiver's onboard computer; to generate the double-differences, resolve the ambiguities and perform the position calculations (Rizos, 1999). This is termed as Real Time Kinematic (RTK) GPS positioning.

3. Generation of InSAR DEM and GPS campaigns

3.1 InSAR DEM

Interferometric SAR is now established as a method for generating DEM from complex SAR data. Validation of such InSAR derived DEMs is still in progress and some results are founded in literature (Balan and Mather, 1999). Interferometry is a technique that interprets the phase difference between two identical SAR images of a single area taken one or more repeat orbit cycles apart. The two ERS satellites operated in tandem for a time, and this allowed for the collection of excellent interferometric pairs.

In this paper, the InSAR DEM was derived using the images acquired during tandem mission of the ERS-1 (20/10/1995) and ERS-2 (30/10/1995) satellites, where there was only one-day difference between the acquisitions of two radar images. Fig. 3 and 4 presents the procedure for DEM generation from both SAR Images and InSAR derived DEM, respectively.

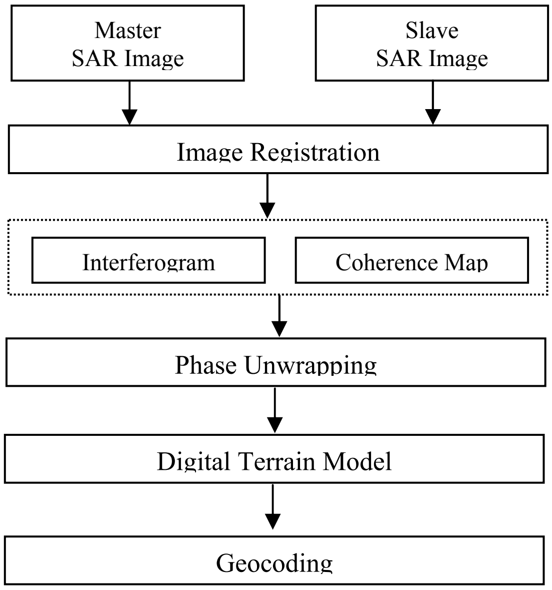


Fig. 3 Generation of InSAR DEM

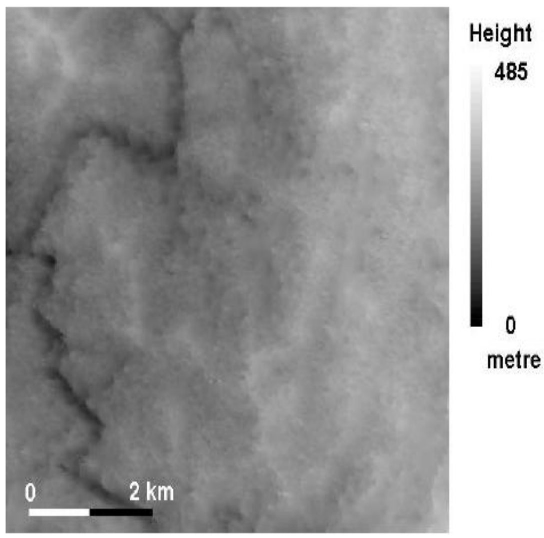


Fig. 4 InSAR Derived DEM

3.2 GPS Field Observation

In theses GPS campaigns, a pair of Leica SR530 receivers with firmware allowing dual-frequency and OTF technique, essential for RTK GPS, and a pair of AT502 antennas, L1/L2 microstrip built-in ground-plane, and a pair of radio modem for transmitting data between a reference station and a rover were employed. This campaign was conducted at the Mining site, Appin, in Australia.

For RTK GPS and Kinematic GPS positioning, a reference station was set up at a site that had a good view to track satellites during the period of test, and a rover moved along the motorway of test field. Positions of a rover antenna were recorded every 1 second in the receiver in real-time with accuracy in several centimeters. At the same time, raw data of both antennas were also stored in the receiver for post processing. With these data, Kinematic GPS positioning was processed. A reference station and a rover set up on the roof of vehicle are shown In Fig. 5.

