FILTRATION AND ENHANCEMENT OF ENVIRONMENTAL CHARACTERISTICS EXTRACTED FROM SAR IMAGERY USING DYNAMIC KALMAN TECHNIQUE

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Abstract - In this study, we propose a new computational paradigm based on the use of the Kalman filtering technique adjusted to reconstruct the dynamic behavior of the physical and electrical characteristics of different environmental monitoring data provided via reconstructive SAR imagery. As a matter of particular study we develop and report the Kalman filter-based algorithm for high-resolution filtration of the dynamic behavior of the hydrological indexes of the particular real-world SAR images of the test remotely sensed scenes. The simulation results verify the efficiency of the proposed approach.

Keywords: Image Processing, Kalman Filtering, Remote Sensing, SAR.

I. INTRODUCTION

Modern applied theory of reconstructive signal and image processing for environmental monitoring is now a mature and well developed research field, presented and detailed in many works ([1], [2], [3] are only some indicative examples). Although the existing theory offers a manifold of statistical and descriptive regularization techniques to tackle with the particular environmental monitoring problems in many application areas there still remain some unresolved crucial theoretical and data processing problems related particularly to the extraction and enhancement of environmental characteristics and end-user computing aspects that incorporate the high-precision filtering techniques for evaluation and prediction the dynamic characteristics of the particular extracted environmental processes.

II. PROBLEM PHENOMENOLOGY

Radar/SAR ground return is described by the differential scattering cross section or scattering coefficient (scattering cross section per unit area) [3]. The total cross section of a patch of ground varies with the illuminated area and this is determined by the geometric SAR parameters (pulse width, beam width, etc.) and particular physical and electrical characteristics of the monitored scene. The use of a differential scattering cross section implies that the return from the ground is contributed by a large number of scattering elements whose phases are independent [3]. This is primarily because of differences in distance that, although small fractions of total distance, are many wavelengths. If this condition is not applicable to a particular ground target, the differential-scattering-cross-section concept has no meaning for that scene. Numerous programs to gather scattering coefficient data and extract and filter different physical characteristics of the monitored scenes were extensively developed and studied since 1972, but sizable data collections with accompanying "ground truth" were rare. In this study, we undertake the attempt to develop and verify via computational simulation a new particular filtering method that provides the possibility to extract, filter and predict the dynamical behavior of the physical characteristics extracted from the remotely sensed scenes provided with the high-resolution SAR data. The proposed methodology aggregates the Kalman filtering technique [5] with the high-resolution algorithms for enhanced SAR imagery [1], [2].

III. SUMMARY OF THE APPLIED KALMAN FILTERING TECHNIQUE

The most efficient statistical way to provide optimal linear estimation of the non-stationary random characteristics extracted from the SAR imagery is to apply the Kalman dynamic filtering technique [4].

The Kalman technique that we employ in this study [5] allows one to filter the state of dynamic behavior of the particular process under the study by using some specific a priori statistical information. We consider a discrete observation characteristic data ξ_v composed as a mixture of a discrete desired signal characteristic λ_v contaminated with white observation noise n_{ov} [5]. The basic observation and state equations [5] are given as

$$\xi_v = H_v\lambda_v + u_v + n_{ov} \quad \text{and} \quad \lambda_v = \beta_{v-1}\lambda_{v-1} + n_{\lambda v} \quad , \tag{1}$$

respectively. Here H_v represents the measurement coupling operator, u_v is a dynamic control function [5], β_v defines a transition function, n_{ov} represents a discrete white Gaussian observation noise with zero mean and variance D_{ov}, while $n_{\lambda v}$ is referred to as the system dynamic model zero-mean white Gaussian noise. The later is characterized by the variance $D_{\lambda v}$ and $\Delta(t_v\text{-}t_{v\text{-}1})$ represents a sample step in discrete time. The algorithm of optimal Kalman technique for precise filtering of the desired characteristics λ_v is determined by the set of the following evolutionary equations [4]

