FOUR-DIMENSIONAL OF EARTHQUAKE DISPLACEMENT FROM SENTINEL-1A SATELLITE USING HOLOGRAPHIC INTERFEROMETRY

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ABSTRACT: Holographic interferometry is new subject matter for dealing with synthetic aperture radar interferometry (InSAR) issues. In addition to four-dimensional reconstruction from artificial aperture radar interferometry. This study utilizes 4-D phase unwrapping for holographic interferometry method to retrieve earthquake displacement due to Nepal earthquake, 2015. In doing so, the hybrid genetic algorithm is implemented to optimize 4-D phase unwrapping algorithm primarily based on fourth-dimensional best-path avoiding singularity loops (4DBPASL) algorithm. The algorithm modification from 3-D to 4-D has implemented prior to hybrid genetic algorithm. The study suggests 4DBPASL can existing the holographic interferometry from 3-D to 4-D. The learn about also shows that the integration between holographic interferometry and 4DBPASL competent to reconstruct 2-D earthquake displacement into 4-D. In conclusion, 4DBPASL algorithm can be used to produce accurate 4-D quake deformation usingSentinel-1A satellite.

1. INTRODUCTION

Presently, the elevation fashions that are on hand for large components of Earth are of low resolution, inconsistent or incomplete. Scientists addressed temporal, geometric and atmospheric decorrelations are most quintessential boundaries (Pepe 2012; Marghany 2012; Marghany 2014a). Consistent with Zebker et al., (1997), rapid temporal baseline, high-quality spatial baseline, respectable climate events and ascending and descending SAR files are consistent standards to restrain decorrelation and noise to produce a dependable DEM. ERS-1 and ERS-2, Terara X-SAR in tandem mode are the wonderful instance of short temporal resolution.

In extensive range of contexts, TanDEM-X and TerraSAR-X are imaging the terrain beneath them simultaneously, from exclusive angles Marghany (2014b). These images are processed into particular elevation maps with a 12 m resolution and any vertical accuracy better than 2 m. Image coregistration, InSAR an interferometric section estimation (or noise filtering) and interferometric phase unwrapping (Zebker et al., 1997; Hussien 2005; Marghany 2012) are three keys processing processes of InSAR. It is properly regarded that the overall performance of interferometric phase estimation suffers severely from poor picturecoregistration. Interferogram filtering algorithms such as adaptive contoured window, pivoting imply filtering, pivoting median filtering, and adaptive phase noise filtering are the main techniques for the traditional InSAR interferometric phase estimation (Pepe 2012). Recently, Pepe (2012) referred to that DInSAR has recently utilized with success to look at the temporal evolution of the detected deformation phenomena thru the technology of displacement time-series. In this context, two most important classes of advanced DInSAR methods for deformation time-series era have been proposed in literature, often referred to as Persistent Scatterers (PS); and small Baseline (SB) techniques, respectively. The PS algorithms pick out all the interferometric data pairs with reference to a single frequent master image, barring any constraint on the temporal and spatial separation (baseline) amongst the orbits (Hai and Renbiao (2012). Further, Marghany (2003) and Marghany (2011) introduced holographic interferometry techniques for modelling shoreline changes from SAR data.

But, the two-dimensional unwrapping methods may want to introduce discontinuous areas when the noise is high. The resulting inconsistent baselines within a slice might produce an incorrectly unwrapped baseline. Then the only-dimensional baseline unwrapping may want to deliver wrong consequences. A few of the techniques practice to fine map to manual the unwrapping methods. The first-class map turned into defined with the first-class of the edges that connects two neighboring voxels and unwrap the most dependable voxels first (Marghany 2013). Consequently, 3-dimensional segment unwrapping technique, which considers the temporal domain and the spatial domain restrictions concurrently (Marghany 2014a).

The fourth Dimension are dissected with the aid of scientists, psychologists, mathematicians and physicists ,later the 1800s. Indeed, scientists have utilized 4-D principles to explicate roughly of the universe. At early stage, scientists created 4-D from 3-D with the aid of spinning 3-D about its image or itself. Scientists therefore, have deliberated the time as a dimension beside the 3-D. Nevertheless, this concept scientifically is no longer precise. The fourth Dimension axis which goes by using the *Z*,*Y* and *Z*. The 4-D object has 4 quintessential unite: width, length heights and 4-D which is W. A hypercube, for instance, has a length, width, top and a fourth dimension that is perpendicular to all three of the different units. Consequently, 4-D is exploring the internal objects of 3-D. In remote sensing satellite-based interferometric synthetic aperture radar (InSAR) is a manageable device for unique measurements of 3-D ground shifts caused off by earthquakes or landslides.