Fig. 5 A reference station and a rover

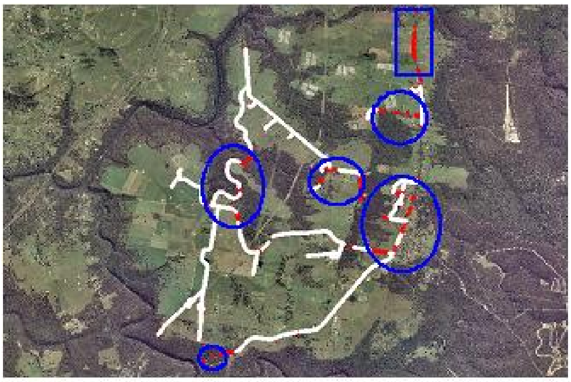
4. Analysis of GPS Observable and Assessment of DEM accuracy

4.1 Kinematic GPS positioning and RTK GPS

First of all, the coverage of test area between Kinematic GPS positioning and RTK GPS and was evaluated according to the number of usable sampled points. Fig. 6 (a) and (b) indicate the display map of points acquired from Kinematic GPS positioning and RTK GPS, respectively and Fig. 6(c) presents the overlaid points of Kinematic GPS positioning and RTK GPS with an aerial photograph as background.

(a)

(b)



(c)

Fig. 6 Points of Kinematic GPS positioning (a), RTK GPS (b), and the overlaid map of both (c)

It seems that there is no much difference of point coverage between Kinematic GPS positioning and RTK GPS in Fig. 6, because some measurements recorded in receivers while a vehicle was stationary were already excluded in statistical analysis. However, in actuality, there is a wide difference of data coverage between these two methods.

Especially, some areas marked as circle and square in Fig. 6(c), showed the different data coverage between Kinematic GPS Positioning and RTK GPS. Kinematic GPS positioning has about two times as many usable sampling points as RTK GPS. This may be due to the interference of radio linkage between reference-rover, leading no position solution (e.g. in area, marked as square in Fig.6(c)), and the initialisation problem, leading no solution in RTK GPS (e.g., in area, marked as circle in Fig.6(c)). There is also some probability of both aspects in some areas.

The RMSE of height differences between Kinematic GPS positioning and RTK GPS is within several centimeters. This error value might be good as is the case with both methods.

4.2 Assessment of DEMs' accuracy

In this paper, 1 arc-second photogrammetric DEM and ERS-1/2 Tandem InSAR DEM as space-borne radar have the pixel size of 30m and 20m, respectively, and SRTM DEM as shuttle-borne radar has the pixel sizes of about 90m. And GPS height profiles were used as ground truth data.

Comparison of three DEMs, i.e. 1 arc-second photogrammetric DEM, SRTM DEM, ERS-1/2 Tandem InSAR DEM against GPS height profiles was used. For this, each height profile of three DEMs was extracted along the same locations where the sampling points in Kinematic GPS positioning were collected. And height profiles of Kinematic GPS positioning were chosen as ground truth data in that the Kinematic GPS positioning had more number of usable sampling points than RTK GPS.

Table 1 indicates the RMSE of height difference between three DEMs and GPS height profiles according to routes.

Tab. 1 RMSE of height difference between three DEMs and GPS height profiles

Sensors / Routes	Photogrammetric DEM	SRTM DEM (Shuttle-borne Radar)	ERS-1/2 Tandem InSAR DEM (Space-borne Radar)
R1	2.95m	1.57m	18.01m
R2	3.26m	2.02m	30.27m
R3	2.16m	3.18m	17.31m
R4	3.24m	1.85m	14.81m

