Application of harmonic analysis for the quantitative description of Earth surface topography

Kharchenko S.
Kazan Federal University, 420008, Kremlevskaya 18, Kazan, Russia

Abstract

The paper is focused at perspectives of Discrete Fourier Transform (DFT) as a tool for morphometric studies. Characterized are the mathematical basics and MathCAD algorithm of one- and two-dimensional DFT when applied to topographical profiles and digital elevation models (DEMs). One-dimensional DFT allows to replace an empirical spatial series with a periodic function as a sum of waves with different frequencies and wavelengths. Amplitude of each wave describes the contribution of the corresponding frequency to the total elevation variations along the studied profile, which allows to compare different harmonics (waves of certain frequency) in terms of their importance in shaping the Earth surface. Two-dimensional DFT allows also to determine the direction of wave distribution. In an ideal fractal erosional system in which different-order thalwegs have equal ranking both by width and by depth of incision, strict decrease of harmonic amplitude with increasing spatial frequency would occur. However this feature is only rarely occurring in the real Earth surface. Consequently, the DFT method can be used for spatial classification and regionalization according to topographic patterns formally described by harmonic components of the Earth surface elevation.

Keywords

References

[1] Bassett K. and Chorley R.J. An experiment in terrain filtering//Area. 1971. No. 3. P. 78-91.

[2] Pelletier J.D. Quantitative modeling of Earth surface processes. New York: Cambridge University Press, 2008. 325 p.

[3] Florinsky I. Digital terrain analysis in soil science and geology. Amsterdam: Elsevier Academic Press, 2012. 379 p.

[4] Peixoto J. P., Saltzman B., and Teweles S. Harmonic analysis of the topography along parallels of the Earth //Journ. of Geophys. Res. 1964. Vol. 69. No. 8. P. 1501-1505.

[5] Lee W.H.K, and Kaula W.M. A spherical harmonic analysis of the Earth's topography // Journ. of Geophys. Res. 1967. Vol. 72. No. 2. P. 753-758.

[6] Balmino G., Lambeck K., and Kaula W. A spherical harmonic analysis of the Earth's topography // Journ. of Geophys. Res. 1973. Vol. 78. No. 2. P. 478-481.

[7] Rapp R.H. The decay of the spectrum of the gravitational potential and the topography of the Earth // Geophysical Journ. Intern. 1989. No. 99. P. 449-455.

[8] Bills B.G. and Ferrari A.J. Mars topography harmonics and geophysical implications // Journ. of Geophys. Research. 1978. Vol. 83. No. B7. P. 3497-3508.

[9] Balmino G. The spectra of the topography of the Earth, Venus and Mars // Geophys. Research Letters. 1993. Vol. 20. No. 11. P. 1063-1066.

[10] Bills B.G. and Kobrick M. Venus topography: a harmonic analysis // Journ. of Geophys. Res. 1985. Vol. 90. No. B1. P. 827-836.

[11] Rozema W.J. The use of spectral analysis in describing lunar surface roughness// USGS Professional Paper 650-D. Washington: US Govern. Printing Office, 1968. P. 180-188.

[12] Bills B.G. A harmonic analysis of Lunar topography // ICARUS. 1977. No. 31. P. 244-259.

[13] Stone R. and Dugundji J. A study of microrelief: its mapping, classification, and quantification by means of a Fourier analysis // Engineering Geology. 1965. No. 1. P. 89-187.

[14] Nordin C.F. Statistical properties of dune profiles. USGS Prof. Paper 562-F. Washington: US Govern. Printing Office, 1971. 41 p.

[15] Pike R.J. and Rozema W.J. Spectral analysis of landforms // Annals of the Assoc. of American Geographers. 1975. Vol. 65. No. 4. P. 499-516.

[16] Fox C.G. and Hayes D.E. Quantitative methods for analyzing the roughness of the seafloor// Reviews of Geophysics. 1985. No. 23. P. 1-48.

[17] Chin A. The periodic nature of step-pool mountain streams // American Journ. of Science. 2002. Vol. 302. P. 144-167.

[18] Fredericksen P. Terrain analysis and accuracy prediction by means of the Fourier transformation // Photogrammetria. 1981. No. 36. P. 145-157.

[19] Nimes CR., Sarmento A.J.N.A., and O'Connor B.A. Statistical description of sand waves in a submerged bank // Transactions on the Built Environment. 1995. Vol. 9. P. 257-264.

