Nonlinear Analysis in Satellite Imagery of India

Sai Venkatesh Balasubramanian
Sree Sai Vidhya Mandhir, Mallasandra, Bengaluru-560109, Karnataka, India
saivenkateshbalasubramanian@gmail.com

Abstract:

The development of Satellite Imagery and associated analysis has opened up avenues in applications as diverse as meteorology, navigation, warfare and biodiversity. Motivated by this trend, the present article explores the application of nonlinear analysis tools such as entropy and fractal dimension in satellite imagery of the 29 states of India. It is seen that sharp and rich variations in terrain from green to arid or snow-clad mountainous regions contribute to high entropy, while rich variations in borders and varying scales of vegetation patches correspond to high fractal dimensions. The results obtained thus illustrate the significance and relevance of nonlinear analysis tools such as entropy and fractal dimension in satellite imagery.

Keywords: Satellite Imagery, Nonlinear Analysis, Entropy, Fractal Dimension, India

1. Introduction

The understanding of various atmospheric, biospheric, hydrospheric and lithospheric properties of our home, the planet Earth, has increased tremendously in recent years, thanks single handedly to Satellite Imagery [1-9]. Satellite images have found widespread application such as meteorology, oceanography, fishing, agriculture, biodiversity conservation, forestry, landscape, geology, cartography, regional planning, education, intelligence and warfare [8-9].

Owing to the costs of developing and maintaining a suitable infrastructure, Satellite Imagery has always been initiated and controlled by National Governments, International Collaborations and High-end Businesses [10-13]. However, tools such as Google Maps have been effective in bringing the power of this technology to the common man [14-15].

Recently, scientists have pondered over the possibility of using Satellite Imagery to forecast and predict natural disasters and catastrophes, such as earthquakes, cyclones and tsunamis, and subsequently also enhance the quality of satellite imagery based meteorology [8-13]. It is seen that, to achieve this, the various features and terrains and their association to satellite imagery must be established as a preliminary step.

It is in this light that the present article outlines the application of nonlinear analysis tools such as Entropy and Fractal Dimension to satellite imagery. As a study subject, the satellite images of the 29 states of the country of India, as obtained from Google Maps are used. The significance of the parameters, as well as their correlations with other key statistics such as area and elevation are outlined. The results obtained thus illustrate the significance and relevance of nonlinear analysis tools such as entropy and fractal dimension in satellite imagery.

2. Methodology

The base platform for the nonlinear analysis discussed in the present work consists of satellite images of the 29 Indian states, as obtained from Google Maps. For each state, the uncropped satellite image focusing on the corresponding state location is used as the base image. A sample of such an image is shown for the state of Rajasthan in Fig. 1.

Figure 1 Satellite Image of Rajasthan

This image is read into MATLAB as a collection of three 2-Dimensional arrays, corresponding to the intensity distributions of red, green and blue. The nonlinear analysis then comprises of the following two techniques:

1. Entropy: A standard chaotic characterization measure, this is essentially a statistical measure of the uncertainty in the signal. By assigning each of the N quantifiable states of the amplitude of C as an event 'i', the Entropy E obtained depends on their probabilities 'p_i' according to the relation [16-18]:

$$E = -\sum_{i=1}^{N} p_i \log(p_i) \ \ (bits/symbol) \qquad (1)$$

2. Fractal Dimension: The fractal/self-similar nature of a signal is further confirmed by computing the fractal dimension, using the Minkowski Bouligand Box Counting Method. In this method, various square 'boxes' of different sizes e are formed and for each size e, the number of boxes N(e) required to cover the entire set is computed. The fractal dimension is then given by [19-20]:

$$D = \lim_{e \to 0} \frac{\log(N(e))}{\log(e)} \qquad (2)$$

For the satellite images under consideration, the entropy is calculated for each of the 2D arrays, corresponding to R, G and B intensity distributions. The average of these 3 values gives the entropy of the image. However, the fractal dimension is computed directly in 3D.

3. Results and Discussion

The table of obtained entropies and fractal dimensions is shown in Table 1.