$$\hat{\lambda}_v = \beta_{v-1}\hat{\lambda}_{v-1} + k_v\left(\xi_v - u_v - H_v\beta_{v-1}\hat{\lambda}_{v-1}\right) \quad ; \tag{2}$$

$$\frac{1}{R_v} = \frac{1}{\beta_{v-1}^2 R_{v-1} + D_{\lambda v}} + \frac{H_v^2}{D_{ov}} \quad ; \tag{3}$$

$$k_v = H_v \cdot \frac{R_v}{D_{ov}} \ . \tag{4}$$

IV. COMPUTER SIMULATIONS

In the simulations, we considered the SAR with partially/fractionally synthesized array [1], [2] as a prime remote sensing imaging system. Figures from 1.a to 1.f show the 2-*D* 256-by-256 pixel format original scene images provided by the carrier SAR sensor system. These data was borrowed from the real-world remotely sensed SAR imagery of the tested scene of the Guadalajara region (Forest of Primavera) in Mexico. To study the dynamics of the particular hydrological indexes [3] of these scenes that were considered as the particular physical characteristics of interest, the experimental data covered the period of expertise from the year 2000 up to the year 2005, respectively. Figures 2.a and 2.b show the results obtained with the application of the Kalman technique algorithm summarized in the previous section for enhanced filtering of the dynamics of the hydrological indexes of the tested scenes. In the reported simulations we applied the a priori dynamic scene information modeled by (1).

V. DISCUSSIONS AND CONCLUDING REMARKS

In this work, a development of a specific Kalman filtering technique was undertaken and applied for high-resolution extraction and precise filtering of particular physical environmental characteristics (hydrological indexes) of the test monitored scenes provided by the SAR imagery. We analyzed the dynamical behavior of the hydrological indexes [3] studied in the normalized virtual time [4] related to the physical time of the dynamics of the characteristics under our particular study. To achieve the better precision of the filtered data, the reconstructed SAR imagery was employed as an initial filter data. Figure 1.f shows the reconstructed image of the tested particular scene (Guadalajara region), monitored in January 2005. Figure 1.a shows the same scene previously monitored in January 2000. The late data was used as a priori model information for the dynamic filtering algorithm (2)-(4) to obtain the resulting enhanced filtered indexes.

This study is intended to establish the foundation to assist in understanding the basic theoretical aspects of how to aggregate the enhanced SAR imaging techniques with the Kalman filtering for high-precision filtration of the dynamical behavior of the physical characteristics of the remotely monitored scenes, in our particular study, the dynamics of the hydrological indexes of the SAR maps of the particular tested terrestrial zones (Guadalajara region). The reported results can be also expanded to other fields related to the study of the dynamical behaviors of different physical characteristics provided by remote sensing systems of other particular implementations.

