FOUR-DIMENSIONAL OF SRI LANKA COASTAL DAMAGES DURING 2004 TSUNAMI USING HOLOGRAM INTERFEROMETRY OF QUICKBIRD SATELLITE DATA

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ABSTRACT: Yet advanced remote sensing technology does not implement n-dimensional and just restricted to three-dimensional. However, n-dimensional recently, is curious topic between mathematicians and physicians. This work aims at using hologram interferometric with 4-D phase unwrapping to reconstruct fourth-dimensional of box-day Tsunami 2004 impacts on Kalutara coastline. The data are used that involved two QuickBird images with implementation of 4-D phase unwrapping. The results show that the hologram Interferometric an excellent tool for reconstructing tsunami chaotic effects on land uses from QuickBird satellite data. The study shows coastline of Kalutara is flooded by tsunami run-up of 6 m which totally damaged road network and urban structures. Hologram interferometry able to reconstruct 4-D of coastal water turbulent flows along Kalutara coastline. In conclusion, 4-D view of tsunami coastal damages can be reconstruct using the optical hologram Interferometric from QuickBird satellite data.

1. INTRODUCTION

Hitherto developed remote sensing technology disables to implement n-dimensional and is just constrained to simulate three-dimensional of any object in ground. Though, n-dimensional newly, is interested theme for mathematicians and physicians. String theory, M-theory, and Supergravity are most well known n-dimensional theories. String theory, consequently, proposed that the universe is shaped in multiple dimensions: (i) height, (ii) width, and (iii) length compose three-dimensional space; and (iv) time contributes an entirety of four observable dimensions. String theories, nonetheless, continued the probability of ten dimensions – the remaining six of which human capability cannot depiction precisely (Alday et al., 2010 and Marghany 2015).

Though, the geometry of 4-dimensional (4-D) space is abundant extra convoluted than that of 3-dimensional space, because of the extraordinarily degree of freedom. Consequently, 4-D involves 4-polytopes which are formulated of polyhedral (Figure 1). In addition, 4-D also contains 6 convex regular 4-polytopes, which are the analogues of the Platonic solids. Therefore, as 3-D beings it cannot transfer freely in time, but in 4-D it could be achievable. In this context, 4-D can distinguish three-dimensional and it cannot be conveyed to Euclidean space which suggests that fourth- dimension is spatial. Therefore, 4-D can be generated algebraically, by utilizing the regulations of vectors and coordinate geometry to a space in 4-D (Anne 2013, Marghany 2014).

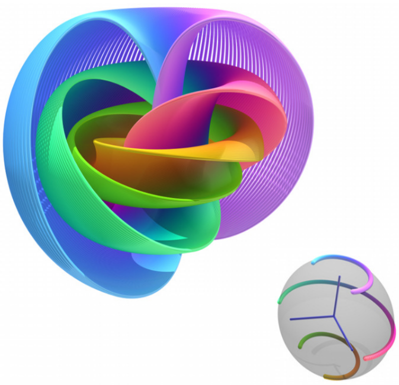


Figure 1: Four-dimensional.

Though, there are great advances in remote sensing technology which can provide 3-D maps through LIDAR, TanDAM TerraSAR –X etc., the human eyes are restricted to view 2-D or 3-D objects and not able to be viewed in n-dimension. In free space universe, there are parallel coordinates which can view the universe in n-dimensional. One of the accurate remote sensing technique for 3-D visualization is interferometry synthetic aperture radar techniques. Yet, the performance of interferometric phase estimation suffers seriously from poor image coregistration. Interferogram filtering algorithms such as adaptive contoured window, pivoting mean filtering, pivoting median filtering, and adaptive phase noise filtering are the main methods for the conventional InSAR interferometric phase estimation Pepe, A., (2012). Recently, Marghany (2011) implemented hologram interferometry for shoreline change. Marghany (2014) introduced a new technique to reconstruct 4-D from hologram interferometry for optical remote sensing and ENVISAT ASAR data. However, these studies does not explained clearly the mathematical formula used to reconstruct 4-D. In fact, 4-D is required to formulate mathematical protocols to be implemented in several applications (Marghany 2015).

