Differential Synthetic Aperture Radar Interferometry (DINSAR) for 3D Coastal Geomorphology Reconstruction

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Summary

This paper introduces a new method for three-dimensional (3D) coastal geomorphology reconstruction using differential synthetic aperture interferometry (DInSAR). The new method is based on an integration between fuzzy B-spline algorithm and DInSAR method. DInSAR algorithm is involved two parts: (i) 3D map simulation which is based on interferogram simulation and (ii) satellite orbit parameters. 3D coastal geomorphology reconstruction is realized by fuzzy B-spline algorithm with the midpoint displacement method and the terrain roughness. Consequently, fuzzy B-spline was used to eliminate topographic phase from the interferograms. The study shows the DInSAR technique provides information about coastal geomorphology change with accuracy of ± 0.1 m.

Keywords: DInSAR, interferogram, Fuzzy B-spline algorithm, 3D reconstruction.

1. Introduction

Synthetic Aperture Radar interferometry (InSAR) is a relatively new technique for 3D topography mapping [10]. Scientists and researchers have been defined InSAR as a technique that utilizes interference of waves for precise determination of distance [5]. In SAR interferometry path length differences with millimeter accuracies can be detected based on the interferometric phase generated by conjugating two SAR images of the same scene at different times with slightly different viewing angles [2]. In this context, it could be a major tool for 3D coastal geomorphology reconstruction in real time. Consequently, synoptic data over large areas at comparatively low cost can be produced by InSAR. The coastal geomorphology features etc., spit, dunes and beach profile can be reconstructed by SAR interferometry.

According to Zekber et al. [10], topographic information as well as movement information can be acquired from the phases. In fact, phases are corresponding to differential range change in the interferogram for two or more SAR images of the same scene. Recently, Luo et al.,[2] have introduced a technique which is based on utilization three pass differential interferometry (TPDI) to measure topography displacement. They reported that the displacement will be result in component called deformation phase in interferomateric phase, if the topography surface deformed at interval of SAR repeat [2].

In this paper, we address the question of utilization fuzzy-B-spline in 3D topography reconstruction before phase unwrapping. In fact, there are several factors could be impact the accuracy of DEMs are derived from phase unwrapping. These factors are involved radar shadow, layover, multi-path effects and image misregistration, and finally the signal-to–noise ratio (SNR) [9]. This demonstrated with RADARSAT-1 SAR fine mode using integration between DInSAR [2] and fuzzy B-spline algorithm Maged and Mazlan [4]. Three hypotheses examined are: (i) fuzzy B-spline which is based on triangle-based criteria and edge-based criteria can be used as filtering technique to reduce noise before phase unwrapping. (ii) 3D topography reconstruction can be produced using satisfactory phase unwrapping (iii) high accuracy of deformation rate can be estimated by using the new technique.

2. DInSAR-Fuzzy B-spline Procedures

The procedures of involving fuzzy B-spline in DInSAR are shown in Fig. 1. Following, Luo et al.[2] if the surface displacement is as a result of single or cumulative surface movement occurred between the acquisition times of three RADARSAT-1 SAR images S_1 , S_2 and S_3 , the component of surface displacement in the radar-look

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direction, ζ , contributes to additional interferometric phase as

$$\phi = \frac{4\pi}{\lambda}((R_1 - R_2) + \zeta) = -\frac{4\pi}{\lambda}((R_1 - R_3) + \zeta) + \frac{4\pi}{\lambda}\Delta r \qquad (1)$$

where R_1, R_2 and R_3 are slant range from satellite to target respectively at different time, λ is the RADARSAT-1 SAR fine mode wavelength which is about 5.6 cm for C_{HH}- band. Finally Δr is the projection of displacement P_1P_2 on look of sight (LOS) $S_1 \rightarrow P_1$.

