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Advanced Covariance-Based Stochastic Inversion and Neuro-Genetic Optimization for Rosetta CONSERT Radar Data to Improve Spatial Resolution of Multi-Fractal Depth Profiles for Cometary Nucleus

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The paper is devoted to results of doctoral research work at University of Bochum as applied to the radar transmission experiment CONSERT of the ESA cometary mission Rosetta. This research aims at achieving the limits of optimum spatial (and temporal) resolution for radar remote sensing by implementation of covariance informations concerned with error-balanced control as well as coherence of wave propagation effects through random composite media involved (based on Joel Franklin's approach of extended stochastic inversion). As a consequence the well-known inherent numerical instabilities of remote sensing are significantly reduced in a robust way by increasing the weight of main diagonal elements of the resulting composite matrix to be inverted with respect to off-diagonal elements following synergy relations as to the principle of correlation receiver in wireless telecommunications. It is shown that the enhancement of resolution for remote sensing holds for an integral and differential equation approach of inversion as well.

In addition to that the paper presents a discussion on how the efficiency of inversion for radar data gets achieved by an overall optimization of inversion due to a novel neuro-genetic approach. Such kind of approach is in synergy with the priority research program "Organic Computing" of DFG / German Research Organization. This Neuro-Genetic Optimization (NGO) turns out, firstly, to take into account more detailed physical informations supporting further improved resolution such as the process of accretion for cometary nucleus, wave propagation effects from rough surfaces, ground clutter, nonlinear focusing, etc. as well as, secondly, to accelerate the computing process of inversion in a really significantly enhanced and fast way, e.g., enabling online-control of autonomous processes such as detection of unknown objects, navigation, etc. The paper describes in some detail how this neuro-genetic approach of optimization is incorporated into the procedure of data inversion by combining inverted artificial neural networks of adequately chosen topology and learning routines for short access times with the concept of genetic algorithms enabling to achieve a multi-dimensional global optimum subject to a properly constructed and problem-oriented target function, ensemble selection rules, etc.

Finally the paper discusses how the power of realistic simulation of the structures of the interior of a cometary nucleus can be improved by applying Benoit Mandelbrot's concept of fractal structures. It is shown how the fractal volumetric modelling of the nucleus of a comet can be accomplished by finite 3D elements of flexibility (serving topography and morphology as well) such as of tetrahedron shape with specific scaling factors of self similarity and a Maxwellian type of distribution function. By applying the widely accepted fBm-concept of fractal Brownian motion basically each of the corresponding Hurst exponents 0 (rough) $< H < 1$ (smooth) can be derived for the multi-fractal depth (and terrain) profiles of the equivalent dielectric constant per tomographic angular orbital segment of intersection by transmissive radar ray paths with the nucleus of the comet. Cooperative efforts and work are in progress to achieve numerical results of depth profiles for the nucleus of comet 67P/Churyumov-Gerasimenko.