The principle contribution of this study is to combine Hybrid Genetic set of regulations (HGA) with 4-D area unwrapping set of regulations of 4-D high-quality-direction heading off singularity loops (4-DBPASL) algorithm with InSAR approach. Hypotheses examined are: (i) the HGA algorithm may additionally be used as filtering method to minimize noise inside the 4-D phase unwrapping; and (ii) 4-D Nepal earthquake displacement can be reconstructed the use of remarkable phase unwrapping of 4DBPASL with the aid of way of involving HGA optimization algorithm.

2. FOURTH-DIMENSIONAL USING HOLOGRAPHIC INTERFEROMETRY

The 4-D unwrapping is built through the use of the temporal phase unwrapping method with pace of ground movement which is encoding rather than time as the unwrapping course. This method uses 4 dimensions: x, y, t and V. Every voxel (x, y, t) is unwrapped independently of the relaxation of the voxels using the speed encoding measurement. Following Karout (2007), the HGA set of rules is based on estimating the parameters of an nth order-polynomial to approximate the unwrapped floor solution from the wrapped segment statistics. The coefficients of the polynomial that fine unwrap the wrapped phase map are received with the aid of initial solution of GA algorithm to avoid long term to converge to the global optimal answer. In this context, GA minimizes minimum 4-DBPASL and errors between the gradient of the polynomial unwrapped surface answer and the gradient of the authentic wrapped segment map. On other words, extra precision and lower minimum 3DBPASL and errors are done by means of increasing the order of the polynomial. This proposed set of rules is specially applicable to adjoining segment distributions (albeit with gaps). Any optimization trouble using a GA calls for the problem to be coded into GA syntax shape, that's the chromosome form. On this trouble, the chromosome consists of a number of genes in which every gene correspond to a coefficient within the nth-order surface fitting polynomial as described into equation 1

$$f := n \to \sum_{V}^{n} \sum_{k=0}^{n} \sum_{j=0}^{n} \sum_{i=0}^{n} a_{i,j,k} \hat{\phi}_0^{i} \hat{\phi}_0^{j} \hat{\phi}_0^{k} \hat{\phi}_0^{V} \qquad (1)$$

where $a[0....n]$ are the parameter coefficients which are retrieved by the genetic algorithm to approximated the unwrapped phase that can achieve the minimum 4DBPASL and $Q_{i,j,k,V}$ errors. Further, *i*,*j*, *kand V* are indices of the pixel location in the unwrapped phase respectively, *n* is the number of coefficients (Hussien et al., 2005 and Marghany 2014c).

The initial population is generated by creating an initial solution using one of the Quality guided phase unwrapping algorithm (BPASL algorithm) (Hussien et al., 2005). Following Karout (2007), the initial solution is approximated using a 'polynomial Surface-fitting weighted least-square multiple regression' method. The initial population is then generated based on the initial solution. In doing so, every a_g in each chromosome in the population, a small number relying on the accuracy of the gene that is added or subtracted to the value of the gene as given by,

$$a_g = a_g + (\pm 1)\{10^{[\log(a_g)+\Re]}\} \qquad (2)$$

where a_g is the coefficient parameter stored in gene *g*, and $\Re$ is a random number generated between the values.

Following De la Torre et al., (2010), 4-D holographic interferometry can be given by

$$FFT\{I_N\} = \sum_{N=1}^{4} [A_N(f_x + f_y + f_z) + B_N(f - f_{Nx}, f - f_{Ny}, f - f_{Nz}) + B_N^{*}(f - f_{Nx}, f - f_{Ny}, f - f_{Nz})] \qquad (3.0)$$

where N represents fourth -dimensional are used, A_N is the incoherent in 4-D holographic interferometry. B_N and B_N^* are lobes for each illumination wavelength in SAR satellite data. The relative optical phase difference can be associated to a physical displacement through the sensitivity vector found in the hologram interferometry in two satellite data which can be expressed in 4-D as (Marghany and Mansor 2016a and 2016b),

$$\begin{pmatrix} \Delta\Phi_1 \\ \Delta\Phi_2 \\ \Delta\Phi_3 \\ \Delta\Phi_4 \end{pmatrix} = \frac{2\pi}{\lambda} \begin{pmatrix} \vec{d}_{1i} & \vec{d}_{1j} & \vec{d}_{1k} & \vec{d}_{1p} \\ \vec{d}_{2i} & \vec{d}_{2j} & \vec{d}_{2k} & \vec{d}_{2p} \\ \vec{d}_{3i} & \vec{d}_{3j} & \vec{d}_{3k} & \vec{d}_{3p} \\ \vec{d}_{4i} & \vec{d}_{4j} & \vec{d}_{4k} & \vec{d}_{4p} \end{pmatrix} \begin{pmatrix} U \\ V \\ W \\ O \end{pmatrix} \quad (4.0)$$