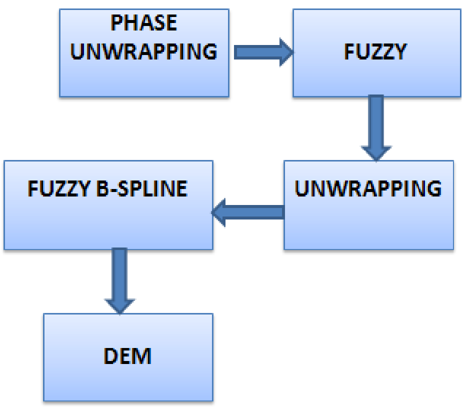

Fig. 1. **Fuzzy B-spline block diagram for 3D Coastal geomorphology reconstruction by DInSAR**

The phase difference, ϕ_d, only from the surface displacement as

$$\phi_d = \phi - \frac{\Delta R}{\Delta R'}\phi' = \frac{4\pi}{\lambda}\zeta . \qquad (2)$$

There are various decorrelation factors can be effected the phase unwrapping such as geometrical, thermal, temporal, and Doppler Centroid. These factors are contributed to reduce the signal-to-ratio (SNR). In fact, the phase unwrapping could be due to low SNR [10]. In this context, noise filtering is essential stage prior to phase unwrapping. In such tropical zone as Malaysia which is dominated by heavy vegetation covers which are the main source for deccorelation problem during InSAR or DInSAR procedures. This decorrelation could be effected of amplitudes of the complex master and slave images. Furthermore, Unreliability of the wrapped phases could be raised up due to decorrelation. Following, Yang et al., [9], the degree of coherence $\gamma(j,k)$ can be defined based on the basic rule of fuzzy theory as

$$\gamma(j,k) = \begin{cases} \frac{\sum s_M(j,k)s_s(j,k)}{\sqrt{\sum |s_M(j,k)|^2 \sum |s_s(j,k)|^2}} \frac{\min(|s_M(j,k)|,|s_s(j,k)|)}{0.5} - 10^{-5} & if\ 10^{-5} < \min(|s_M(j,k)|,|s_s(j,k)|) \leq 0.5 \\ \frac{\sum s_M(j,k)s_s(j,k)}{\sqrt{\sum |s_M(j,k)|^2 \sum |s_s(j,k)|^2}} & if\ \min(|s_M(j,k)|,|s_s(j,k)|) < 0.5 \\ 0 & if\ \min(|s_M(j,k)|,|s_s(j,k)|) \leq 10^{-5} \end{cases} \qquad (3)$$

where, s_M , s_s are the master and slave complex amplitudes, respectively. The numerical values 10^{-5} and 0.5 are threshold values used in this study. According to Yang et al. [9], the weighted square error is defined as:

$$w_e(j,k) = \sum_{y=-1}^{I} \sum_{x=-1}^{I} \gamma(j+y,k+x) \left| a_I(j,k)x + b_I(j,k)y + c_I(j,k) - s_I(j+y,k+x) \right|^2 \qquad (4)$$

where s_I and *I=(s,M)* are donated both pixels location at *j,k* in slave and Master images while *y,x* donated the relative coordinates of adjacent pixel from *j,k* and $x, y \in \{-1,0,1\}$. Finally, $a_I(j,k), b_I(j,k)$ and $c_I(j,k)$ are the complex coefficient. Equation 2 can be written based on weight error as

$$\phi' = \phi_d + (1-(2s+1)^2 - 1)\frac{\sum_{y=-s}^{s}\sum_{x=-s}^{s}(\phi_d(j+y,k+x) - \phi_d'(j+y,k+x) - \bar{v}(j,k))^2}{\mathrm{var}(\phi_d + v)}(\phi_D)) \qquad (5)$$

where *2s+1* is window size which is taken here as 3 x 3, v is the additive noise, ϕ_D is sum of difference phase ϕ_d and *–v*. Then, fuzzy B-spline 3D surface topography reconstruction was introduced by Maged and Mazlan [4], and modified to involve phase difference and correlation coefficient of master and slave complex amplitude patches is given by

$$S(p,q) = \frac{\sum_{i=0}^{M}\sum_{j=0}^{O} \phi' C_{ij}\beta_{i,4}(p)\beta_{j,4}(q)\gamma(j,k)}{\sum_{m=0}^{M}\sum_{l=0}^{O} \beta_{m,4}(p)\beta_{l,4}(q)\gamma(j,k)} = \sum_{i=0}^{M}\sum_{j=0}^{O} \phi' C_{ij}S_{ij}(p,q) \qquad (6)$$

