

## Fuzzy B-spline optimization for urban slum three-dimensional reconstruction using ENVISAT satellite data

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**Abstract.** A critical challenges in urban areas is slums. In fact, they are considered a source of crime and disease due to poor-quality housing, unsanitary conditions, poor infrastructures and occupancy security. The poor in the dense urban slums are the most vulnerable to infection due to (i) inadequate and restricted access to safety, drinking water and sufficient quantities of water for personal hygiene; (ii) the lack of removal and treatment of excreta; and (iii) the lack of removal of solid waste. This study aims to investigate the capability of ENVISAT ASAR satellite and Google Earth data for three-dimensional (3-D) slum urban reconstruction in developed countries such as Egypt. The main objective of this work is to utilize some 3-D automatic detection algorithm for urban slum in ENVISAT ASAR and Google Earth images were acquired in Cairo, Egypt using Fuzzy B-spline algorithm. The results show that the fuzzy algorithm is the best indicator for chaotic urban slum as it can discriminate between them from its surrounding environment. The combination of Fuzzy and B-spline then used to reconstruct 3-D of urban slum. The results show that urban slums, road network, and infrastructures are perfectly discriminated. It can therefore be concluded that the fuzzy algorithm is an appropriate algorithm for chaotic urban slum automatic detection in ENVISAT ASAR and Google Earth data.

### 1. Introduction

The United Nations termed an urban slum as a tumble-down area of the city which portrayed by poor quality housing, dirtiness, and lacking in tenancy security. In this regard, urban slums refer to housing areas that were once relatively affluent but which deteriorated as the original dwellers moved on to newer and better parts of the city, but has come to include the vast informal settlements originated in cities in the developing world. In addition, slum buildings vary from simple shacks to permanent and well-maintained structures. Most slums lack clean water, electricity, sanitation and other basic services [20]. Therefore, Ismail et al., [21] argued that urban slum is considered as cancer cells or pockets within the healthy urban area that is required critical surgical intervention. They proposed a new method to identify urban slum which is based on Coexistent Urbanism approach. They proposed approach that is considered three groups of factors to differentiate between slums. These involve basic and socioeconomic factors, urban analysis factors and fabric morphological factors. Finally they applied space Syntax to slums network, then slums can be classified by a devised normalized index called Coexistence Potential index which measures effectiveness and Neediness for intervention.