where d is the displacement in along orthogonal components of $U,V,W,O,$ in $i,j,k,$ and p , respectively. Phase unwrapping in Equation 4 can be extended to fourth-dimensional by given equation,

$$\sum_{i,j,k,p} W^{x}_{i,j,k,p} \left|\Delta\phi^{x}_{i,j,k,p} - \Delta\psi^{x}_{i,j,k,p}\right|^{L} + \sum_{i,j,k,p} W^{y}_{i,j,k,p} \left|\Delta\phi^{y}_{i,j,k,p} - \Delta\psi^{y}_{i,j,k,p}\right|^{L} \quad (5.0)$$
$$+ \sum_{i,j,k,p} W^{z}_{i,j,k,p} \left|\Delta\phi^{z}_{i,j,k,p} - \Delta\psi^{z}_{i,j,k,p}\right|^{L} + \sum_{i,j,k,p} W^{z}_{i,j,k,p} \left|\Delta\phi^{w}_{i,j,k,p} - \Delta\psi^{w}_{i,j,k,p}\right|^{L}$$

where $\Delta\phi$ and $\Delta\psi$ are the unwrapped and wrapped phase differences in x,y,z,w respectively, and W represents user-defined weights. The summations are carried out in both x ,y, z, and w directions over all i,j,k, and p respectively. L^L-norm which uses similar methods like the two previous least square methods to solve the phase unwrapping problem. However, this method does not compute the minimum L^2-norm but the general minimum L^L-norm. In essence, by computing the minimum L^L-norm where $p\neq 2$; this method can generate data dependent weight unlike the weighted least-square method. The data-dependent weights can eliminate iteratively the presence of the residues in the unwrapped solution.

2.2 Record Pareto Optimal Solutions

Calculate the objective values of chromosomes in the population and record the Pareto optimal solutions.

Definition: Pareto Optimal Solutions

Let $\phi_i, \phi_{i,j}, \phi_{i,j,k}, \phi_{i,j,k,p} \in F$, and F is a feasible region in 4-D coordinate . And ϕ_0 is called the Pareto optimal solution in the minimization problem of 4-D phase unwrapping if the following conditions are satisfied.

1. If $f(\phi_1)$ is said to be partially greater than $f(\phi_2)$, i.e $f_i(\phi_1) \geq f_i(\phi_2), \forall\ N = 1,2,\ldots,n$ and $f_i(\phi_1) > f_i(\phi_2), \exists N = 1,2,\ldots,n,$ (8.0)
   Then ϕ_1 is said to be dominated by ϕ_2 .
2. If there is no $\phi \in F$ s.t. ϕ dominates ϕ_0 , then ϕ_0 is the Pareto optimal solutions (Marghany 2015).

2.3 Fitness Evaluation

In this step, the quality of the solution is evaluted at every generation to determine the global optimum solution to the parameter estimation phase unwrapping problem. Therefore, the genes of a chosen chromosomes are substituted as coeficients in equation (8.0) to evaluate the approximated phase value at coordinate (i, j, k,p). Then,the obtained phase is subtracted from the contiguous pixel approximated phase value to reteieve the approximated unwrapped phase solution gradient. It is then subtracted from the gradient of the wrapped phase in the i, j, k and p direction Marghany and Mansor 2016a).

2.4 Crossover and Mutation

Following Haupt and Haupt (2004), the two point greedy continuous crossover are implemented in crossover operator. Therefore, crossover is less problem than the mutation operator. Thus, Mutation operator concerns deliberate changes to a gene at random, to keep variation in genes and to increase the probability of not falling into a local minimum solution. It involves exploring the search space for new better solutions. This proposed operator uses a greedy technique which ensures only the best fit chromosome is allowed to propagate to the next generation (Karout 2007).

