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Full Length Research Paper

Three-dimensional visualisation of coastal geomorphology using fuzzy B-spline of dinsar technique

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This paper introduces a new approach for mapping coastal geomorphology by using differential synthetic aperture radar interferometry (DInSAR). Fuzzy B-spline is used to accelerate and improve the accuracy of 3-D map from DInSAR. The DInSAR algorithm is involved two parts: 3-D map simulation and interferogram simulation with discrete element method (DEM) and satellite orbit parameters. 3-D coastal geomorphology reconstruction is realised by the fuzzy B-spline algorithm with the midpoint displacement method and the terrain roughness, and average slope are determined by two describing parameters of the model. Furthermore, fuzzy B-spline was used to eliminate topographic phase from the interferograms. Three RADARSAT-1 data sets of fine beam mode (F1) had been obtained between November 1999 and March 2004. The study shows incomplete fringe interferometry pattern because of decorrelation. Furthermore, fuzzy B-spline of DInSAR performs higher overall accuracy of 95% compared to DInSAR technique and ground data. Finally, prefect fringe pattern is clearly produced in ocean water body that refers to ocean water InSAR or liqui-InSAR. In conclusion, fuzzy B-spline of DInSAR provide accurate map of 3-D coastal geomorphology construction from historical RADARSAT-1 SAR fine mode data and can be also tool for liqui-InSAR.

Key words: RADARSAT-1 SAR, differential synthetic aperture radar interferometry (DInSAR), fuzzy B-spline, 3-D, coastal geomorphology.

INTRODUCTION

Coastal geomorphology is considered to provide the key parameter for coastal engineering. The coastal geomorphology information is valuable for economic activities, for security and for marine environmental protection. Electronic theodolite is the classical system to map digital elevation of coastal geomorphology. Although, this conventional technique can provide high precision results, it is very costly and time consuming especially when the large area being surveyed. Synthetic aperture radar (SAR) interferometry is a relatively new technique for 3-D topography mapping (Massonet and Rabaute, 1993; Zebker et al., 1994; Tsay and Chen, 2003). In this context, It could be a major tool for 3-D coastal geomorphology reconstruction in real time. Furthermore, it could produce synoptic data over large areas at comparatively low cost. The coastal geomorphology features, etc., spit, dunes and beach profile can be reconstructed by SAR interferometry. Differential synthetic aperture radar interferometry (DInSAR) is new tool which is derived from SAR interferometry. Scientists and researchers have defined InSAR as a technique that utilises interference of waves for precise determination of distance (Massonet and Rabaute, 1993; Nizalapur et al., 2011). In SAR interferometry, path length differences with millimetre accuracy's 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 (Luo et al., 2006). According to Zekber et

Abbreviations: ESRIN, European Space Research Institute; **SNR,** signal-to-noise ratio; **TPDI,** three passes differential interferometry; **DInSAR,** differential synthetic aperture radar; SAR, synthetic aperture radar.

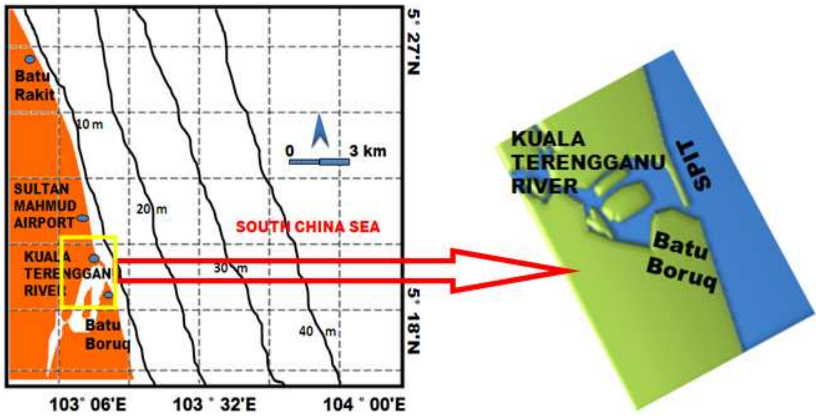

Figure 1. Location of spit along Kuala Terengganu river mouth.

al. (1992), 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. (2006) have introduced a technique which is based on utilization of the three passes differential interferometry (TPDI) to measure topography displacement. Luo et al. (2006) reported that the displacement will be resulted in component called deformation phase in interferomateric phase, if the topography surface deformed at interval of SAR repeat pass.