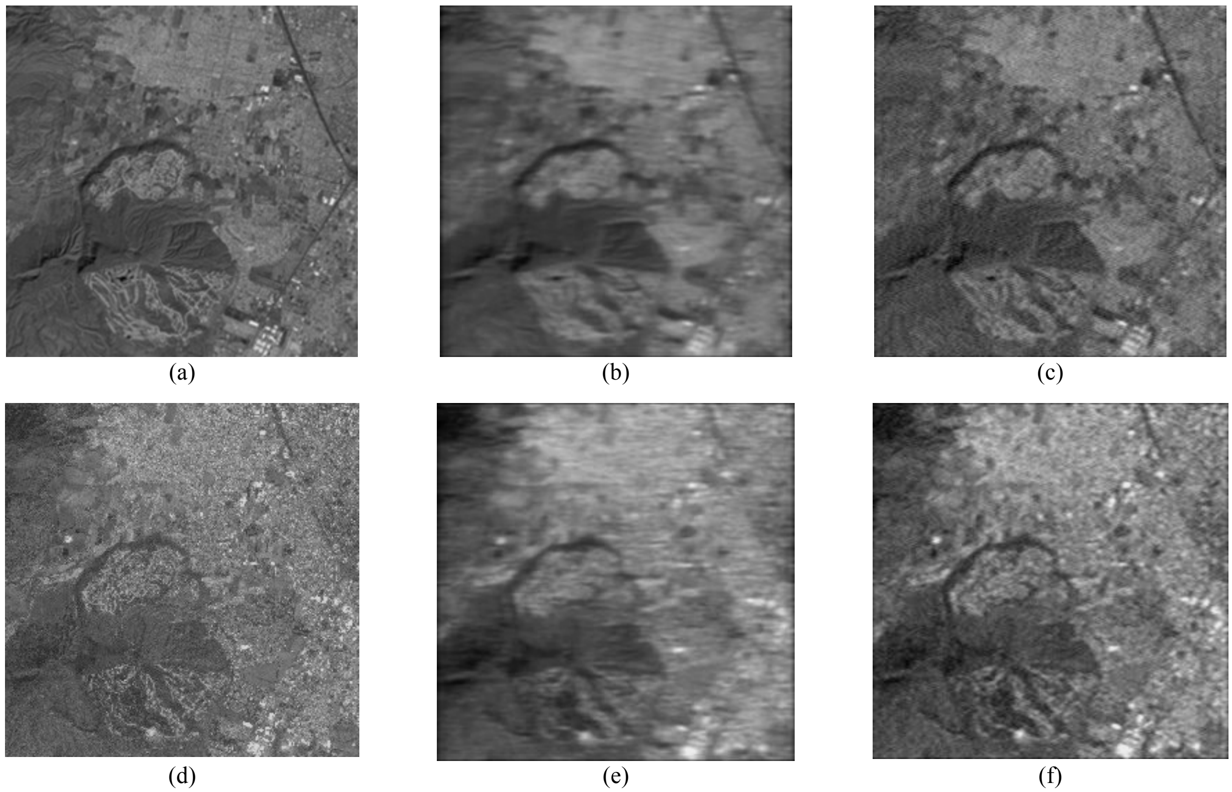

Figure 1. Tested SAR imagery: (a) Year 2000; (b) Year 2001; (c) Year 2002; (d) Year 2003; (e) Year 2004; (f) Year 2005.

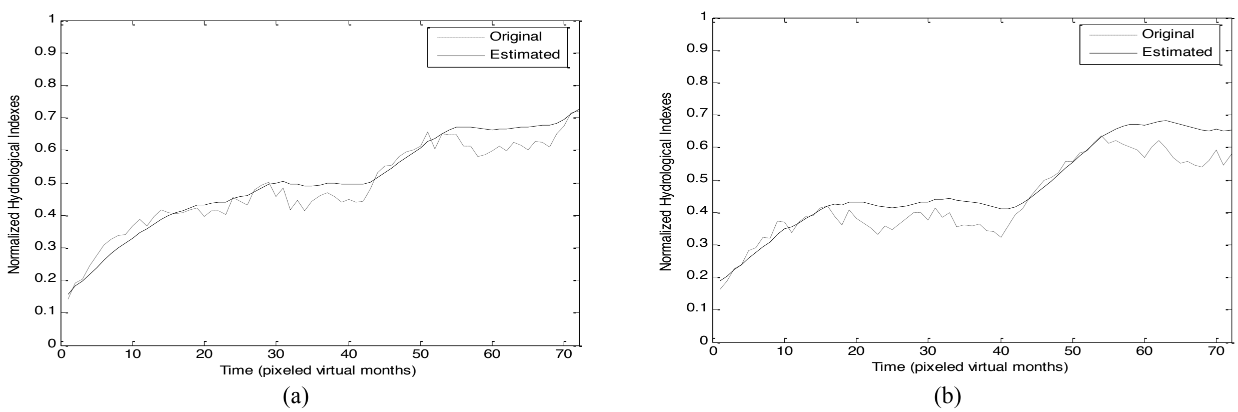

Figure 2. Dynamics of hydrological indexes (in the normalized virtual time):
(a) Results of filtering of the original degraded SAR data; (b) Results of filtering of the enhanced SAR data.

VI. REFERENCES

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