2.5 Phase Matching

The accurate 4-D phase unwrapping can be obtained by phase matching algorithm proposed by Schwarz (20040. According to Schwarz (2004), phase matching algorithm is matched the phase of wrapped phase with unwrapped phase by the given equation

$$\psi_{i,j,k,p} = \Delta\phi_{i,j,k,p} + 2\pi\rho\left[\frac{1}{2\pi}\left(\Delta\hat{\phi}_{i,j,k,p} - \Delta\phi_{i,j,k,p}\right)\right] \quad (9.0)$$

where $\psi_{i,j,k,p}$ is the phase matched unwrapped phase, *i,j,*and *k* are the pixel positions in the quality phase map, $\Delta\phi_{i,j,k,p}$ is the given wrapped phase, $\Delta\hat{\phi}_{i,j,k,p}$ is the approximated unwrapped phase, $\rho[.]$ is a rounding function which is defined by $\rho[t] = \lfloor t + 1/2 \rfloor$ for $t \geq 0$ and $\rho[t] = \lfloor t - 1/2 \rfloor$ for $t < 0$ and are *i,j, k* and *p* the pixel positions in *x* and *y,z,w* directions, respectively.

3. RESULTS AND DISCUSSION

Gorkha earthquake is utmost horrible natural catastrophe to crash into Nepal for the reason that 1934 Nepal–Bihar earthquake. Gorkha earthquake used to be surpassed off on April 25, 2015 at eleven:56 NST and killed multiplied than 10,000 human beings and injured greater than 23,000 populace. Its epicenter flip out to be east of the district of Lamjung, and its hypocentre was as soon as with about intensity of 15 km with most magnitude two of 8.1 Mw. Consequently, within 15 to twenty minutes, aftershock flip out to be struck all through Nepal with an importance of 6.7 on 26 April at 12:54:08 NST. Hence, the epicenter of a predominant aftershock used to be as soon as shut to the Chinese border between the capital of Kathmandu and Mountain (Figure 1) of Everest with a 7.3 M_w (Rajghatta, 2015).

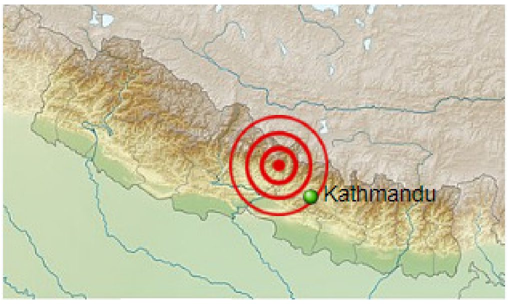

Figure 1. Epicenter of Nepal's earthquake.

Ravilious (2015) referred to that the modern quake follows the equal pattern as a duo of huge tremors that passed off over 700 years ago, and consequences from a domino effect of pressure transferring along the fault. The last time the fault ruptured at this vicinity used to be again in 1344. It used to be preceded in 1255 by means of a big tournament to the east of Kathmandu. The remaining rupture there was in 1934, hinting strain might accumulate westward. This ability that 2015's quake follows the pattern with a gap between events of eighty years or so. In this understanding, the essential frontal thrust, on common an exquisite earthquake takes place each and every750 ± 140 and 870 ± 350 years in the east Nepal area (Marghany 2015).

Figure 2 suggests the Sential-1A information were obtained pre-earthquake and post-earthquake on April 17 and 29 2015, respectively. The city zones and pinnacle of mountains are dominated with greater coherence of 0.8 and 1 respectively as compared to vegetation and water. On contrast, The water has lower backscatter and coherence of two -30 dB and 0.25, respectively (Figure 2b). As a matter of fact, Sential-1A beam mode of interferometric extensive swath has spatial decision of 5 x 20 m and swath width of 250 km with VV polarization.

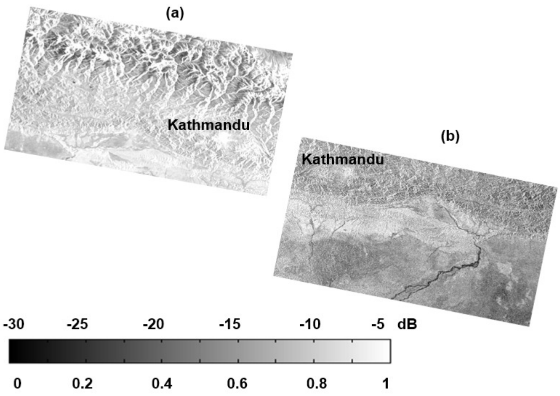

Figure 2. Sential-1 A satellite data (a) pre and (b) post earthquake.

Figure 3 shows the comparison between the interferogram fringes produced via using the mixture of 3DBPASL (Figure 3a and 4DBPASL (Figure 3b) algorithms respectively which are optimized by HGA algorithm. Clearly, the proposed algorithm for 4-D phase unwrapping produced bright fringe cycles which point out crucial floor motion of 8.5 cm which is coincided with floor motion of 1.4 m north of Kathmandu (Figure 3b). In fact, the 4DBPASL algorithm acquires most suitable unwrapping path, whereas it is also taking into account the impact of singularity loops. In addition, zero-weighted aspect is used zero-weighted edges to adjust the most advantageous course and keep away from these singularity loops. With this regard, 4-D 4DBPASL interferometry fringes produced through using Hybrid Genetic Algorithm. It is fascinating to locate that the proposed algorithm has produced clear fringe patterns. In fact, the proposed algorithm has minimized the error in interferogram cycle due decorrelation effects. This ought to be enchantment of such previous work of Hussein et al. (2005); Karout(2007);Marghany (2015).