The main question is how to reconstruct 4-D from 3-D? This study postulates that 4-D can be implied from 3-D phase unwrapping of optical hologram interferometry. As a matter of fact, optical interferometry is a powerful approach to measure shifts of the stability of electromagnetic wavelength spectra. One significant limitation of common interferometric methods is that they require specular reflectors. This limitation can be removed by utilizing holography, allowing very small motions of arbitrary, diffusely reflecting, objects to be detected. The main novelty of this study is to derive a new formula for 4-D hologram interferometry phase unwrapping Hybrid Genetic Algorithm (HGA). The main objective is to reconstruct fourth-dimensional box-day Tsunami 2004 impacts on Kalutara coastline from high resolution Quickbird satellite data by optimization of 4-D hologram interferometry.

2. STUDY AREA AND SATELLITE DATA

Kalutara coastline is located in Sri- Lanka between 6°34’21.03” N to 6°34’ 57.28” N and 79°57’ 13.63” E to 79°58’ 04.87” E (Figure 2). Moreover, Sri Lanka is dominated by two monsoon periods. Indeed, southwest monsoon brings that rain mainly from May to July to the western, southern and central regions of the Sri Lanka island, while the northeast monsoon rains occur in the northern and eastern regions in December and January which are influenced the coast of Sri Lanka frequently.

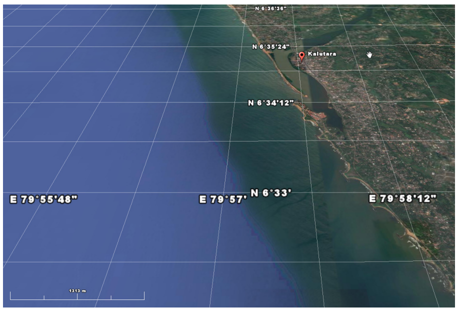


Figure 2. Kalutara coastline.

In this study, the high-resolution Quickbird satellite data were acquired from Digital Global archives data. The images of Quickbird were acquired before, and after tsunami disaster of Kalutara coastline. The multispectral QuickBird satellite data within less than 1 m pixel resolution is chosen. For ocean wave spectra extraction the composite color bands of 450-520 nm (blue), 520-600 nm (green), and 630-690 nm (red) is used. The multispectral QuickBird satellite was acquired on Sunday December 26, 2004, at 10:20 am local time, slightly less than four hours after the 6:28 a.m. (local Sri Lanka time) earthquake and shortly after the moment of tsunami impact.

3. ALGORITHM

3.1. 4-D Hologram Interferometry

Following Marghany (2015), assume that I_1 and I_2 are the different acquisition times of two optical satellite data for instance, QuickBird . Consequently, $I_1 \in E_1$ and $I_2 \in E_2$ where $E_1 \notin E_2$ or $E_1 \neq E_2$ as E is electromagnetic spectra which presents in two QuickBird satellite data. Both electromagnetic spectra waves interfere at the surface of point in space or time. Hence, their amplitudes will add as vector. If one of these is a plane wave pointing in the z direction and the other is a spherical wave, then it can described by

$$I(x,y) = | E(x,y)\, e^{(i\phi_O(x,y))} + r(x,y)\, e^{(i\phi_R(x,y))}|$$
$$= (E_2(x,y)\, e^{(i\phi_R(x,y))})(r(x,y)\, e^{(i\phi_R(x,y))})^* + (E_1(x,y)\, e^{(i\phi_O(x,y))})(E(x,y)\, e^{(i\phi_O(x,y))})^*$$
$$+ (E_1(x,y)\, e^{(i\phi_O(x,y))})(E_2(x,y)\, e^{(i\phi_R(x,y))})^* + (E_2(x,y)\, e^{(i\phi_R(x,y))})(E_1(x,y)\, e^{(i\phi_O(x,y))})^* \quad (1)$$

where $\boldsymbol{E}$ is the is the complex amplitude of the object wave with real amplitude E_1 and phase ϕ_O , $\mathbf{E_2}$ is the complex amplitude of the reference wave with real amplitude E_2 and phase ϕ_R and * denotes the conjugate complex. The phase changes due to deformation can be obtained by using 2-DFFT into the above equation [21]

