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Validation of DEM Derived from ERS Tandem Images Using GPS Techniques

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Abstract

Interferometric Synthetic Aperture Radar(InSAR) is a rapidly evolving technique. Spectacular results 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 sources of errors due to the satellite positions and attitude, atmosphere, and others. Therefore, it is important to validate its accuracy, especially for the DEM derived from Satellite SAR images. In this study, Real Time Kinematic(RTK) GPS 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 of test area in terms of the number of measurements than RTK GPS. But tracking the satellites near and/or under trees and transmitting data between reference and rover receivers are still pending tasks in GPS techniques.

Keywords : InSAR, DEMs, Real Time Kinematic (RTK) GPS, Kinematic GPS

要 旨

InSAR(Interferometric Synthetic Aperture Radar)는 급속히 발전하고 있는 기술이며 지표면의 수치지형모델 제작과 토지이용 분류뿐만 아니라, 지진, 화산, 지반침하와 빙하흐름의 모니터링과 같은 다양한 응용분야 적용은 그것의 장점을 강화시켜 주고 있다. InSAR는 원격탐측 기술의 한 부류이므로, 위성위치와 자세, 대기, 그리고 기타 요소에 의한 다양한 오차원인을 가지고 있으므로, 이 시스템의 정확도 검증, 특별히 SAR 영상으로부터 제작된 수치지형모델에 대해서는 중요하다. 본 연구에서는 RTK GPS와 Kinematic GPS 측위가 InSAR 기술로 제작된 수치지형모델의검증 도구로 이용되었다. 그 결과로서, Kinematic GPS는 실험지역에서 RTK GPS보다 많은 관측값을 얻을 수 있었지만, 안테나 주위 나무 등에 의한 위성추적 문제와 통신거리에 따른 기준국과 이동국사이의 자료전송 문제 등이 여전히 시급히 해결해야 할 과제로 나타났다.

핵심용어 : 간섭합성개구 레이더(InSAR), 수치지형모델(DEM), 실시간이동측량(RTK), 이동측량(Kinematic GPS)

1. Introduction

A DEM measures the height of terrain above datum and absolute altitude or elevation of the points in the mode. DEM as a term is in widespread use in U. S. A and generally refers to the creation of a regular array of the terrain$^{(5.12)}$. Conventionally, height(altitude) has been determined through field surveys and to some extent from stereo-photogrammetry provided that the aerial photographs are available. The field surveys, including GPS positioning, provide elevation information to a elevations, normally squares or hexagon pattern, over 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 spatial information. The spatial extent of height can be obtained from DEM.

With the advent of Interferometry Synthetic Aperture (InSAR), it may now be possible to obtain height infor-

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mation on spatial basis. 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, etc(2,8, 10,11). Nowadays DEMs can be generated with several methods such as ground surveys, photogrammetry(e. g. Analytic Photogrammetry and Digital Photogrammetry), RADAR and Airborne Laser Scanning(ALS). The photogrammetric DEMs can be generated by stereo-compilation methods, automatic collection of elevation data by digital correlation from digitized film or digital imagery, and hybrid approaches(1).

The main aim of this paper is to assess the suitability of GPS positioning for assessment of DEMs and to reveal the problems encountered here.

2. Basic Concept of InSAR and GPS positioning

2.1 InSAR Overview

Synthetic Aperture Radar(SAR) produces all weather, day and night, and 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"(3). 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(13).

Figure 1 presents imaging geometry for a repeat-pass interferometer. One interferogram is formed with images acquired from positions A1 and A2. Assume two antennas, namely 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

$$\triangle\rho = |\overrightarrow{\rho_2}| - |\overrightarrow{\rho_1}| \approx B\sin(\theta - \alpha) \tag{1}$$

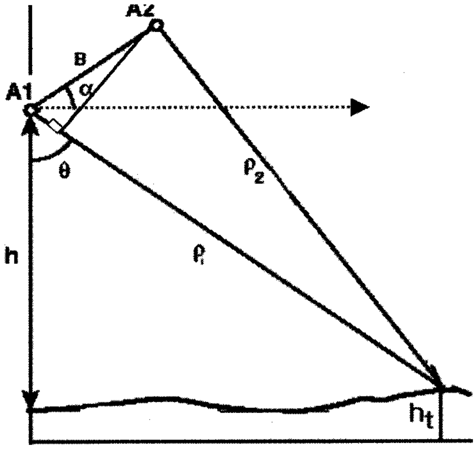


Figure 1. Radar Interferometric geometry

where $\overrightarrow{\rho_i}$ 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:

$$\phi = -\frac{2\pi\triangle\rho}{\lambda}, m = 1, 2 \tag{2}$$

where λ is the radar wavelength and m equals 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 Figure 1, the height of a target, h_t, is given by

$$h_t = h - \rho\cos(\theta) \tag{3}$$

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(4,11).