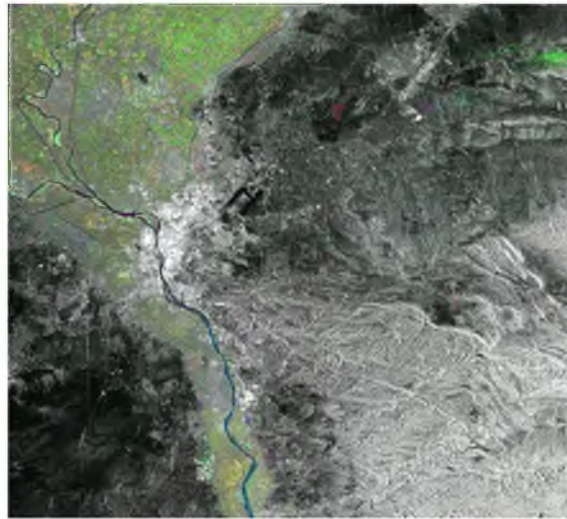


The accurate technology is required to identify and monitor the change and growth of the urban slums. Recent advances in space technology might show excellent promises for land use and change monitoring [9,16]. In this context, remote sensing and Google Earth plays a tremendous role in monitoring land use spatial variations. Mahogany [9] has proposed that a should utilize Google Earth for urban slum investigation. There are many other studies have utilized the optical remote sensing satellite for urban slum monitoring. High resolution imagery has been used for many years [16]. Some of these studies have established the new rule which is based on infrastructures and urban planning morphology to identify the urban slum. Kit et al. [5] used very high resolution satellite imagery from the Quick Bird satellite with resolutions of 2.44-2.88m and 0.61-0.72 m, respectively to identify the urban slums. Further, they concluded that remote sensing technologies provide urban managers with the to increase the efficiency of their often very limited resources and to target support and improvement measures at those particularly in need. The relatively low hardware requirements and absence of software licensing costs to also make the technique feasible for use in developing countries. According to Holden [4], the poor in the dense urban slums are the most vulnerable to infection due to (i) inadequate and restricted access to safety, drinking water and sufficient quantities of water for personal hygiene; (ii) a lack of removal and treatment of excreta; and (iii) a lack of removal of solid waste, particularly the organic fraction, which attracts vermin. Therefore, Holden [4] stated that modern and reliable technologies is required to solve and improve the problem of urban slums. According to Kohli et al. [14] the absence of a unique and consistent definition of a slum hinders the development of objective, universally applicable slum detection methods using remote sensing and OOA, which require a clear conceptualization of the object of interest. According to Dekker [15], SAR data are suitable for monitoring urban land use. In fact, various bands of L, C, or X bands; with a wide range of incidence angles between 35° and 50°; and HH and HV polarization (HV interesting to investigate urban land use or quad pol monitoring urban environments). He stated that ENVISAT ASAR satellite data with 30 m resolution cannot detect small objects. On the contrary, the same system can be used in combination with higher resolution satellites such as RADARSAT-2 SAR, TerraSAR X and airborne SAR systems for monitoring land use. Amarsaikhan et al. [17] and Brook et al. [18] have also shown how the combined use of optical and SAR data sets can enhance urban feature detection and enhancement.

Therefore, Google Earth is often considered as a rapid source for information. In fact, it includes all the imagery for each country of the world. In other words, Google Earth is a database viewer that combines satellite data to reconstruct a three-dimensional model (3-D) of the ocean and Earth's surface. The overall objective of this work is to investigate spaceborne SAR data and Google Earth for automatic detection of urban slum in Cairo, Egypt. The main hypotheses is to reconstruct three-dimensional of urban slum in SAR satellite data and Google Earth uses fuzzy B-spline algorithm.

## 2. Data acquisition

This multi-colored composite ENVISAT Advanced Synthetic Aperture Radar (ASAR) wide swath mode image over Egypt's capital city of Cairo. Clearly ENVISAT ASAR image shows the Nile River is running from south to north. Radar images measure surface roughness rather than reflected light. The color in the image was produced by a combination of the three acquisitions of ENVISAT ASAR. A color is assigned to each date of acquisition: red for 7 June 2004, green for 20 November 2003 and blue for 8 April 2004, with a spatial resolution of 12.5 meters (Figure 1).



**Figure 1.** Composite colour image of ENVISAT ASAR over Cairo, Egypt.

### 3. Fuzzy B-spline algorithm

Following Marghany et al., [9] a fuzzy number is defined whose range is given by the minimum and maximum values of DTM along each kernel window size. Furthermore, the identification of a fuzzy number is acquired to summarize the estimated DTM data in a cell and it is characterized by a suitable membership function. The choice of the most appropriate membership is based on triangular numbers which are identified by minimum, maximum, and mean values of DTM estimated. Furthermore, the membership support is the range of digital elevation data in the cell and whose vertex is the median value of DTM data [1].

There are two basic notions that we combine together [1,3]: (i) confidence interval and (ii) presumption level. A confidence interval is a real value interval which provides the sharpest enclosing range of urban 's elevation spatial variation values [9,10]. Based on assumption issued by Anile [1], that  $\mu$  -level is an estimated truth value in the  $[0, 1]$  interval on our knowledge level of the digital terrain model (DTM). The 0 value corresponds to minimum knowledge of urban 's topography, elevation gradients, and 1 to the maximum urban 's topography elevation gradients. A fuzzy number is then prearranged in the confidence interval set, each one related to an assumed level  $\mu \in [0, 1]$ . Moreover, the following must hold for each pair of confidence intervals which define a number:  $\mu \succ \mu' \Rightarrow \xi \succ \xi'$  [9].