$$FFT\{I\} = A(f_x + f_y) + B(f - f_x, f - f_y)B^*(f - f_x, f - f_y) \quad (2)$$

where FFT denote the Fourier spectra and f is the spatial frequency in the x and y directions, are the carry frequencies in the x and y directions, respectively. Following De la Torre et al.,(2010), 4-D holographic interferometry can be given by

$$FFT\{I_N\} = \sum_{N=1}^{4} [A_N(f_x + f_y + f_z) + B_N(f - f_{Nx}, f - f_{Ny}, f - f_{Nz}) + B_N^*(f - f_{Nx}, f - f_{Ny}, f - f_{Nz})] \quad (3)$$

where N represents fourth -dimensional, A_N is the incoherent in 4-D holographic interferometry. B_N and B_N^* are lobes for each illumination wavelength in QuickBird 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,

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

Following Marghany (2015) where d is the displacement in along orthogonal components of $U,V,W,O,$ in i,j,k, and p, respectively. According Marghany (2015) Phase unwrapping can be extended into fourth-dimensional by the given equation,

$$\sum_{i,j,k,p} W^x_{i,j,k,p} \left|\Delta\phi^x_{i,j,k,p} - \Delta\psi^x_{i,j,k,p}\right|^L + \sum_{i,j,k,p} W^y_{i,j,k,p} \left|\Delta\phi^y_{i,j,k,p} - \Delta\psi^y_{i,j,k,p}\right|^L$$
$$+ \sum_{i,j,k,p} W^z_{i,j,k,p} \left|\Delta\phi^z_{i,j,k,p} - \Delta\psi^z_{i,j,k,p}\right|^L + \sum_{i,j,k,p} W^z_{i,j,k,p} \left|\Delta\phi^w_{i,j,k,p} - \Delta\psi^w_{i,j,k,p}\right|^L \quad (5)$$

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 (2015).

3.2. Hybrid Genetic Algorithm (HGA)

The HGA algorithm relies on estimating the parameters of an nth order-polynomial to approximate the unwrapped surface solution from the wrapped phase data (Karout, 2007 and Marghany 2015). Any optimisation problem using a genetic algorithm (GA) requires the problem to be coded into GA syntax form, which is the chromosome form. In this problem, the chromosome consists of a number of genes where every gene correspond to a coefficient in the nth-order surface fitting polynomial this can be extand into 4-D as follows (Marghany 2015),

$$f := n \to \sum_{p=0}^{n} \sum_{k=0}^{n} \sum_{j=0}^{n} \sum_{i=0}^{n} a_{i,j,k,p}\, \Delta\phi^x_{i,j,k,p}\, \Delta\phi^y_{i,j,k,p}\, \Delta\phi^z_{i,j,k,p}\, \Delta\phi^w_{i,j,k,p} \quad (6)$$

where $a[0....n]$ are the parameter coefficients which are retrieved by the genetic algorithm to approximated the unwrapped phase. Further, i,j, k and p are indices of the pixel location in the unwrapped phase in 4-D, respectively, n is the number of coefficients.

3.3. Phase Matching

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

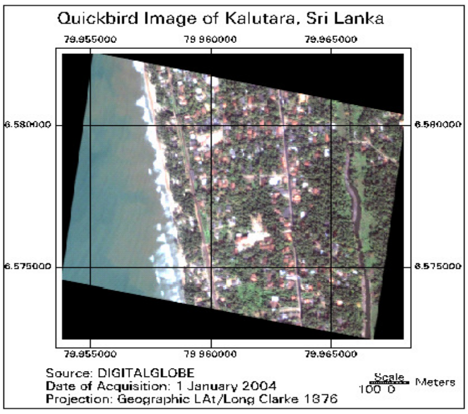
$$\psi_{i,j,k,p} = \Delta\phi_{i,j,k,p} + 2\pi\rho\left[\frac{1}{2\pi}\left(\Delta\hat{\phi}_{i,j,k,p} - \Delta\phi_{i,j,k,p}\right)\right] \quad (7)$$

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 $\rho[t]=\lfloor t+\frac{1}{2}\rfloor$ for $t \geq 0$ and $\rho[t]=\lfloor t-\frac{1}{2}\rfloor$ for $t < 0$ and are *i,j, k* and *p* the pixel positions in *x* and *y,z,w* directions, respectively (Schwarz O. 2004;Pepe, A., 2012; Marghany 2015).