2.2 GPS positioning techniques

Kinematic GPS positioning are the most productive in that the greatest number of points can be determined in the least time. In Kinematic GPS positioning, the unknown rover GPS receiver was positioned 'relative' to a reference GPS receiver that occupied a point of known 3-D coordinates. Figure 2 presents the graphic overview 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 with least squares adjustments or search techniques(7).

RTK GPS is the dynamic GPS positioning technique. 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(14). This is defined as "Real Time Kinematic"(RTK) GPS(9).

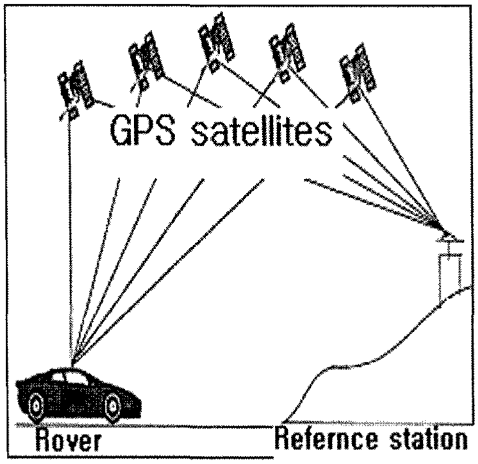


Figure 2. Kinematic GPS positioning

3. Generation of InSAR DEM and GPS observation

3.1 Generation of InSAR DEM

Interferometry is a technique that interprets the phase difference between two SAR images of the same 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 images acquired during tandem mission of the ERS-1(29/10/1995) and ERS-2(30/10/1995) satellites, where there was only one-day difference between the acquisitions of two radar images, were used to derived the InSAR DEM. Figure 3 and 4 present the procedures for DEM generation from two SAR Images and InSAR derived DEM, respectively. And Table 1 contains several parameters related to ERS-1 and ERS-2 sensors. Figure 5 and 6 indicate the coherence map and Interferogram generated from ERS Tandem pairs used in this study.

3.2 GPS Observation

The GPS campaign was conducted on June 9, 2004, at mining sites around Appin, Australia. A pair of LEICA SR530 receivers with firmware allowing dual-frequency, on the fly(OTF) ambiguity resolution, essen-

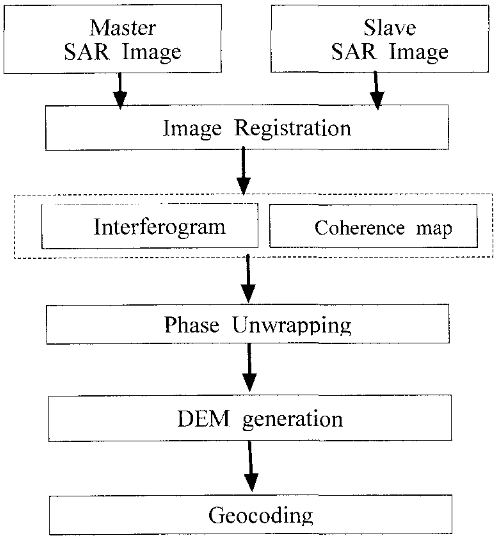


Figure 3. Generation of InSAR derived DEM

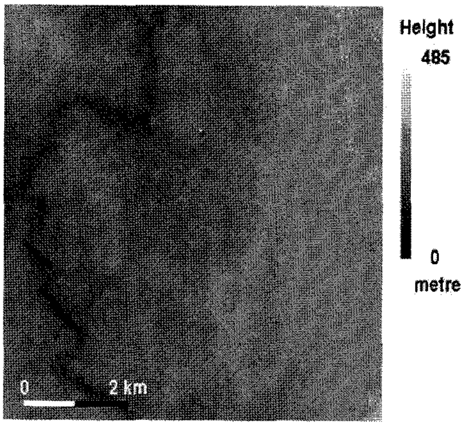


Figure 4. DEM from ERS tandem pairs

Table 1. ERS-1 and ERS-2 SAR sensor parameters

Country	European Union
Platform	Satellite
Launch date	7/1991, 4/1995
Life time(years)	3a
Frequency(GHz)	5.3(C-band)
Polarization	VV
Orbit altitude(km)	780
Orbit inclination(deg)	98.5
Look angle(deg)	2.3
Swath width(km)	100
Antenna dimensions(m)	10×1
Resolution(m)	25