Table 1 Entropies and Fractal Dimensions of the 29 State Satellite Images

State	E	D	State	E	D
Andhra Pradesh	6.6818	1.6962	Manipur	6.4657	1.6962
Arunachal Pradesh	7.2466	1	Meghalaya	6.4214	0.7925
Assam	6.7967	1.661	Mizoram	5.8658	0.7925
Bihar	6.6301	1.4534	Nagaland	6.7092	1.6962
Chattisgarh	6.5141	1.661	Odisha	6.6284	1.585
Goa	5.9606	1.7925	Punjab	6.5486	1.6962
Gujarat	6.8047	1.4534	Rajasthan	7.066	1.585
Haryana	6.667	1	Sikkim	7.7576	1.6962
Himachal Pradesh	7.6382	1.6962	Tamilnadu	6.9439	1.7925
Jammu & Kashmir	7.5337	1.5646	Telangana	6.7456	1.585
Jharkhand	6.4915	1.5646	Tripura	6.3188	1
Karnataka	6.6426	1	Uttar Pradesh	6.9518	1.4534
Kerala	6.5025	1.661	Uttarakhand	7.3694	1.4534
Madhya Pradesh	6.5671	1.4534	West Bengal	6.8436	1.661
Maharashtra	6.4231	1.4534			

The following can be inferred from the table:

1. States which are predominantly mountainous, such as Jammu & Kashmir, Himachal Pradesh, Uttarakhand, Arunachal Pradesh and Sikkim exhibit the highest entropy values, which lead to the inference that entropy is a measure of terrain height variations, since these mountainous states have highly varying terrains from plains to snow capped mountain peaks, as seen in Fig. 2.

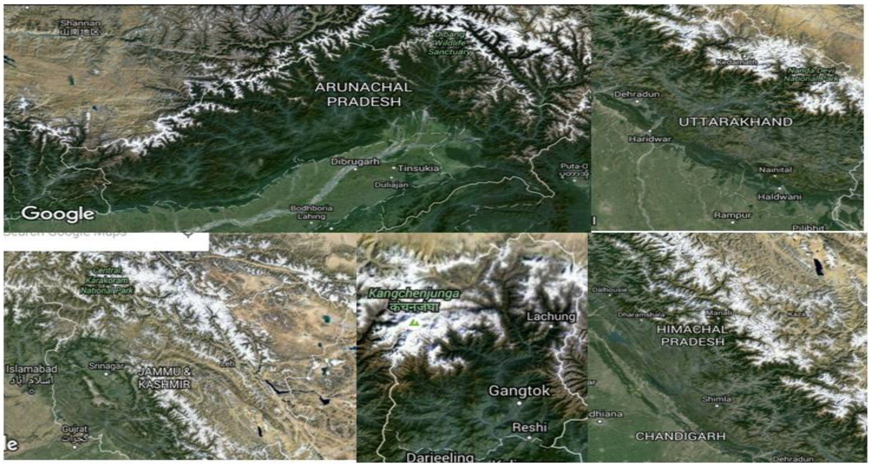

Figure 2 Satellite Images of J&K, Uttarakhand (top) Himachal, Sikkim and Arunachal Pradesh (bottom)

2. The fact that entropy is a measure of overall variation in terrain and not just height variation is illustrated by the fact that Mizoram, Goa, Tripura and Meghalaya exhibit the lowest entropy values. This is because, in these states, while there are hills and valleys, vegetation cover is more or less uniform (seen as green in the images), with arid (brown/golden) or snow-capped regions (white) hardly seen, as in Fig. 3.