In this paper, we address the question of utilisation fuzzy-B-spline in 3-D topography reconstruction before phase unwrapping. In fact, there are several factors that could impact the accuracy of discrete element method (DEM) that was derived from phase unwrapping. These factors are involved radar shadow, layover, multi-path effects and image misre-gistration and finally the signal-to-noise ratio (SNR) (Yang et al., 2007). This demonstrated with RADARSAT-1 the SAR fine mode using integration between DInSAR (Luo et al., 2006) and the fuzzy B-spline algorithm (Marghany and Mazlan, 2009). The main contribution of this study is to implement fuzzy B-spline with DInSAR technique. Three hypotheses examined are: (i) Fuzzy B-spline which is based on triangle-based criteria and edge- based criteria which can be used as filtering technique to reduce noise before phase unwrapping; (ii) 3-D topography reconstruction can be produced using satisfactory phase unwrapping by involving the fuzzy B-spline algorithm; and (iii) high accuracy of deformation rate can be estimated by using the new technique.

METHODOLOGY

Study area

The study area is selected along the mouth river of Kuala Terengganu, Malaysia. According to Marghany (1999, 2000) and Marghany et al., (2001a), the coastline appears to be linear and oriented at about 45° along the east coast of Malay sia (Stanely 1985). In addition, spit was located across the largest hydrological communications between the estuary and the South China Sea that is the mouth river of Kuala Terengganu (Figure 1) which lies on the equatorial region, and is affected by monsoon winds (Marghany and Mazlan, 2010). Indeed, during the northeast monsoon period, the strong storm and wave height of 4 m can cause erosion (Marghany, 2001b). The 20 km stretches of coastal along the Kuala Terengganu shoreline composed of sandy beach, the somewhat most frequently eroded region. The significant source of sediment is from the Terengganu River which loses to the continental shelf due to the complex movements of waves approached from the north direction (Marghany, 2001c; Marghany et al., 2002).

Differential synthetic aperture radar (DInSAR)-Fuzzy B-spline Procedures RADARSAT-1 SAR data sets of 23 November 1999 (SLC-1), 23 December 2003 (SLC-2) and March 26, 2005, (SLC-3) of fine mode data (F1) are used. The fine mode RADARSAT-1 SAR data are assembled as interferometric pairs. The master image was one acquired on November 23 1999, while the other pair of images was assigned as slave for respective interferomatric pair.

Marghany and Mazlan (2009) introduce a method to construct 3-D object visualisation from unwrapping phase as follow:

$$S(p,q)=\frac{\sum_{i=0}^{M}\sum_{j=0}^{O}\phi_d C_{ij}\beta_{i,4}(p)\beta_{j,4}(q)w_{i,j}}{\sum_{m=0}^{M}\sum_{l=0}^{O}\beta_{m,4}(p)\beta_{l,4}(q)w_{ml}}=\sum_{i=0}^{M}\sum_{j=0}^{O}\phi_d C_{ij}S_{ij}(p,q) \quad (1)$$

where $\beta_{i,4}(p)$ and $\beta_{j,4}(q)$ are two bases of B-spline functions, $\{C_{ij}\}$ is the bidirectionally control net and $\{w_{ij}\}$ is the weighted correlation coefficient which was estimated based on Mordeson and Nair (2001) as:

$$w_{ij}=\frac{\left|\frac{\sum S_M(i,j)S_s(i,j)}{\sqrt{\sum|S_M(i,j)|^2\sum|S_s(i,j)|^2}}\right| x\min(|S_M(i,j)|,|S_s(i,j)|)-t_1}{t_2-t_1} \quad (2)$$

where $|S_M(i,j)|$ and $S_s(i,j)$ are master and slave complex

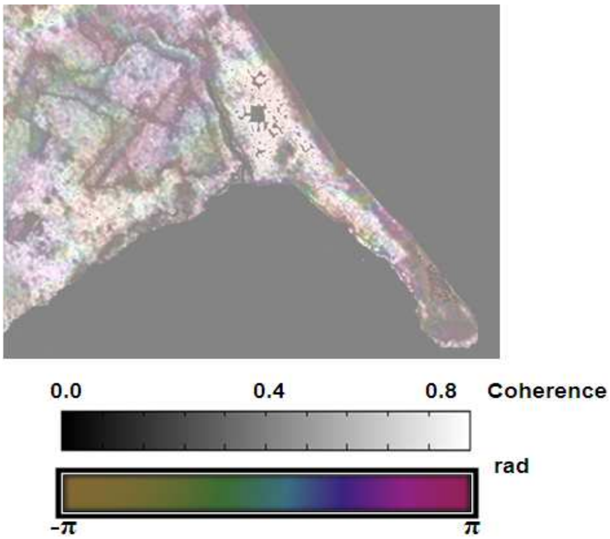

Figure 2. Combination between coherence and phase of the interferogram produced from the RADARSAT-1 SAR F1 mode tandem pair of December 23 1999 and March 26 2004.

data while t_1 and t_2 are thresholds. The curve points *S(p,q)* are affected by $\{w_{ij}\}$ 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, the order B-spline basis is used $\beta_{j,4}(.)$ to ensure the continuity of the tangents and curvatures on the whole surface topology including at the patches' boundaries.