Figure 5. Coherence map

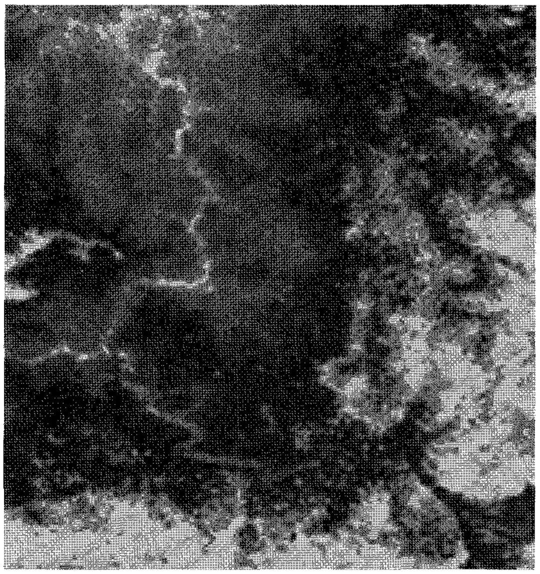


Figure 6. Interferogram

tial for real-time RTK, a pair of AT502 antennas, L1/ L2 microstrip built-in ground-plane, and a pair of radio modem for transmitting data between reference station and rover were used. And GPS measurements were processed using SKI PRO, developed by Leica for real-time and post-processing.

For the RTK GPS and Kinematic GPS positioning, a reference station was set up at site that had a good view to track satellites during the period of test and rover moved along motorway of test field. And positions of rover antenna were stored every 1 second in the receiver in real time with accuracy of several center meters. At the same time, raw data of both receivers also were stored for post processing. With these data, Kinematic GPS positioning was processed. In Figure 7, a reference station and rover antenna on the vehicle are shown. For reference, mean RMSE(Root Mean Square Error) between RTK GPS and Kinematic GPS positioning is about several centre meters(cm). This error value may be good as is the case with both methods.

4. GPS measurement analysis and Assessment of DEM accuracy

4.1 Kinematic GPS positioning and RTK GPS

First of all, the coverage of test area in terms of the

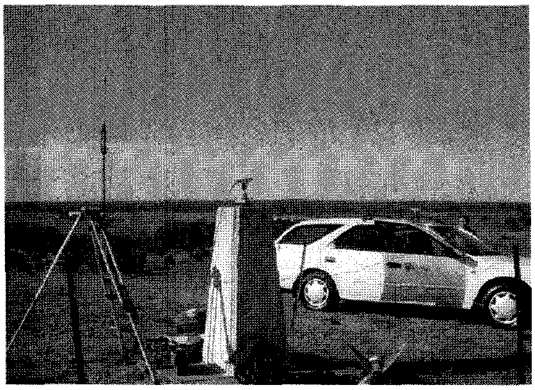


Figure 7. A reference station and rove unit

number of points observed between RTK GPS and Kinematic GPS was compared. Figure 8 presents the overlaid map of Kinematic GPS positioning and RTK GPS with an aerial photos as background.

As seen in Figure 8, there are a little difference of coverage between Kinematic GPS positioning and RTK GPS. Additionally, some areas which were symbolized as circle and square indicate the different coverage between Kinematic GPS Positioning and RTK GPS in Figure 8. Kinematic GPS positioning has measurements of about two times more than RTK GPS. This may be due to the radio linkage interruption between reference station and rover, thus leading to no position solution (e. g. area marked as square(□) in Figure 8), and an initialization problem, leading to no solution(e. g. area marked as circle(○) in Figure 8) in RTK GPS. And there were also some regions with both aspects mentioned above.

4.2 Assessment of DEM Accuracy

In this study, 1 arc-sec photogrammetric DEM and InSAR derived DEM with pixel sizes of 30m and 20m respectively, and GPS measurement were used. Accuracy comparison of two DEMs, that is, 1 arc-sec Photogrammetric DEM and InSAR derived DEM against Kinematic GPS positioning has been done. For this, elevation profiles were extracted from two DEMs at the same locations where Kinematic GPS positioning samples were collected. The comparison of RMSE of the height profiles of the two DEMs against Kinematic GPS positioning as ground truth data are summarized in Table 2. The average, minimum. and maximum errors were represented in absolute values in Table 2.

