Data Mining Applications in Telecommunications

Doctoral thesis - Abstract

for obtaining the scientific title of doctor at

Polytechnic University of Timisoara

in PhD field: Electronic Engineering, Telecommunications and Information Technologies

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March 2022

Due to the unprecedented increase in the volumes of data transmitted in telecommunications recorded at the beginning of the 3rd millennium, Data Mining (DM) technology is increasingly used in complex applications based on image processing and on other signals from sensors (eg RADAR). The objective of this thesis is to diversify the algorithms for implementing the steps of the DM standard, proposing new methods of processing signals and images based on wavelets. The thesis contains a number of eight original contributions, scientifically validated by publications in the volumes of international conferences or prestigious journals.

This thesis aims to address a topical issue and to contribute to improving the performance of RADAR signal and image processing methods (especially Synthetic Aperture Radar-SAR type) using convex optimization methods and wavelets. These methods were conceived havin in mind two types of DM applications:

- for the monitoring of global phenomena deployed in different regions around the globe, and
- for the assistance to cars' drivers or to decisions making systems in case of driverless vehicles.

Chapter 1 represent the synthesis of the thesis and presents its content.

Chapter 2 reviews the wavelets' theory and their applications in image processing, introducing the main families of mother wavelets and different types of wavelet transforms: continuous, discrete, stationary, complex with dual tree, analytic (hyperanalytic: Hyperanalytic Wavelet Transform-HWT) or with wavelet packets.

A first contribution of the thesis is formulated in connection with the interpretation of the Hyperanalytic Wavelet Packets Transform-HWPT as a Principal Component Analysis (PCA) of an image. This original interpretation was published in an ISI-indexed conference paper:

G.A Magu, M. Kovaci, "Images' Principal Component Analysis using Hyperanalytic Wavelet Packets", 2018 International Symposium on Electronics and Telecommunications (ISETC), 1-4.

This implementation of the image's PCA allows the identification of the main orientations contained in that image and can be used in the data preparation phase of a DM project, to reduce the size of the image.

The main applications of wavelets in image processing: denoising, compression, contrast enhancement, edge detection and evaluation the surfaces' smoothness degree with the help of Hurst exponent local values are also presented in chapter 2.

The second contribution of the thesis refers to a new white Gaussian noise and speckle noise removing method from natural images and SAR images respectively, based on HWT.

The idea of this denoising method is the cooperation of two nonlinear filters: an improved

variant of bishrink filter and an Adaptive Soft Thresholding Filter-ASTF; in the field of HWT. The ASTF filter is the result of applying a convex optimization method called LASSO regularization. The results of the simulations performed prove the superiority of this method of denoising compared to other noise removal methods. A future research direction could be to replace HWT with HWPT, as HWPT is a more appropriate dictionary than HWT with a higher number of preferential orientations. The proposed denoising method could be used in the future as a preprocessing method in image processing applications that are insufficiently robust to noise. This contribution can also be used in the data preparation phase of a DM project.

The third original contribution of the thesis is a robust (against additive white Gaussian noise and multiplicative speckle noise) edges detection method in natural and SAR images which consists in the application of the Canny's edges detector after the application of the despeckling method already mentioned. These two related methods and their simulation results were published in an article in an ISI Q1 indexed journal:

A. Isar, C. Nafornita, G. Magu, "Hyperanalytic Wavelet-Based Robust Edge Detection", Remote Sensing 13 (15), 2888.

The edges detection results are remarkable. An important result from a practical point of view is the identification of radiolocation images' number of looks for which the use of the denoising system before the Canny's edge detector is still required. The proposed edge detection method is more suitable for radiolocation images than Machine Learning (ML) type methods, being much faster. This contribution of the thesis can be used in the modeling phase of a DM project as well.

The fourth contribution of the thesis refers to the evaluation of the degree of smoothness of some surfaces in the images. Because the smoothness of an area in a given region can be assessed by estimating the local Hurst exponent and because the estimation of the local Hurst exponent can be done using wavelets, the fourth contribution of the thesis is a wavelet based method of generating textures with Hurst exponent specified. This generation method can be used to calibrate the roughness estimation methods. The scientific validation of this method was done by publishing a BDI indexed article:

P. Gajitzki, A. Isar, G. Magu, "A New Algorithm for Fractional Brownian Motion Processes Generation", Acta Technica Napocensis 59 (1), 6-9.