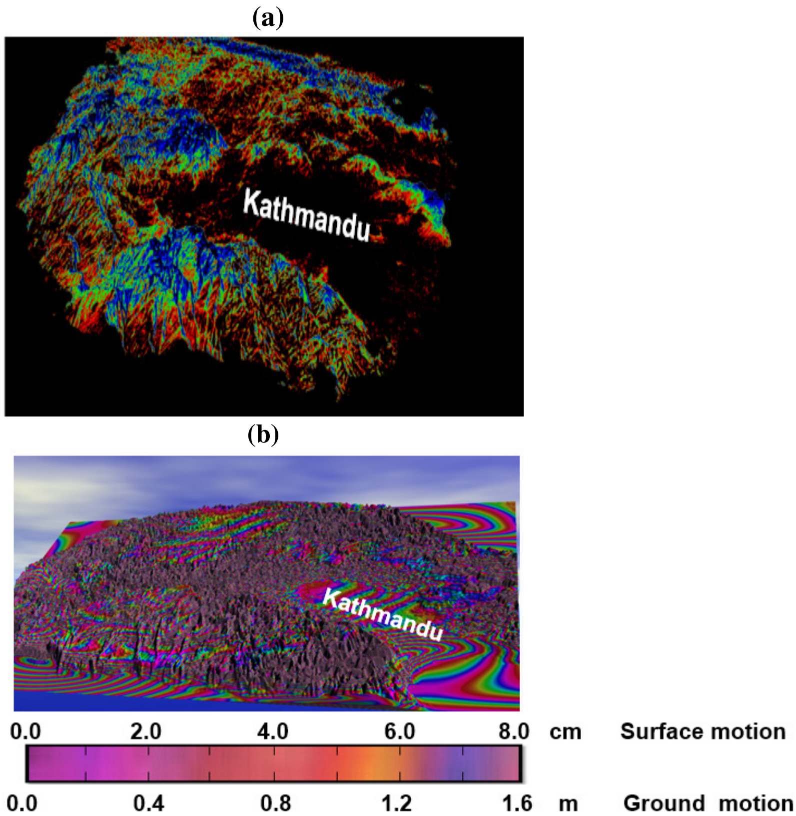

Figure 3. Interferometry produced by Hybrid Genetic Algorithm for (a) 3-DBPASL and (b) 4-DBPASL algorithms.

Generally, 4-D holographic interferometry fringes produced by using Hybrid Genetic Algorithm based on Pareto Optimal Solutions. It is interesting to find that the proposed algorithm has produced clear features detection of infrastructures. In fact, the proposed algorithm has minimized the error in interferogram cycle due the low coherence in water and vegetation zones. Corresponding to Hussien et al., (2005), and Marghany and Mansor (2016) the 4DBPASL for holographic interferometry phase unwrapping not only identifies these singularity loops, though it also computes the prodigious of every voxel to make certain that the most reliable voxels are unwrapped first and therefore the effects of singularity loop ambiguities are minimized or eliminated entirely. Consequently, the aggregate of 4DBPASL for holographic phase unwrapping with hybrid Genetic algorithm produced extra exactly fringe cycle. In this regard, hybrid Genetic algorithm fits the phase of the wrapped phase with approximated unwrapped phase to set up the satisfactory illustration of the unwrapped phase and displacement deformation.

6. CONCLUSIONS

This work has demonstrated a new approach for 4-D phase unwrapping technique to retrieve earthquake displacement due to the fact of Nepal earthquake, 2015. In doing so, the hybrid genetic set of guidelines is carried out to optimize 4-D phase unwrapping algorithm primarily based on fourth-dimensional nice-path heading off singularity loops (4DBPASL) algorithm. The algorithm trade from 3D to 4-D has implemented prior to hybrid genetic set of rules. The take a appear at indicates 4DBPASL can present the interferogram from 2-D to 4-D. The take a seem to be at additionally suggests that 4DBPASL capable to reconstruct 2-D earthquake displacement into 4-D view. In conclusion, 4DBPASL set of regulations can be used to furnish precise 4-D quake deformation the use of Sentinel-1A satellite data.

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