$\beta_{i,4}(p)$ and $\beta_{j,4}(q)$ are two basis B-spline functions, and $\{C_{ij}S_{ij}\}$ are the bidirectional control net. The curve points *S(p,q)* are affected by $\{w_e(j,k)\}$ in case of $p \in [r_i, r_{i+P+1}]$ and $q \in [r_j, r_{j+P'+1}]$, where *P* and *P'* are the degree of the two B-spline basis functions constituted the B-spline surface. Two sets of knot vectors are *knot p*=[0,0,0,0,1,2,3,……,*O,O,O,O*], and *knot*

q=[0,0,0,0,1,2,3,….,M,M,M,M]. Fourth order B-spline basis are used $\beta_{j,4}(.)$ to ensure continuity of the tangents and curvatures on the whole surface topology including at the patches boundaries. According to Tsay and Chen [8], the quality of determine DEM is function of the accuracy of GCPs which collected using GPS during the RADARSAT-1 SAR pass over on 1999 and 2004 along the coastline of Kuala Terengganu. Finally, height map is created and statistically compared with ground field data to acquire precisely coastal geomorphology 's DEM.

3. Result and Discussion

The coherence image of topographic pair along the Kuala Terengganu mouth river is shown in Fig. 2. Clearly, the coherence values are ranged between 0.0 and 1.0 where 0.0 value is represented incoherence while 1 is represented perfect coherence. Fig. 2, however, shows the high coherence value of 0.8 which is corresponded to urban and sandy areas while low coherence value is corresponds to vegetation zone due to the impact of decorrelation in tropical zone such as Malaysia. Indeed, baseline decorrelation is major contribution of noise as well as the changes in atmospheric conditions in which is causing difficulties in phase reconstruction [10]. Therefore, decorrelation could attribute for low accuracy of digital elevation model [9].

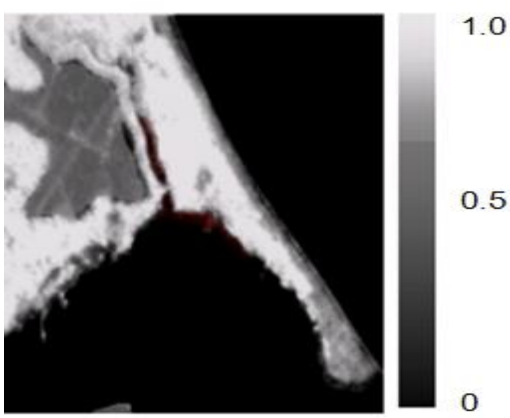

Fig. 2. Coherence image

Fig. 3 shows interferograms of two pairs. It is obvious that there is a great deformations which are occurred in pairs of 1999 and 2004 data (Fig. 3). The topographic phase of Fig.3 is modulated into deformation of the pair interferomateric phase. This is clearly obvious along the coastline (Fig. 3). This can be used to explain the changes have been occurred along the coastal geomorphology which can clearly notice in the spit area. Further, it can be noticed that the new method preserves detailed edges with discernible fringes. Indeed, Fig 3. Shows smooth interferogram, in terms of spatial resolution maintenance, and noise reduction, as compared to traditional conventional methods [2,5,8,10].

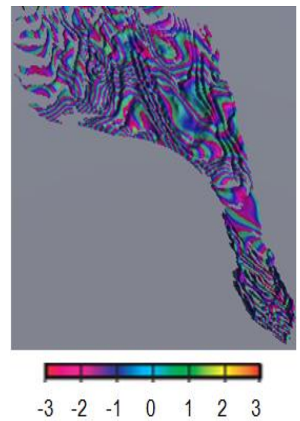

Fig. 3. Interferogram of deformation pairs December 1999 and March 2004.

The 3D fringes are indicating that the actual pattern of deformation along the coastline specially in the spit area (Fig. 4). It is interesting to find that the coastal geomorphology patterns are exposed to tremendous changes since 1999 to 2004. The rate change of spit is 2.4 m/yr with maximum elevation height of 2.4 m (Fig. 5).

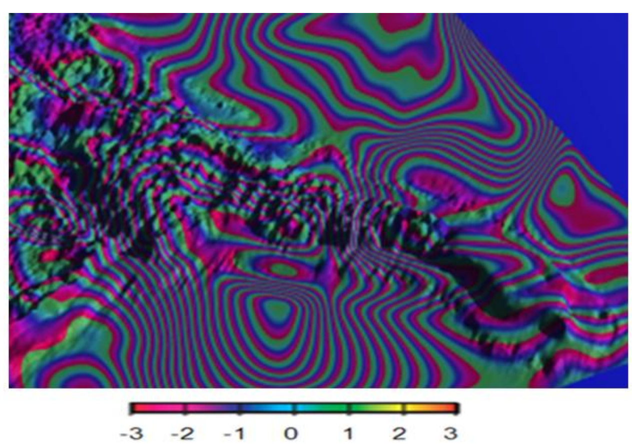

Fig. 4. 3D Fringes of deformation phase Produced from fuzzy B-splines.