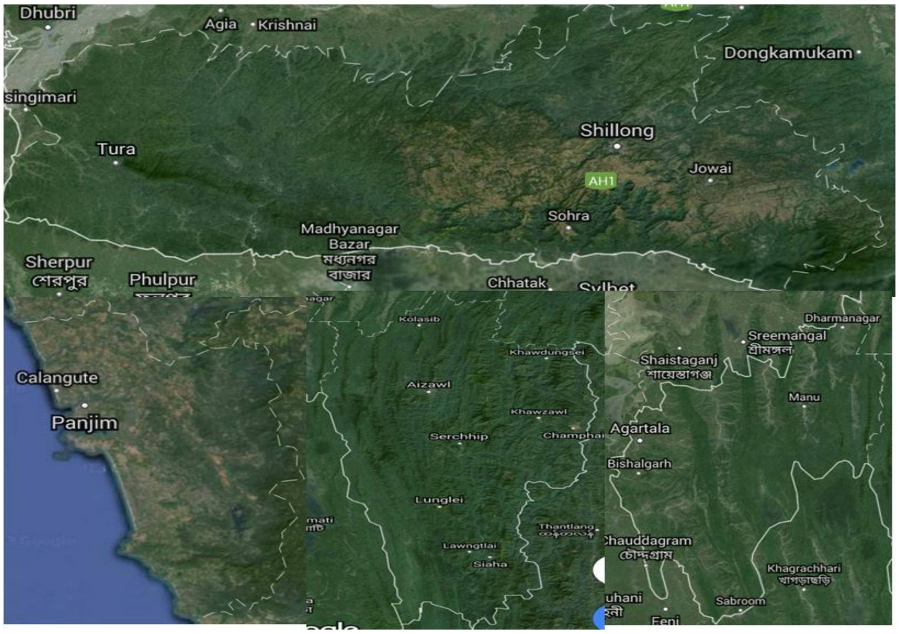

Figure 3 Satellite Images of Meghalaya (top) Goa, Mizoram and Tripura (bottom)

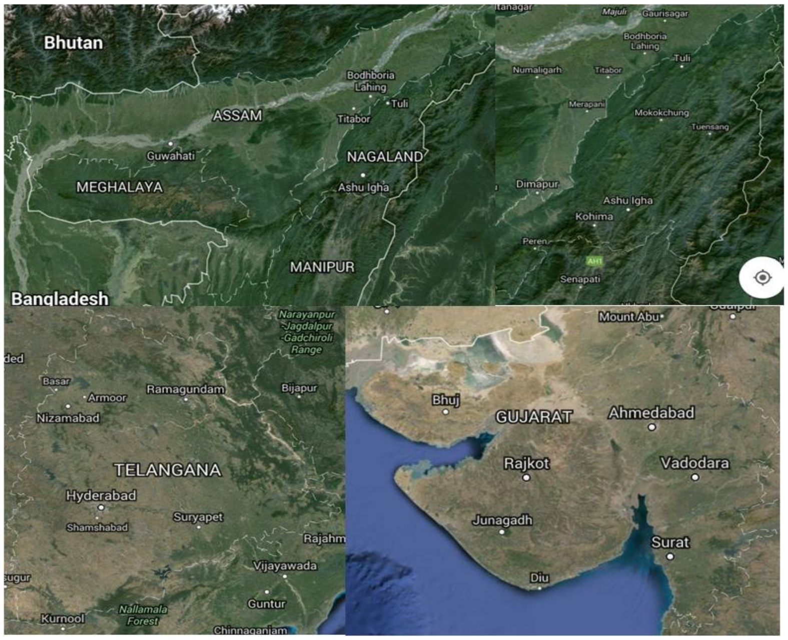

Figure 4 Satellite Images of Assam, Nagaland (top) Telangana and Gujarat (bottom)

3. The mean value of entropy is obtained at 6.749, and the states closest to this value are Nagaland, Telangana, Assam and Gujarat. As seen in Fig. 4, these states are characterized by a moderate

amount of terrain variation, with predominance of greenery (as in Nagaland and Assam) or aridity (as in Gujarat and Telangana), with the other terrain forms interspersed in between.

4. The only cases of sub-unity fractal dimension are seen in Mizoram and Meghalaya. In accordance with Fig. 3, these states are characterized by a largely uniform greenery dominant terrain with very few variations. Thus, there is little scope for self-similar patterns in a multiscale resolution. Also, the aspect ratios of these two states are unique in that Meghalaya and Mizoram span large longitudes and large latitudes respectively.
5. Tripura, Karnataka, Haryana and Himachal Pradesh exhibit unity fractal dimensions. This is because, these states are characterized by either nearly uniform landscapes (as in Tripura), or landscapes which show a directional gradient (green to arid eastward in Karnataka, snowy to green southward in Himachal Pradesh and green to arid westward in Haryana). In such cases, while some form of fractal resembling branching is seen in the transition, as in Haryana, the self similarity does not spread through the entire area to warrant a significant fractal dimension.