Following Marghany et al. [8], let us consider a function  $f: \xi \rightarrow \xi'$ , of  $N$  fuzzy variables  $\xi_1, \xi_2, \dots, \xi_n$ . Where  $\xi_n$  are the global minimum and maximum values of urban 's topography, elevation gradients along the space. Based on the spatial variation of the urban 's elevation gradients, the fuzzy B-spline algorithm is used to compute the function  $f$  [7]. Following Marghany et al., [9]  $\xi(i, j)$  is the urban elevation value at location  $i, j$  in the region  $R$  where  $i$  is the horizontal and  $j$  is the vertical coordinates of a grid of  $m$  times  $n$  rectangular cells. Let  $N$  be the set of eight neighbouring cells. The input variables of the fuzzy are the amplitude differences of urban 'elevation  $\xi$  defined by [1]:

$$\Delta \xi_N = \xi_i - \xi_0, N = 1, \dots, 4 \quad (1)$$

where the  $\xi_i$ ,  $N=1, 4$  values are the neighbouring cells of the actually processed cell  $\xi_0$  along the horizontal coordinate  $i$ . To estimate the fuzzy number of urban's elevation  $\xi_i$  which is located along the vertical coordinate  $j$ , we estimated the membership function values  $\mu$  and  $\mu'$  of the fuzzy

variables  $\xi_i$  and  $\xi_j$ , respectively by the following equations were described by Rövid et al. [11]

$$\mu = \max \left\{ \min \{ m_{pl}(\Delta \xi_i) : \xi_i \in N_i \}; N = 1, \dots, 4 \right\} \quad (2)$$

$$\mu^* = \max \left\{ \min \{ m_{LNI}(\Delta \xi_i) : \xi_i \in N_i \}; N = 1, \dots, 4 \right\} \quad (3)$$

Equations 2 and 3 represent the urban elevation in 2-D, in order to reconstruct fuzzy values of the urban elevation in 3-D, then the fuzzy number of the DTM elevation in  $z$  coordinate is estimated by the following equation proposed by Russo [11]

$$\xi_z = \Delta \mu \text{MAX} \{ m_{LA} | \xi_{i-1,j} - \xi_{i,j} |, m_{LA} | \xi_{i,j-1} - \xi_{i,j} | \} \quad (4)$$

where  $\xi$  fuzzy set of urban 's elevation values in  $z$  coordinate which is function of  $i$  and  $j$  coordinates i.e.  $\xi_z = F(\xi_i, \xi_j)$ . Fuzzy number  $F_o$  for urban 's elevation in  $i,j$  and  $z$  coordinates then can be given by

$$F_o = \{ \min(\xi_{z_0}, \dots, \xi_{z_\Omega}), \max(\xi_{z_0}, \dots, \xi_{z_\Omega}) \} \quad (5)$$

where  $\Omega = 1, 2, 3, 4$ ,

The fuzzy B-spline algorithm has been implemented with ENVISAT ASAR data which acquired over Cairo, Egypt.

#### 4. Results and discussion

Figure 2 shows the selected study area from the Google Earth tool that suggested the location of urban slum. This area is located away from Misr Al Qadima between 29 58 12 N at 30 00 36 N and 31 12 36 E to 31 15 00 E. This was selected based on the criteria of low quality building, poor infrastructures, overlapping between high quality and low quality buildings, high building density, hazardous location, poor environmental condition, durability. Figure 3 shows that urban slum are dominated by poor roof material, absence of roads, irregular roads, lack of vegetation, irregular shape of settlement association with neighboring areas, texture and locality. This confirms the study of Kohli et al. [14].