Following Luo et al. (2006), 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 direction, φ, contributes to additional interferometric phase as:

$$\phi = \frac{4\pi}{\lambda}((R_1 - R_2) + \zeta) = -\frac{4\pi}{\lambda}((R_1 - R_3) + \zeta) + \frac{4\pi}{\lambda}\Delta r \qquad (3)$$

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 the 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) $S_1 \rightarrow P_1$.

The surface displacement is given by:

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

The global positioning system (GPS) data collected within 20 sample points scattered along 400 m coastline during the RADARSAT-1 SAR pass over on March 26 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.

RESULTS AND DISCUSSION

Figure 2 shows the combination between coherence and the phase of the interferogram produced from the RADARSAT-1 SAR F1 mode tandem pair of December 23 2003, and March 26 2005. It in interest to find the interferogram fringes are corresponding with the high coherence area of 1 for example urban and sandy areas. In contrast, vegetation area and water zone of value less than 0.2 are coincided with absent of interferogram fringe absents. This occurs because of decorrelation. In fact, the baseline decorrelation and temporal decorrelation make InSAR measurements unfeasible. In this context, Gens (2000) reported the length of the baseline designates the sensitivity to height changes and sum of baseline decorrelation. Furthermore, Nizalapur et al. (2011) stated the time difference for two data acquisitions is a second source of decorrelation. Indeed, the time difference while comparing data sets with a similar baseline length acquired one and 35 days a part suggest only the temporal component of the decorrelation. Therefore, the losses of coherence in the same repeat cycle in data acquisition are most likely because of baseline decorrelation.

The topographic phase of Figure 3 was modulated into deformation of the interferomateric phase of 3 November 1999, 23 December 2003 and March 26, 2005 to investigate deformation of coastline geomorphology. This can be seen along the spit. The 3-D fringes are indicating the actual pattern of deformation along the coastline specially the spit area (Figure 3).

It is interesting to find that the coastal geomorphology patterns have been exposed to tremendous changes since 1999 to 2004 (Figure 3). In addition, fuzzy B-spline is able to produce fringe pattern in coastal water. It may be these fringe patterns represent the direction of wave, current and wave-current interaction. It is interesting to find that fuzzy B-spline can produce solid interferomatery and ocean dynamic interferometry. In addition, Parviz (2011) proposed new method name by Liqui-InSAR on aquatic bodies in different locations all around the globe "the project C1P.8242" under the ESA affiliated European Space Research Institute (ESRIN). Furthermore, Parviz (2011) can generate fringe patterns on the water bodies with the temporal baseline of maximum 16 seconds. Nevertheless, fuzzy B-spline generates DInSAR fringe patterns with a long temporal baseline. Moreover, the continue fringe pattern from the land ocean show that the wide fringe patterns occurred on water body. This could due to coastal hydrodynamic interaction between coastline, water flow from the mouth river and ocean motion

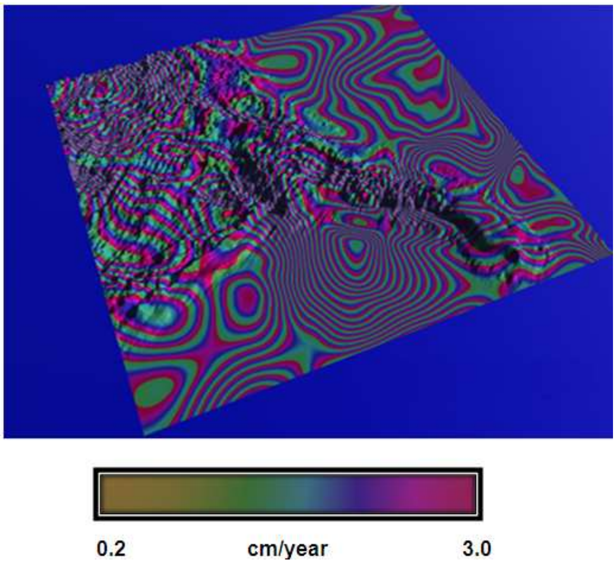

Figure 3. 3-D Fringes of deformation phase produced from fuzzy B-spline of DInSAR.

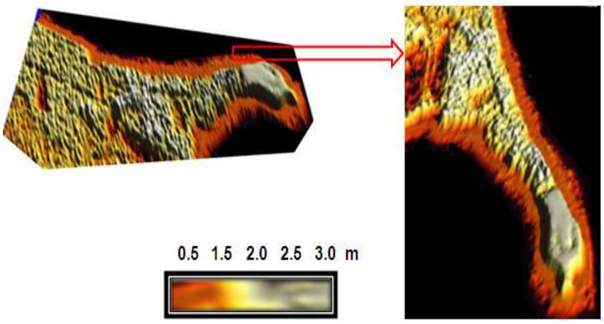

Figure 4. 3-D reconstruction of Spit using fuzzy B-spline algorithm of DInSAR.

