Weighted Pixel Statistics for Multispectral Image Classification of Remote Sensing Signatures: Performance Study

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Abstract — **The extraction of remote sensing signatures from a particular geographical region allows the generation of electronic signature maps, which are the basis to create a high-resolution collection atlas processed in continuous discrete time. This can be achieved using a new multispectral image classification approach based on pixel statistics for the class description. This is referred to as the Weighted Pixel Statistics Method. This paper explores the effectiveness of this novel approach developed for supervised segmentation and classification of remote sensing signatures, with a comparison with the traditional Weighted Order Statistics Method. The extraction of remote sensing signatures from real-world high-resolution environmental remote sensing imagery is reported to probe the efficiency of the developed technique.**

Keywords — **Image Segmentation, Image Classification, Remote Sensing, Statistics**

I. INTRODUCTION

Considerable progress has been made generally in the application of remote sensing techniques to both research and operational problems for urban planning and natural resource management. Modern applied theory of image processing for urban planning and natural resources management is now a mature and well developed research field, presented and detailed in many works ([1] thru [4] are only some indicative examples).

Although the existing theory offers a manifold of statistical techniques to tackle with the particular environmental monitoring problems, in many applications areas there still remain some unresolved crucial theoretical and data processing problems. One of them is particularly related to the extraction of physical characteristics (e.g., water, land cover, vegetation, soil, humid content, and dry content) for applications in natural resources management (modeling and planning).

The development of a novel tool for supervised segmentation and classification of remote sensing signatures (RSS) from multispectral remote sensing (MRS) imagery is based on the analysis of pixel statistics, and is referred to as the weighted pixel statistics (WPS) method.

II. WEIGHTED ORDER STATISTICS METHOD

The weighted order statistics (WOS) method has been long used for classification in remotely sensed images [1]. It basically is considered as a generalization of the median filter, and is characterized by a weight vector and a threshold value. The order statistics (OS) filtering methodology [2] shifts a $n \times n$ window $\mathbf{W}$ (with cardinality $n \times n$, i.e., $|\mathbf{W}| = n \times n$) over an input remote sensing (RS) image frame and, at each position of the frame, takes the $n \times n$ inputs ($w_{11}, w_{12}, \ldots, w_{ij}, \ldots, w_{nn}$) under $\mathbf{W}_{ij}$ and then outputs the r-th element of the sorted input.

The WOS method is a generalization of the OS filter that is characterized by a weight vector $\mathbf{Y}_{ij} = (\upsilon_1, \upsilon_2, \ldots, \upsilon_{n \times n})$ of $n \times n$ positive weight thresholds w, $0 \leq w \leq 255$ (gray-level threshold). To compute the output of the filter, each input w is duplicated to the number of corresponding weight υ, then they are sorted and the w-th order element (median) is chosen as the output. This is expressed as

$$\mathbf{WOS}_{ij} = median(\mathbf{Y}_{ij}) , \qquad (1)$$

where $\mathbf{WOS}_{ij}$ is the weighted order of the (i, j)-th pixel of the image.

The decision rule for classification based on the WOS filter determines that, based on the a priori information for class segmentation (number of classes to be classified and their respective thresholds), the WOS value for each image pixel is compared with the a priori thresholds (gray-level) and classified according to the most proximal value [4].

III. WEIGHTED PIXEL STATISTICS METHOD

Multispectral imaging is a technology originally developed for space-based imaging. Multispectral images are the main type of images acquired by RS radiometers. Usually, RS systems have from 3 to 7 radiometers; each one acquires one digital image (also called scene) in a small band of visible spectra, ranging 450 nm to 690 nm, called red-green-blue (RGB) regions [5].

For different purposes, combinations of spectral bands can be used. They are usually represented with red (R), green (G) and blue (B) channels. This is referred to as True-Color RS imagery [5].

The wavelengths for the spectral bands are as follows (the values are approximated, exact values depends on the particular RS instruments [6])

1) *blue*: 450-520 nm,

2) *green*: 520-600 nm,

3) *red:* 600-690 nm.

The WPS classificatory rule is computationally simple and this study shows that it can result in classification accuracy comparable to other more computationally intensive algorithms (WOS method [4]). It is characterized by the mean and variance values of the RSS signatures (classes) and the Euclidean distances based on the Pythagorean Theorem. An important aspect of this method is that it is applied to the MRS imagery.