Figure 5 Satellite Images of UP, MP, Karnataka (top) Maharashtra, Bihar and Tamilnadu (bottom)

6. The highest fractal dimension is seen for Goa and Tamilnadu. In the case of Goa, striata of near-hemispherical arid patches are seen interspersed into the greenery, and this fact, along with the coastline and the state border of Goa contribute to the high D value. In the case of Tamilnadu, self-similarity can be seen in its coastline reminiscent of a human face, in the four protrusions towards the Bay of Bengal at Chennai, Nagapattinam, Rameshwaram and Thoothukudi, resembling the forehead, nose, mouth and chin respectively. Additionally, the patches of dense greenery as seen in Nilgiris, Kollimalai and Kodaikanal are all of different areas, allowing scope for multiscale self-similarity.
7. The mean fractal dimension is obtained as 1.468, and the states closest to this value are Uttarakhand, Uttar Pradesh, Bihar, Gujarat, Madhya Pradesh and Maharashtra. These states exhibit moderate amounts of self-similarity both in respect of borders and vegetation patches.
8. As seen from Fig. 6, one notes a significant positive correlation between the entropies of states and the maximum height (metres) recorded in those states, in accordance with the first inference

that variations in terrain height contribute to entropy. While such a significant correlation is absent for fractal dimensions, it is observed that the states having high fractal dimensions do possess high values of maximum heights.

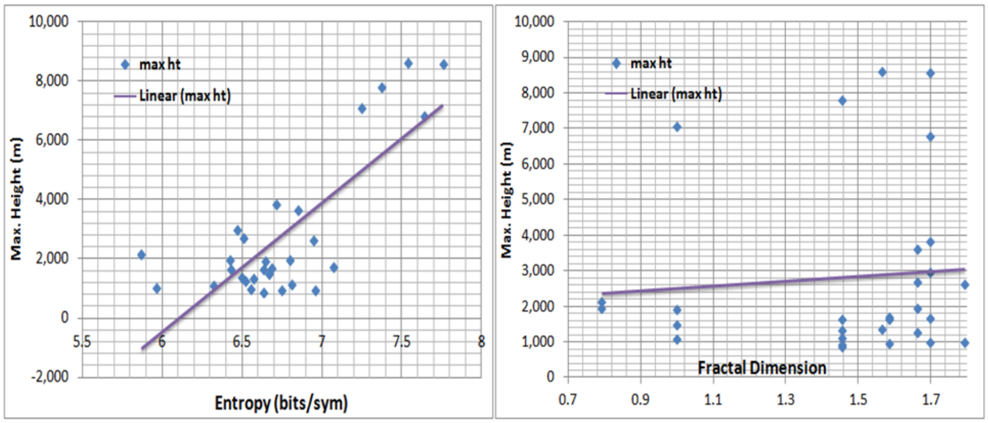

Figure 6 Entropy-Height and Fractal Dimension-Height Correlations

4. Conclusion

Motivated by the increasing popularity and applications of satellite imagery, the present article explores nonlinear analysis in satellite images of the 29 states of India. Specifically, two parameters, entropy and fractal dimension are considered, and computed for the 29 states. The inferences are discussed, where it is found that sharp and rich variations in terrain from green to arid or snow-clad mountainous regions contribute to high entropy, while rich variations in borders and varying scales of vegetation patches correspond to high fractal dimensions. The results obtained thus illustrate the significance and relevance of nonlinear analysis tools such as entropy and fractal dimension in satellite imagery.

References

[1] Leue, C., M. Wenig, T. Wagner, Oliver Klimm, U. Platt, and B. Jahne. "Quantitative analysis of NO x emissions from Global Ozone Monitoring Experiment satellite image sequences." Journal of Geophysical Research: Atmospheres (1984–2012) 106, no. D6 (2001): 5493-5505.

[2] Shepherd, Gordon G., G. Thuillier, W. A. Gault, B. H. Solheim, C. Hersom, J. M. Alunni, J-F. Brun et al. "WINDII, the wind imaging interferometer on the upper atmosphere research satellite." Journal of Geophysical Research: Atmospheres (1984–2012) 98, no. D6 (1993): 10725-10750.