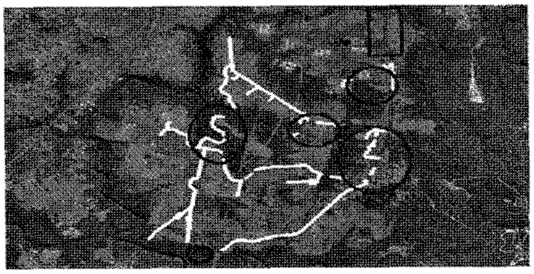


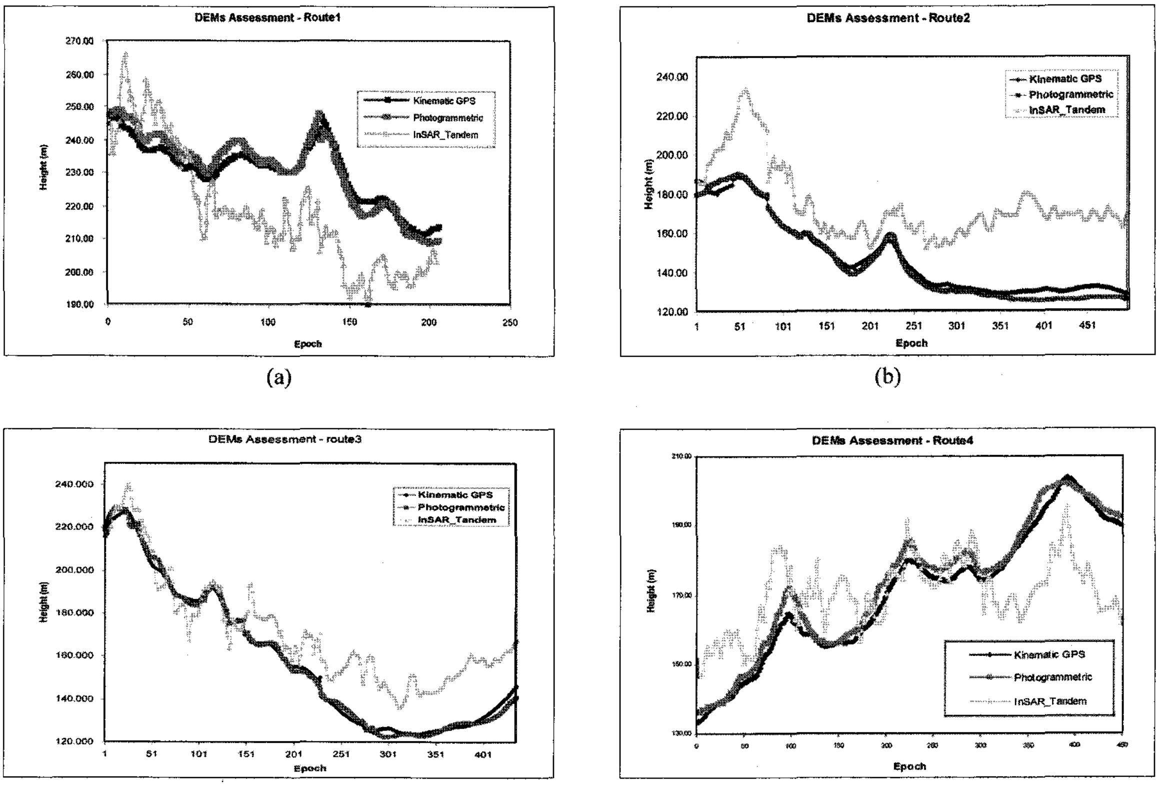
Figure 8. The vehicle routes by Kinematic GPS positioning(in red) and RTK GPS(in white)

The profiles derived from the Photogrammetric DEM has the mean RMSE of 2.907m variations, while InSAR derived DEM has the mean RMSE of 20.100m against the profiles of Kinematic GPS positioning. For InSAR derived DEM, values mentioned in Table 2 are similar to the accuracy mentioned in other literature(15).

Figure 9 showed the height profiles of two DEMs and Kinematic GPS. Both DEMs showed the similar trend of the variation of the terrain comparing to the ground truth data. The error of InSAR DEM is the composite of satellite inherent errors(e. g. positions and orientations of the satellite), precision of geometric correction, phase unwrapping errors, and atmospheric disturbances, bias of GPS campaign, etc.

Table 2. Comparison of RMSE of two DEMs against Kinematic GPS positioning

Systems / Routes	photogrammetric DEM(m)				InSAR derived DEM(m)			
	Average	Min.	Max.	RMSE	Average	Min.	Max	RMSE
Route 1	2.582	0.006	7.347	2.952	16.222	0.008	41.063	18.012
Route 2	2.790	0.011	7.789	3.266	27.706	0.068	50.629	30.274
Route 3	1.749	0.001	5.506	2.163	14.787	0.160	35.050	17.308
Route 4	2.729	0.007	7.710	3.245	12.555	0.021	28.509	14.807



(a) (b)

(c) (d)

Figure 9. Profiles of two DEMs and Kinematic GPS positioning along (a) Route 1, (b) Route 2, (c) Route 3, and (d) Route 4

5. Conclusions

This paper dealt with the assessment of DEM derived from ERS Tandem images against RTK GPS and Kinematic GPS positioning as ground truth data. Results have shown that Kinematic GPS positioning had more better coverage of the test area 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 several problems, such as the interference of radio linkage between reference and rove, especially for RTK GPS, the impossibility of receiving satellite signals and multipath errors near and/or under trees were identified. Network-Based RTK GPS will be an alternative to obtain many GPS measurements, and the integration of SAR with Airborne Laser Scanning(ALS) will also become an alternative to obtain the high precise DEM.

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