The training data for class segmentation requires the number of RSS to be classified (c); the means matrix **M** ($c \times c$ size) that contains the mean values μ_{cc}: ($0 \leq \mu_{cc} \leq 255$, gray-level) of the RSS classes for each RGB bands; and the variances matrix **V** ($c \times c$ size) that contains the variances of the RSS classes for each RGB bands. The matrix **M** and **V** represents the weights of the classification process.

Next, the image is separated in the spectral bands (R, G and B) and each (i, j)-*th* pixel is statistically analyzed calculating the means and variances from a neighborhood set of *5x5* pixels for each RGB band, respectively.

To compute the output of the classifier, the distances between the pixel statistics and the training data is calculated using Euclidean distances based on the Pythagorean Theorem for means and variances, respectively.

The decision rule used by the WPS method is based on the minimum distances gained between the weighted training data and the pixel statistics.

The WPS techniques provide a high level of RSS segmentation and classification. Figure 1 shows the detailed processing structure of the WPS classifier.

The detailed stages of the computational algorithm of the WPS method for RSS classification of the MRS scenes is described as follows

1) Set the number of RSS to classify.

2) Select one point on the MRS image for each class to be classified.

3) Separate the spectral RGB band from the true-color MRS image.

4) The selected points determine the training weights that consist of the means matrix **M** and the variances matrix **V**. These matrixes contain the mean and variance of each point in the R, G and B bands, respectively.

5) For each (i, j)-th pixel in the R, G and B bands, respectively, perform the following process

Set a *5x5* pixel neighbourhood shift window **W**.

Determine the mean of the shift window **W**.

Determine the variance of the shift window **W**.

Calculate the Euclidean distances between the means and the training means for each band and for each class (Fig. 1).

Calculate the Euclidean distances between the variance and the training variances for each band and for each class (Fig. 1).

Select the minimum class distance for the means.

Select the minimum class distance for the variances.

Perform a comparison between the class distance for the mean and the class distance for the variance, and classify the pixel according to the minimum value and the class from which is obtained.

IV. VERIFICATION PROTOCOLS

To analyze the overall performance of the WPS technique, a set of three synthesized RGB images are used.

In the reported here simulation results, a set of three synthesized *1024x1024*-pixels RGB image in TIFF format are used to analyze the overall performance of the WPS technique, and moreover, a comparison with the results obtained with the classical WOS method.

