UDC 621.391:53.08

MULTILEVEL VARIATIONAL REGULARIZATION FRAMEWORK FOR FEATURE ENHANCED SENSING IN HARSH ENVIRONMENTS

Yuriy V. Shkvarko, Dr. Eng. Sc.

Center for Advanced Research and Education of the National Polytechnic Institute
Mexico, Guadalajara
shkvarko@gdl.cinvestav.mx

We address a new approach for feature-enhanced (FE) recovery of remote sensing (RS) imagery acquired by conventional low resolution systems operating in harsh environments. Our concept extends the descriptive experiment design regularization (DEDR) framework for the balanced RS image resolution enhancement over noise suppression via incorporating into the conventional DEDR the variational l_2-l_1 metrics structured sparsity preserving and convergence guaranteed regularization modalities. The new FE-DEDR technique outperforms the competing methods and admits efficient neural network computing based implementation.

Keywords: remote sensing, feature enhanced imaging, regularization, neural network computing.

1. Introduction: motivation and challenges in relation to prior work. In modern microwave remote sensing (RS) computational imaging applications [1–3], etc., the enhancement of low resolution RS imagery is stated and treated in a framework of nonparametric inverse problems of reconstructing the RS scattered field spatial spectrum pattern (SSP) i.e., an estimate of the average power reflectivity (the second order statistics) of the wavefield scattered from the 2-D extended remotely sensed scene referred to as its RS image. In harsh sensing environments, the SSP recovery inverse problem solution is complicated due to the random perturbations in the signal formation operator (SFO) and possible system calibration errors that cause multiplicative SFO degradations with the statistics unknown to an observer [3].

The challenging proposition is to solve such uncertain SSP recovery inverse problem with considerable resolution enhancement over noise suppression gains performed in an efficient speeded-up iterative fashion. To attain these goals, we propose to extend the descriptive experiment design regularization (DEDR) framework [2] for the balanced image resolution enhancement over noise suppression via incorporating into the conventional DEDR the additional feature enhancing (FE) variational l_2-l_1 metrics structured sparsity preserving and convergence guaranteed regularization modalities. We demonstrate (via extensive simulations studies) that the developed family of the multilevel FE-DEDR-related techniques outperform the most prominent competing methods in the literature [1–3] and feature the neural network (NN) computing based schemes [3] for efficient implementation of such FE-DEDR-related RS image recovery techniques.

2. Methodological and algorithmic developments. To develop the new framework for FE sensing in harsh environments we perform unification of the minimum risk inspired conventional DEDR method [2] with the dynamic variational analysis (VA) inspired total variation (TV) image enhancement paradigm [3]. Those incorporate the l_2-l_1 metrics-structured sparsity preserving regularizing projections onto convex solution sets (POCS) with adaptive adjustments of the DEDR-, the TV- and the POCS-level regularization degrees of freedom. Thus, our new FE-DEDR framework unifies the "model-based" DEDR approach for high-resolution space-time adaptive data processing [2] with the "model-free" VA-inspired dynamic TV-POCS paradigm [3] providing to the observer a possibility to control the order, the type and the amount of the employed multilevel regularization (at the DEDR level, at the TV level, and at the sparsity preserving POCS level, correspondingly) in the relevant adaptive RS imaging procedures. Our study reveals that with the aggregated FE-DEDR approach, the overall RS image enhancement performances are improved if compared with those obtained using the most prominent competing methods in the literature – the anisotropic diffusion [1], the nonparametric minimum variance distortionless response (MVDR) [2] and the adaptive beamforming employing the robust amplitude-phase estimator (APES)-based high-resolution RS imaging methods [3] that do not unify the DEDR, the VA and the sparsity preserving POCS regularization considerations.

3. NN implementation, simulations and concluding remark. To computationally implement the family of the developed FE-DEDR-related techniques we, first, transform those into the parallelized iterative procedures, and second, develop the Hopfield-type maximum entropy NN (MENN) computing scheme for their numerical implementation with the adaptively controlled MENN operational/structural parameters (neuron synaptic weights, axon thresholds and the overall MENN state updating rule).

In Figure 1, we report some qualitative results of enhancement of a fractional SAR image applying different FE-DEDR-related techniques specified in the figure captions. These results corroborate that the best FE reconstructive imaging performances are attained with the developed FE-DEDR-MENN method.