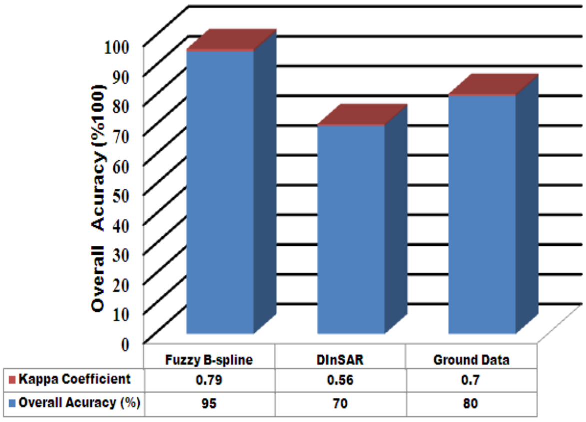

Figure 5. Overall accuracy for fuzzy B-spline of DInSAR, DInSAR technique and ground data.

The rate change of spit is 3 m/year with maximum elevation height of 2.4 m (Figure 4). Clearly, Terengganu's spit was generated due to the deposition of sediment due to hydrodynamic changes between estuary and ocean. According to Marghany (2000), Terengganu's mouth river is the largest hydrologic communication between an estuary and the South China Sea. This spit occurred when longshore drift reaches a section of Terengganu's River where the turn is greater than 30°. It continued out therefore, into the sea until water pressure from a Terengganu's River becomes too much to allow the sand to deposit. The spit be then grown upon and become stable and often fertile. As spit grows, the water behind them is sheltered from wind and waves. This could be due the high sediment transport through the water outflow from the river mouth, or northerly net sediment transport due to northeast monsoon wave effects (Marghany, 2001a). Longshore drift (also called littoral drift) occurs due to waves meeting the beach at an oblique angle, and back washing perpendicular to the shore, moving sediment down the beach in a zigzag pattern. Longshore drifting is complemented by longshore currents, which transport sediment through the water alongside the beach. These currents are set in motion by the same oblique angle of entering waves that cause littoral drift and transport sediment in a similar process. The hydrodynamic interaction between the longshore current and water inflow from the Terengganu Mouth River is causing the changes in spit's geomorphology characteristics. This finding confirms the study of Marghany et al. (2009) and Marghany and Mazlan (2009) and Marghany et al. (2010). The increasing growth of spit across the estuary is due to impact of sedimentation due to littoral drift. According to Marghany (2001), net littoral drift along Kuala Terengganu coastal water is towards the southward which could induce the growth of spit length.

Figure 5 shows that fuzzy B-spline of DInSAR has higher accuracy of 95% compared to DInSAR technique and ground data. On contrary, DInSAR technique performs lower accuracy of 70% because of the impact of decorrelation. This result confirms the study of Gens (2000) and Marghany and Mazlan (2009). The high accuracy DInSARs' DEM could be due to feed of fuzzy B-spline into unwrapped phase. Thus integration between fuzzy B-spline and the DInSAR method has completely maintained the gradients on spit edges (Fuchs et al., 1997). Furthermore, fuzzy B-spline increased the rate of unwrapped phase accuracy. Indeed, the fuzzy B-spline algorithm is able to keep track of uncertainty and provide tool for spatially representing clustered phase points (Russo, 1998).

In general, fuzzy B-spline is able to remove the errors of phase unwrapping because of decorrelation's impacts Indeed, the fuzzy B-spline algorithm provides an interval for possible accurate phase unwrapping. In addition, fuzzy B-spline of DInSAR improves the accuracy and provides easier way to reconstruct 3-D object without uncertainty. This agrees with Gallo et al. (1998) and Marghany et al. (2010).

Conclusions

This study has demonstrated a new method to reconstruct 3-D coastal geomorphology deformation by DInSAR technique. Fuzzy B-spline algorithm was implementted within a phase difference and the correlation coefficient of master and slave complex amplitude patches to map coastline deformation. Historical RADARSAT-1 SAR fine mode data were used. The results have been confirmed that the representing phase difference and the correlation coefficient of master and slave complex amplitude patches by fuzzy B-spline is producing excellent accuracy. Maximum height of spit is 2.4 m and rate change of 3 m/year within overall accuracy of 95%.

This study also shows that fuzzy B-spline of DInSAR produces ocean fringe patterns that could represent ocean dynamic motion and its interaction with coastline features. This study also shows the increasing length of spit across the Terengganu estuary within 2 m. It can be concluded that the integration between fuzzy B-spline and unwrapped phase inteferogram can produce highly accurately 3-D reconstruction of coastal geomorphology features.

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