4. RESULTS AND DISCUSSION

The earthquake and the tsunami, which struck the coastline of the Indian Ocean and Sumatra, Indonesia on 26 December 2004, have caused massive changes in the shorelines of many countries especially in Banda Aceh, Indonesia and Kalatura, Sri Lanka. Scientists investigating the damage in Aceh found evidence that the wave reached a height of 80 feet (24 m) when coming ashore along large stretches of the coastline, rising to 100 feet (30 m) in some areas when travelling inland. This deadliest disaster has caused massive destruction to the environment and the world ecosystems despite killing million of people all over the world. Figure 3 shows the two QuickBird satellite data were acquired over Kalutara coastline pre tsunami and post tsunami, respectively. Evidently, huge damages have been caused by box-day tsunami 2004 (Figure 3b). This is contributed due to fact that QuickBird satellite has multispectral sensors with 0.61 m-0.72 m and 2.44m –2.88 (Table 1) m resolution respectively, depending on the off-nadir viewing angle (0-25 degrees). The sensor therefore has coverage of 16.5 km in the across-track direction. In addition, the along-track and across-track capabilities provide good stereo geometry and a high revisit frequency of 1-3.5 days. These characteristics of the images enable easy management and observation of earth especially for disaster observation and mapping such as tsunami disaster.

(a)



(b)

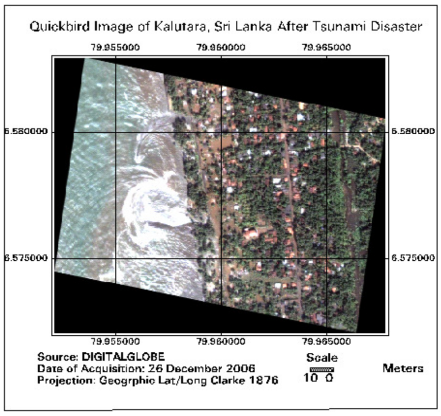


Figure 3. Quickbird satellite data pre and post tsunami Events along Kalutara (a) January 1, 2004, and (b) December 26, 2004.

The comparison between 2-D phase unwrapping; 3-D phase unwrapping; and 4-D phase unwrapping is shown in Figure 4. The hologram interferometry fringes pattern are more vibrant by using 4-D phase unwrapping as compared to other phase unwrapping dimensions i.e. 2-D and 3-D. Particularly, the complete cycle of hologram interferometry fringe patterns are certain with 4-D phase unwrapping algorithm. With this regard, 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 and along the coastline due to tsunami impact. This could be improvement of such previous work of Hussein et al. (2005); Karout(2007);Marghany (2015).

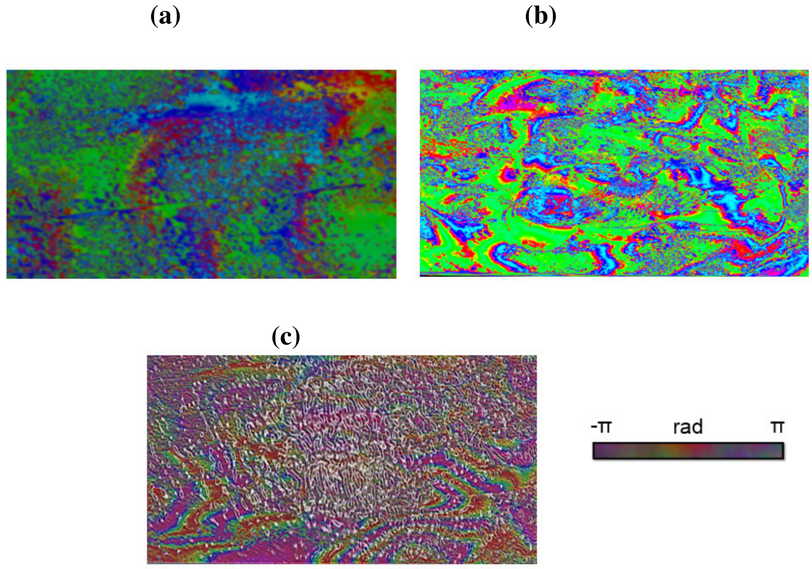


Figure 4. Phase unwrapping (a)2-D;(b)3-D; and (c) 4-D.