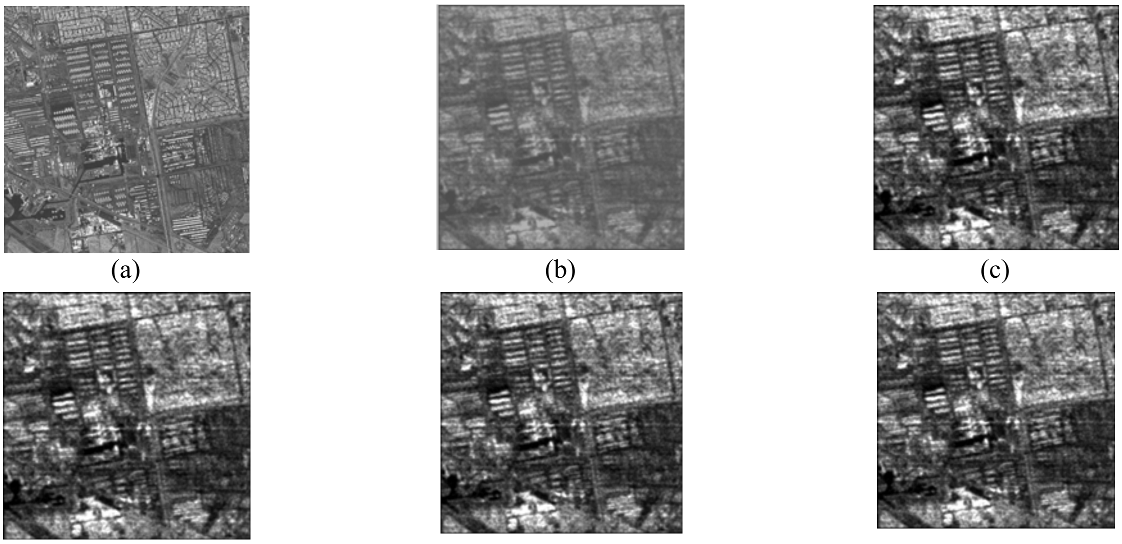

Fig. 1. Simulation results:

a — original high resolution 512×512-pixels test scene borrowed from the real-world high resolution SAR imagery [4] (not observable with the fractional SAR system); b — low resolution speckle corrupted radar image of the same scene (quick look fractional SAR mode with the fully developed speckle); c — image enhanced employing the VA-free MVDR method [2]; d — image enhanced using the DEDR-related APES method [3]; e — image enhanced with the most prominent competing dynamic DEDR-VA technique [3]; f — image reconstructed with the proposed multilevel l_2-l_1 metrics structured TV-POCS regularized FE-DEDR method implemented via MENN computing

REFERENCES

1. H.H. Barrett, K.J. Myers. Foundations of Image Science — New York: Willey, 2004.

2. Y.V. Shkvarko. Unifying experiment design and convex regularization techniques for enhanced imaging with uncertain remote sensing data // IEEE Trans. Geosc. Remote Sensing.— 2010. — Vol. 48. — No. 1. — pp. 82-111.

3. Y.V. Shkvarko, J. Tuxpan, S.R. Santos. Dynamic experiment design regularization approach to adaptive imaging with array radar/SAR sensor systems // Sensors. — 2011. — Vol. 11. — pp. 4483-4511.

4. COSMO SkyMed Images// Available at: http://www.cosmo-skymed.it/en/index.htm.

Ю. В. Шкварко

Многоуровневый вариационный регуляризационный подход к задачам качественно улучшенного дистанционного зондирования в критических операционных условиях.

Предлагается и обосновывается новый многоуровневый регуляризационный подход к формированию изображений дистанционного зондирования (ДЗ) с улучшенными характеристиками разрешения и подавления шумов, адаптированный к системам ДЗ, функционирующим в критических операционных условиях. Метод развивает концепцию планирования эксперимента с многоуровневой вариационной регуляризацией в l_2-l_1 метрически структурированных пространствах решений. Алгоритмически разработанный метод эффективно реализуются в форме параллелизированных численных процедур, адаптированных к вычислительным структурам на основе искусственных нейронных сетей.

Ключевые слова: *зондирование, планирование эксперимента, регуляризация, нейронные сети.*