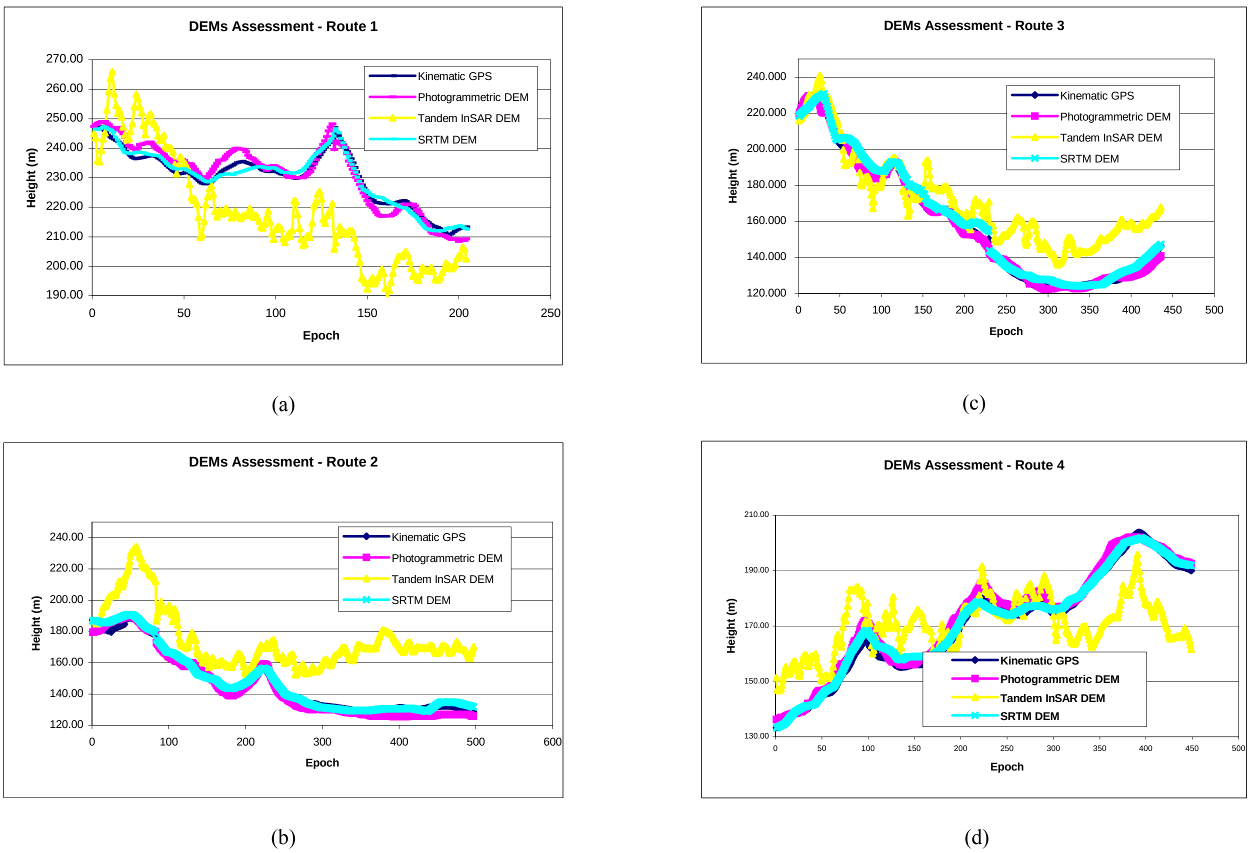


Fig. 7 Comparison of height profiles of three DEMs against Kinematic GPS along (a) Route1, (b) Route2, (c) Route 3, and (d) Route 4

The height profiles derived from the photogrammetric DEM and STRM DEM have the mean RMSE of about 2.90m and 2.16m, respectively, while Tandem InSAR DEM has the mean RMSE of about 20.10m against GPS height profiles. In case of Tandem InSAR DEM, this value is likely to be accepted when considering the vertical resolution of ERS images.

Fig. 7 shows that three DEMs have similar trend of heights. Especially, big turbulence of height profile between three DEMs and Tandem InSAR DEM occurred at Route 2. This may be due to satellite inherent errors (e.g., positions and orientations of the satellite), phase unwrapping errors, and atmospheric errors, etc.

Therefore, the detailed information such as satellite orbit information, phase unwrapping algorithm, and especially tropospheric delay to improve the accuracy of InSAR derived DEM is required, and more powerful method like ALS that can validate the accuracy of InSAR derived DEMs should be introduced.

5. Conclusion

This paper dealt with the validation of InSAR derived DEM against GPS height profiles as ground truth data. The results showed that Kinematic GPS positioning had better coverage at the field test, i.e. larger number of usable sampling points than RTK GPS. Therefore, it is expected that Kinematic GPS positioning plays an important role in the validation of InSAR derived DEM because of its cost-effectiveness. But the interference of radio linkage between reference-rover, the tracking satellites and multipath error near and/or under trees are still pending problems to be solved.

Network-Based RTK GPS and the integration SAR with ALS will be an alternative, and what is the most important is that researches related to validation of DEM are further required.

Acknowledgements

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