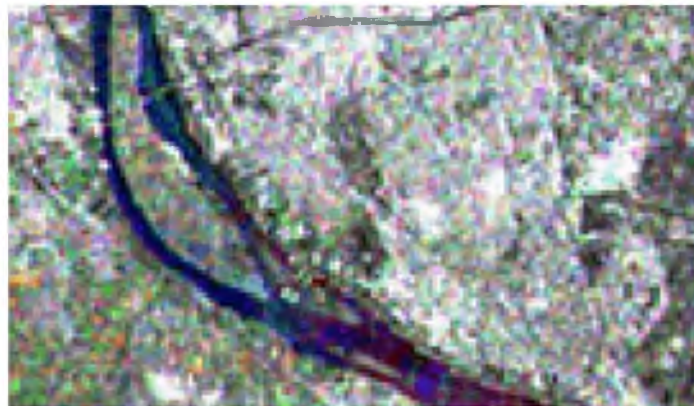
**Figure 2.** Selected location of urban slum.





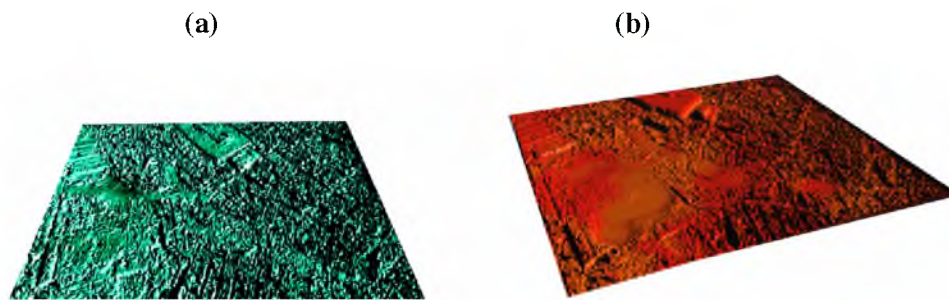
**Figure 3.** Physical indicators for urban slum.

Clearly, Figure 4 contains uncertainties due to speckle. Speckle is considered a major obstacle for SAR data interpretation.[19]. Thus, adaptive filters such as Lee, Kuan, Frost and the co-occurrence matrix are often used to enhance the edges of urban features.[9,15]. However, these filters are not totally able to reduce speckle noise in SAR data. In addition, the ENVISAT ASAR resolution of 30 m does not allow the detection of small objects such as slum dwellings [15].



**Figure 4.** Urban slum selected in ENVISAT ASAR stellite data.

Figure 5 shows the result obtained by using the fuzzy B-spline algorithm. It is clear that the 3-D visualization discriminates between infrastructures and buildings. Roads, buildings and infrastructures are clearly displayed in both ENVISAT ASAR and Google Earth (Figure 5). This is due to the fact that the fuzzy B-spline, is considered as a deterministic algorithm, which is described here to optimize a triangulation only locally between two different points [1][3][6][9]. This corresponds to the feature of deterministic strategies of finding only sub-optimal solutions usually. The visualization of infrastructures of urban slums is sharp with the ENVISAT ASAR and Google Earth because each operation on a fuzzy number becomes a sequence of corresponding operations on the respective  $\mu$ -levels and the multiple occurrences of the same fuzzy parameters evaluated as a result of the function on fuzzy variables [1];[7], [9].



**Figure 5.** 3-D view using fuzzy B-spline algorithm (a) ENVISAT ASAR and (b) Google Earth.

## 5. Conclusion

This study has demonstrated a method to visualize 3-D of urban slums using ENVISAT ASAR and Google Earth imagery. Some urban slums in Cairo city were selected as test area. Then, the fuzzy B-spline was implemented to reconstruct a 3-D visualization of the urban slums. The results show that the high density of housing spatial distributions, inherent in many dense slum areas, together with the high level of infrastructure, can be clearly observed. In conclusions, the ENVISAT ASAR and Google Earth could be used as tool for urban slum monitoring. Further, fuzzy B-spline shows excellent tool for 3-D visualization and discrimination between infrastructures and housing features in remotely sensed data specially with SAR satellite data. With the current operational status of many high resolution SAR satellites, the proposed method described in this paper becomes very useful for urban slum studies.

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