[3] Goutorbe, J. P., Thierry Lebel, A. Tinga, P. Bessemoulin, J. Brouwer, A. J. Dolman, E. T. Engman et al. "HAPEX-Sahel: a large-scale study of land-atmosphere interactions in the semi-arid tropics." In Annales Geophysicae, vol. 12, no. 1, pp. 53-64. European Geosciences Union, 1994.

[4] Kaleschke, L., Christof Lupkes, T. Vihma, Jorg Haarpaintner, Axel Bochert, Jorg Hartmann, and Georg Heygster. "SSM/I sea ice remote sensing for mesoscale ocean-atmosphere interaction analysis." Canadian Journal of Remote Sensing 27, no. 5 (2001): 526-537.

[5] Entekhabi, Dara, Eni G. Njoku, Paul Houser, Michael Spencer, Terence Doiron, Yunjin Kim, Joel Smith et al. "The hydrosphere state (Hydros) satellite mission: An earth system pathfinder for global

mapping of soil moisture and land freeze/thaw." Geoscience and Remote Sensing, IEEE Transactions on 42, no. 10 (2004): 2184-2195.
[6] Verstraete, Michel M., Bernard Pinty, and Ranga B. Myneni. "Potential and limitations of information extraction on the terrestrial biosphere from satellite remote sensing." Remote Sensing of Environment 58, no. 2 (1996): 201-214.
[7] Maus, S., M. Rother, K. Hemant, C. Stolle, Hermannr Luhr, A. Kuvshinov, and Nils Olsen. "Earth's lithospheric magnetic field determined to spherical harmonic degree 90 from CHAMP satellite measurements." Geophysical Journal International 164, no. 2 (2006): 319-330.
[8] Hough, Harold. Satellite Surveillance. Breakout Productions Incorporated, 1991.
[9] Bader, M. J., G. S. Forbes, J. R. Grant, R. B. E. Lilley, and A. J. Waters. Images of weather forecasting: A practical guide for interpreting satellite and radar imagery. Cambridge University Press, 1995.
[10] Campbell, James B. Introduction to remote sensing. CRC Press, 2002.
[11] Shah, S. K. "Modelling the relationship between tree canopy projection area and above ground carbon stock using high resolution geoeye satellite images." PhD diss., MSc Thesis Unpublished, University of Twente (ITC), Enschede. Retrieved from http://www. itc. nl/library/papers_2011/msc/nrm/shah. pdf, 2011.
[12] Saito, Keiko, Robin JS Spence, Christopher Going, and Michael Markus. "Using high-resolution satellite images for post-earthquake building damage assessment: a study following the 26 January 2001 Gujarat earthquake." Earthquake Spectra 20, no. 1 (2004): 145-169.
[13] Altaweel, Mark. "The use of ASTER satellite imagery in archaeological contexts." Archaeological Prospection 12, no. 3 (2005): 151-166.
[14] Pan, Bing, John C. Crotts, and Brian Muller. "Developing web-based tourist information tools using google map." Information and Communication Technologies in Tourism 2007 (2007): 503-512.
[15] Kobayashi, Shinji, Tetsushi Fujioka, Yuji Tanaka, Michiyoshi Inoue, Yoshiyuki Niho, and Akira Miyoshi. "A geographical information system using the Google Map API for guidance to referral hospitals." Journal of medical systems 34, no. 6 (2010): 1157-1160.
[16] Scharf, Louis L. Statistical signal processing. Vol. 98. Reading, MA: Addison-Wesley, 1991.
[17] Moddemeijer, Rudy. "On estimation of entropy and mutual information of continuous distributions." Signal processing 16, no. 3 (1989): 233-248.
[18] Dougherty, Edward R. Random processes for image and signal processing. SPIE Optical Engineering Press, 1999.
[19] Sarkar, Nirupam, and Bidyut Baran Chaudhuri. "An efficient approach to estimate fractal dimension of textural images." Pattern Recognition 25, no. 9 (1992): 1035-1041.
[20] Chase, Clement G. "Fluvial landsculpting and the fractal dimension of topography." Geomorphology 5, no. 1 (1992): 39-57.