Clearly, Fuzzy B-splines method has maintained the fringe information and denoise the inteferogram. Further, the new technique provides fringe pattern with variety properties such as dense and non-dense fringes

(Figs.4 and 5). In fact, fuzzy B-splines smooth the fringe pattern due to the reduction of temporal decorrelation which is caused by dynamical coastal sedimentation and atmospheric conditions.

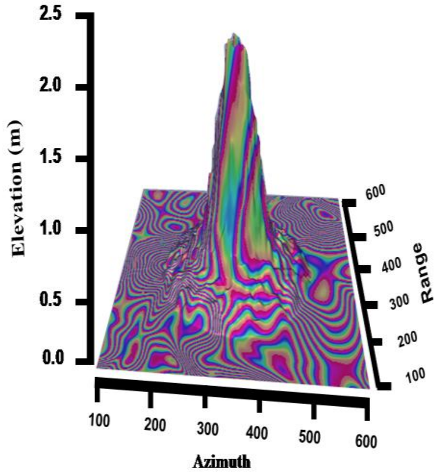

Fig. 5: 3D spit rate change by using fuzzy B-spline algorithm.

Table 1 shows a good agreement between DInSAR s' DEM and ground data with r^2 of 0.86, *p* of 0.002 and rate of RMSE is ± 0.1 m. It is clear that rate of slope change is 1.5 m which considers as steep slope. It might be sand mining activities have induced steep slope of spit (Fig. 6).

Table 1: Significant Relationship between Ground Data and Fuzzy B-spline Interferomatery

Statistical Parameters	Values
r^2	0.86
P	0.002
RMSE	± 0.1 m

In addition, the increasing growth of spit across the estuary thus could be due to impact of littoral sedimentation drift. According to Maged [3,] the net littoral drift along Kuala Terengganu coastal water is towards the southward which could induce growth of spit length. The high accuracy DInSAR s' DEM could be due to feed of fuzzy B-spline into unwrapped phase. In fact, integration between Fuzzy B-spline and DInSAR method has completely maintained the gradients on spit edges [1]. Furthermore, fuzzy B-spline increased the rate of unwrapped phase accuracy. Indeed, fuzzy B-spline algorithm is able to keep track of uncertainty and provide tool for representing spatially clustered phase points [6].

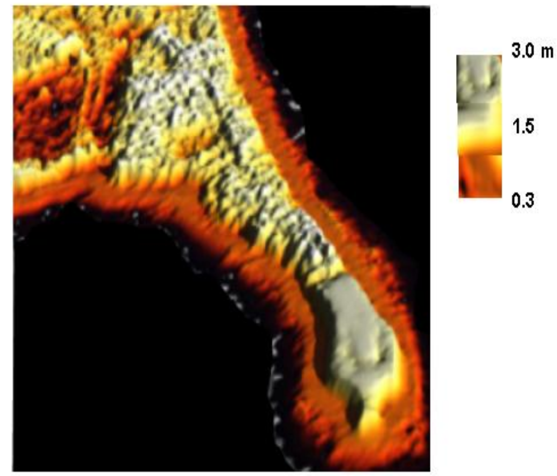

Fig. 6. Coastal geomorphology reconstruction from fuzzy B-spline DInSAR

4 Conclusions

This work has demonstrated a new technique for 3D reconstruction by implementing fuzzy B-spline within DInSAR technique. In doing so, historical pairs of RADARSAT-1 SAR fine mode data were used. The results shows that fuzzy B-spline preserves detailed edges with discernible fringes. Further, the new approach can produce accurate 3D reconstruction from satellite radar data such as RADARSAT-1 SAR fine mode. It can be concluded that that the integration between fuzzy B-spline and unwrapped phase inteferogram can produce highly accurate 3D reconstruction of coastal geomorphology features within accuracy rate of ± 0.1 m

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