Figure 5 shows the 4-D visualization derived from hologram interferometry. Obviously, the 4-D visualization distinguishes between infrastructures and buildings. With this regard, coding 2-D of QuickBird data into 4-D can visualize many information about urban features i.e. building, infrastructures, and roads in spite of the great damages caused by tsunami wave. Indeed, the hologram interferometry is considered as a deterministic algorithm which is described here to optimize a triangulation locally between two different points. This corresponds to the feature of deterministic strategies of finding only sub-optimal solutions usually. This confirms that optical interferometry is a robust means for evaluating displacements of the order of a wavelength of electromagnetic spectra. Therefore, involving a hologram can assist in recovering the matter of specular reflection beside permitting tiny changes of random, diffusely replication, objects to be identified (Saxby 1987).

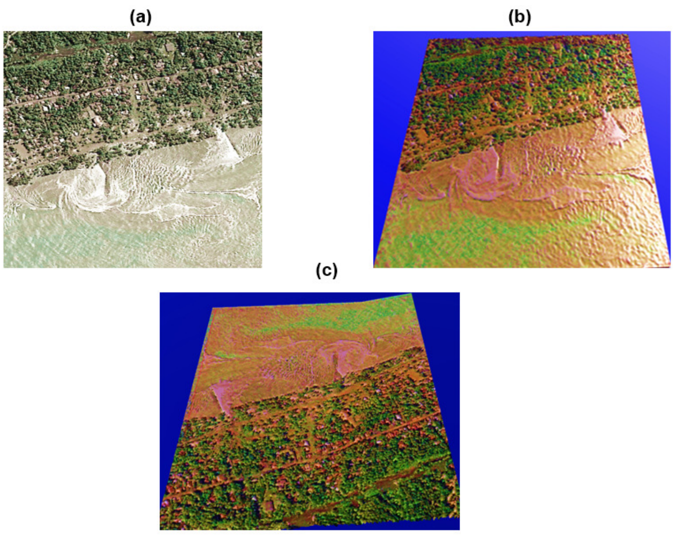


Figure 5. 4-D visualization produced by 4-D hologram interferometry (a) original data;(b) 90°;and (c) 180 °.

The visualization of the infrastructures is sharp by 4-D phase unwrapping based Hybrid Genetic Algorithm. These results delivers an excellent promising for 4-D reconstruction using 4-D phase unwrapping of hologram interferometry. This study is improving the work done by Marghany (2015). Furthermore, the adding fourth coordinate *p* in mathematical formula of 3-D HI shaped an excellent 4-D object visualization. HGA assists to deliver 4-D image and not only discriminating the individual relaxed deformation but also sorting out impeding objects in 4-D.Generally, HGA corresponds the phase of the wrapped phase with guessed unwrapped phase to verify the best representation of the unwrapped phase. Consistent with Karout (2007) and Saravana et al., (2003) a genetic algorithm is used to approximate the coefficient of an $n^{th\text{-}}$order polynomial which is considered as best estimates for the unwrapped phase map. With this regard, it minimizes the variance between the unwrapped phase gradient and the wrapped phase gradient. Furthermore, 4-D results obtained with the hybrid genetic algorithm exceed the performance of the 4-D phase unwrapping of hologram interferometry.

5. CONCLUSIONS

The 4-D phase unwrapping methods outlined are applicable to reconstruct 4-D visualization of tsunami effects using QuickBird data. The involving of Hybrid genetic algorithm to optimize modification formula of hologram interferometry can permit the QuickBird data to be coded into 4-D. The results shows that the varieties of 2-D objects in QuickBird data can be visualize in 4-D. The fine strictures of roads, urban, buildings and infrastructures are well visualized in 4-D. In conclusion, the modification and optimization of hologram interferometry formula hold excellent promise for 4-D object visualization in such optical satellite data of QuickBird data .

References

Alday, L., Gaiotto, D., & Tachikawa, Y., 2010, "Liouville correlation functions from four-dimensional gauge theories", Letters in Mathematical Physics, 91 (2),pp. 167–197.

Anne, D., W., 2013, “Moral Authority, Men of Science, and the Victorian Novel”. Cambridge University Press

De la Torre-Ibarra, M. H., Santoyo, F. M., & Moreno, I., 2010, “Digital holographic interferometer using Simultaneously three lasers and a single monochrome sensor for 3D displacement measurements”, Optics express,18(19),pp. 19867-19875.