[20] Preston F.W. and Harbaugh J.W. BALGOL program and geological applications for single and double Fourier series using IBM 7090/7094 computers. Kansas GS, Spectral Distribution Publication No. 24. Lawrence: Kansas GS, 1965. 72 p.

[21] Preston F. W. Two-dimensional power spectra for classification of landforms // Computer application in the Earth sciences: Colloquium on classification procedure (Kansas Computer Contribution No.7). Lawrence: Kansas GS, Univ. of Kansas, 1966. P. 64-69.

[22] Krumbein W.C. Classification of map surfaces based on the structure of polynomial and Fourier coefficient matrices // Computer application in the Earth sciences: Colloquium on classification procedure (Kansas Computer Contribution No. 7). Lawrence: Kansas GS, Univ. of Kansas, 1966. P. 12-18.

[23] EslerJ.E. and Preston F.W. FORTRAN IVprogram forthe GE625 to compute the power spectrum of geological surfaces. Kansas Computer Contribution No. 16. Lawrence: Univ. of Kansas, 1967. 22 p.

[24] Rayner J.N. Correlation between surfaces by spectral methods // Computer application in the Earth sciences: Colloquium on trend analysis (Kansas Computer Contribution No. 12). Lawrence: Kansas GS, Univ. of Kansas, 1967. P. 31-37.

[25] Clarke K.C Scale-Based Simulation of Topographic Relief // The American Cartographer. 1988. Vol. 15. No. 2. P. 173-181.

[26] Bruno G., Del Gaudio V., Mascia U., and Ruina G. Numerical analysis of morphology in relation to coastline variations and karstic phenomena in the southeastern Mugre (Apulia, Italy) // Geomorphology. 1995. No. 12. P. 313-322.

[27] Harrison J.M. and Lo Ch.-P. PC-based two-dimensional discrete Fourier transform programs for terrain analysis // Computers & Geosciences. 1996. Vol. 22. NO 4. P. 419-424.

[28] Perron J.T., Kirchner J. W., and Dietrich W.E. Spectral signatures of characteristic spatial scales and nonfractal structure in landscapes //Journ. of Geophys. Research. 2008. No. 113. P. 1-14.

[29] Booth A.M., RoeringJ.J., and Perron J.T. Automated landslide mapping using spectral analysis and high-resolution topographic data: Puget Sound lowlands, Washington, and Portland Hills, Oregon // Geomorphology. 2009. No. 109. P. 132-147.

[30] Steyn D.G. and Ayotte K. W. Application of Two-Dimensional Terrain Height Spectra to Mesoscale Modeling//Journ. of the Atmospheric Sc. 1985. Vol. 42. No. 24. P. 2884-2887.

[31] Brook G.A. and Hanson M. Double Fourier series analysis of cockpit and doline karst near Browns Town, Jamaica // Physical Geography. 1991. No. 12(1). P. 37-54.

[32] Jarvis R.S. Classification of nested tributary basins in analysis of drainage basin shape // Water Resources Research. 1976. Vol. 12. No. 6. P. 1151-1164.

[33] GoudieA. Geomorphological techniques. New York: Routledge, 1990. 709 p.

[34] Speight J.G. Meander spectra of the Angabunga River//Journ. of Hydrology. 1965. No. 3. P. 1-15.

[35] Hooke J.M. Changes in river meanders - a review of techniques and results of analyses // Progress in Physical Geography. 1984. No. 8(4). P. 473-508.

[36] Gallant J.C. and Hutchinson M.F. Towards an understanding of landscape scale and structure // 3rd Intern. Conf./Workshop on Integrating GIS and Environmental Modeling (21-26 January 1996). Santa Fe: National Center for Geographic Information and Analysis, 1996. P. 412-418.

[37] Zhang J., Atkinson P., and Goodchild M.F. Scale in Spatial Information and Analysis. Boca Raton: CRC Press, 2014. 367 p.

[38] Rayner J.N. The application of harmonic and spectral analysis to study of terrain // Spatial Analysis in Geomorphology. London: Methuen & Co Ltd., 1972. P. 283-302.

[39] Taylor J., Siegert M.J., Payne A.J., and Hubbard B. Regional-scale bed roughness beneath ice masses: measurement and analysis // Computers & Geosciences. 2004. No. 30. P. 899-908.