The wavelet based generation method is completely justified theoretically, and the simulation results obtained are better than the results obtained using the Matlab function wfbm. The local method of estimating the Hurst exponent based on wavelet functions allows the evaluation of the roughness of some regions in the image and implicitly the detection of waves in an oceanic image, which can be used in the evaluation phase of a DM project.

Chapter 3 of this thesis proposes some methods of processing signals generated by RADAR sensors as the target detection method with Constant False Alarm Rate (CFAR) and targets' tracking methods.

The fifth contribution of the thesis is a method of detecting targets with a very low signal-to-noise ratio based on wavelets. The scientific validation of this contribution was made by publishing the following paper at an ISI indexed international conference:

A. Isar, C. Nafornita, A. Macaveiu, G. Magu, "Wavelet Based Adaptive Detection of Automotive Radar Single Target with Low SNR", 2020 International Symposium on Electronics and Telecommunications (ISETC), 1-6.

RADAR sensors that equip modern cars use the range-Doppler maps generated for each measurement cycle to detect targets. Instant target positions can be estimated based on the instantaneous distances between RADAR and targets by detecting local maxima in the range-Doppler map. In order to maintain a CFAR, it is necessary for the targets to have a sufficiently high signal-to-noise ratio so that the signals strengths from the targets are greater than the power of the disturbing signals (thermal noise and clutter). Therefore, the detection of a target is performed by comparing the value of the corresponding local maximum with a threshold whose value is chosen proportional to the power of the disturbing signals. This contribution of the thesis involves the application of a denoising operation to the image of the range-Doppler map prior to detection, which has the effect of artificially increasing the signal-to-noise ratio of the targets. The association between the two-dimensional DWT transformation and the hard thresholding filter was chosen as the denoising method.

The sixth, seventh and eighth contributions of the thesis consist of methods to reduce the uncertainty of target tracking methods based on implicit, explicit, and wavelets basedpolynomial matching, which have been scientifically validated by publishing two papers at ISI indexed international conferences:

G. Magu, R. Lucaciu, A. Isar, "Polynomial Based Kalman Filter Result Fitting to Data", 2020, 43rd International Conference on Telecommunications and Signal Processing, Milan, Italy

and

G. Magu, R. Lucaciu, "Multiple Radar Targets Tracking and Trajectories Fitting", 2020 International Symposium on Electronics and Telecommunications (ISETC), 11-14,

as well as of an article in a Q2 ISI indexed journal:

G. Magu, R. Lucaciu, A. Isar, "Improving the Targets' Trajectories Estimated by an Automotive RADAR Sensor Using Polynomial Fitting", Applied Sciences, 11 (1), 361.

To track the RADAR targets, usually there are used two algorithms: one for the association of data with targets (usually the Hungarian algorithm) and one for the targets' trajectories tracing (usually the Kalman filtering algorithm). Due to: some errors in estimating the position and relative speed of the targets, the presence of thermal noise of the receiver and of clutter, the missing data, some errors in modeling the kinematics of the targets for Kalman filtering; target tracking is affected by some uncertainty. This uncertainty can be reduced based on the conjecture that the trajectories of the targets are polynomials. The thesis proposes three methods to reduce the tracking's uncertainty. The first method of polynomial matching the target's trajectory is called implicit and the second method is called explicit. The third method of polynomial matching the trajectory of the target proposed in the thesis is based on wavelets.

In the data preparation phase of a DM project, the fifth contribution of the thesis could be used to detect the first of the RADAR targets that are located behind the car. In the modeling phase of this DM project, following the detection of targets and their tracking (performed by the cooperation between the Hungarian data association algorithm and the Kalman filters corresponding to each target) one of the three methods of polynomial matching of the trajectory could be used. Finally, in the evaluation phase of this DM project, the time instant when the distance between the car on which the RADAR sensor is mounted and the first car behind it falls below the distance corresponding to entering the blind spot can be detected and the driver's alarm can be triggered.

Chapter 4 is intended for the conclusions and presentation of the scientific contributions of the author of the thesis.