Kohli D, Richard S, Norman K, & Stein, A, 2012, “An ontology of slums for image-based classification. Computers”, Environment and Urban Systems, 36 (2), pp. 154–163.

Hussein, S. A., Gdeist M, Burton D, & Lalor M., 2005, “Fast three-dimensional phase unwrapping algorithm based on sorting by reliability following a non-continuous path”, Proc. SPIE, 5856,pp. 40.

Haupt, R. L., & Haupt, S. E., 2004, “Practical genetic algorithms” , John-Wiley & Sons.

Karout, S., 2007, “Two-Dimensional Phase Unwrapping”, Ph.D Theses, Liverpool John Moores University.

Marghany, M., 2012, “Simulation of 3-D Coastal Spit Geomorphology Using Differential Synthetic Aperture Interferometry (DInSAR)”.,In I. Padron.,(ed.) Recent Interferometry Applications in Topography and Astronomy, Croatia: InTech – Open Access Publisher, pp. 83-94.

Marghany, M., 2013, “DInSAR technique for three-dimensional coastal spit simulation from radarsat-1 fine mode data”, Acta Geophysica, 61,2, pp.478-493.

Marghany, M., 2014, “Simulation of three-dimensional of coastal erosion using differential interferometric synthetic aperture radar”, Global NEST Journal, 16, 1, pp 80-86.

Marghany, M. 2014, “Hybrid Genetic Algorithm of Interferometric Synthetic Aperture Radar For Three-Dimensional Coastal Deformation”, *Frontiers in artificial intelligence and applications: new trends in software methodologies, tools and technique*, *265*, pp.116-31.

Marghany, M. 2011, “Modelling shoreline rate of changes using holographic interferometry”, *Int. J. of Phys. Sci*, *6*, pp. 7694-7698.

Marghany, M.,2003, “Polarised AIRSAR along track interferometry for shoreline change modeling”, In *Geoscience and Remote Sensing Symposium, 2003. IGARSS'03. Proceedings. 2003 IEEE International* ,Vol. 2, pp. 945-947.

Marghany M.,2014,”Hologram interferometric SAR and optical data for fourth-dimensional urban slum reconstruction”, CD of 35th Asian Conference on Remote Sensing (ACRS 2014), Nay Pyi Taw, Myanmar 27- 31, October 2014,http://www. a-a-r-s.org/acrs/administrator/components/com.../OS-303%20.pdf.[Access on August 2 2016].

Marghany M., 2015, Fourth dimensional optical hologram interferometry of RapidEye for Japan ‘s tsunami effects” CD of 36th Asian Conference on Remote Sensing (ACRS 2015), Manila, Philippines, 24-28 October 2015, http://www.a-a-r-s.org/acrs/index.php/acrs/acrs-overview/proceedings-1?view=publication&task=show&id=1691, Access on August 2 2016.

Pepe, A., 2012, “Advanced Multitemporal Phase Unwrapping Techniques for DInSAR Analyses”, In Padron I. (ed.) "Recent interferometry applications in topography and astronomy". InTech - Open Access Publisher, University Campus STeP Ri, Croatia, pp.57-82.

Smith, J., 2010, “Optimizing remote sensing for disaster monitoring, retrieved May 13, 2005, from http://www.remotesening.net/index.htm.

Saravana, S.S., Ponnanbalam, S.G., & Rajendran, C. A. 2003, “Multiobjective genetic algorithm for scheduling a flexible manufacturing system”, International Journal of Advanced Manufacturing Technology, 22, pp. 229-236.

Ray, I., 1992, Introducing Einstein's Relativity,Clarendon Press, chp. 22.8 *Geometry of 3-spaces of constant curvature*, p.319ff, ISBN 0-19-859653-7.

Schwarz O. 2004. Hybrid phase unwrapping in laser speckle interferometry with overlapping windows, Shaker Verlag.

Takeda, M., Ina, H., & Kobayashi, S.,1982, “Fourier-transform method of fringe-pattern analysis for computer-based topography and interferometry”, *JosA*, *72*(1), pp.156-160.

Saxby G., 1987: “Practical Holography”, Prentice Hall,NJ.