Each synthesized image contains three different regions (in yellow, blue and black colors) with a different pattern; therefore, the WOS and WPS methods will classify three classes.
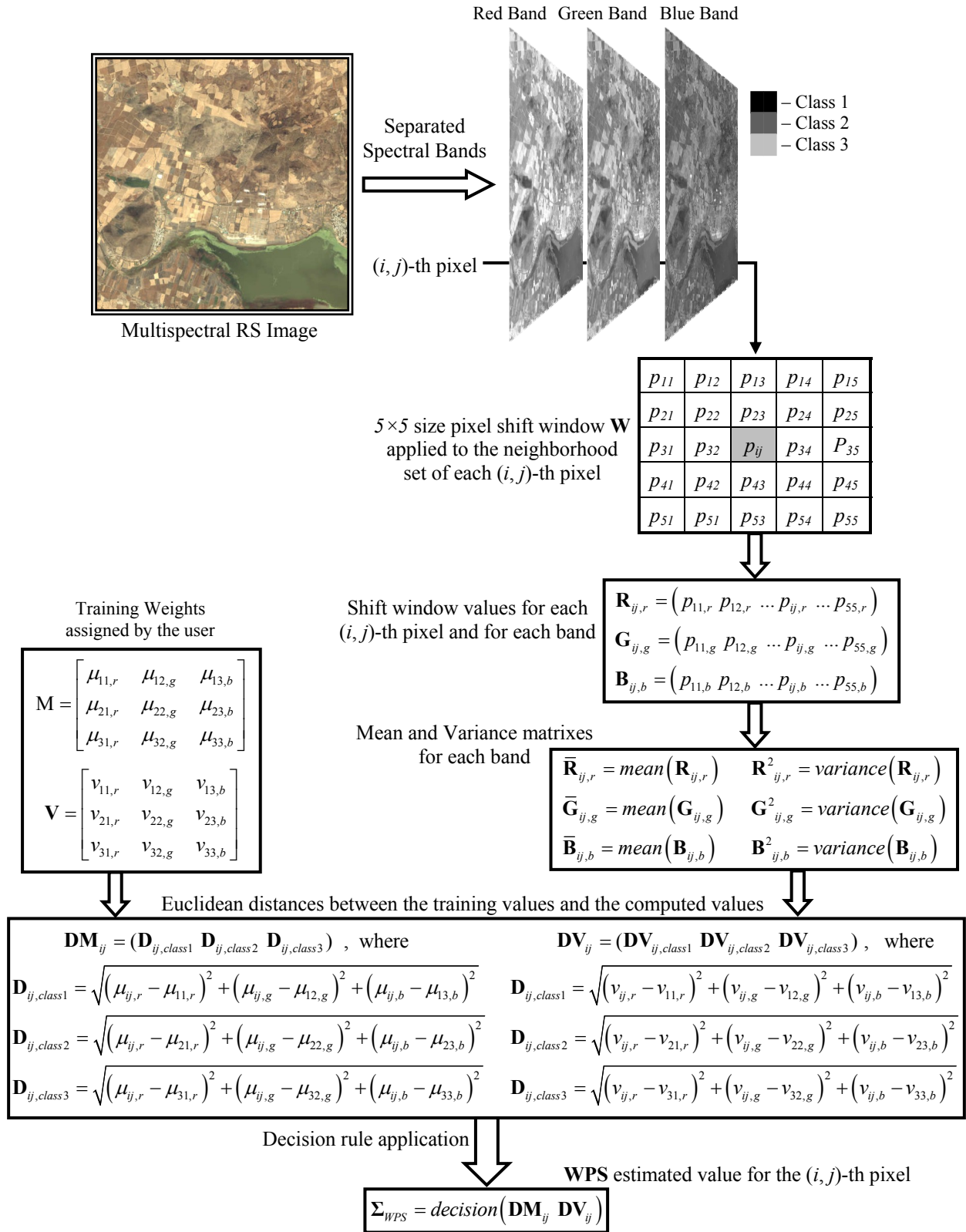
Red Band Green Band Blue Band

− Class 1
− Class 2
− Class 3

Separated
Spectral Bands

(i, j)-th pixel

Multispectral RS Image

p_{11}	p_{12}	p_{13}	p_{14}	p_{15}
p_{21}	p_{22}	p_{23}	p_{24}	p_{25}
p_{31}	p_{32}	p_{ij}	p_{34}	P_{35}
p_{41}	p_{42}	p_{43}	p_{44}	p_{45}
p_{51}	p_{51}	p_{53}	p_{54}	p_{55}

5×5 size pixel shift window **W**
applied to the neighborhood
set of each (i,j)-th pixel

Training Weights
assigned by the user

$$M = \begin{bmatrix} \mu_{11,r} & \mu_{12,g} & \mu_{13,b} \\ \mu_{21,r} & \mu_{22,g} & \mu_{23,b} \\ \mu_{31,r} & \mu_{32,g} & \mu_{33,b} \end{bmatrix}$$

$$\mathbf{V} = \begin{bmatrix} v_{11,r} & v_{12,g} & v_{13,b} \\ v_{21,r} & v_{22,g} & v_{23,b} \\ v_{31,r} & v_{32,g} & v_{33,b} \end{bmatrix}$$

Shift window values for each
(i,j)-th pixel and for each band

$$\mathbf{R}_{ij,r} = \left(p_{11,r}\ p_{12,r}\ ...p_{ij,r}\ ...p_{55,r} \right)$$
$$\mathbf{G}_{ij,g} = \left(p_{11,g}\ p_{12,g}\ ...p_{ij,g}\ ...p_{55,g} \right)$$
$$\mathbf{B}_{ij,b} = \left(p_{11,b}\ p_{12,b}\ ...p_{ij,b}\ ...p_{55,b} \right)$$

Mean and Variance matrixes
for each band

$$\overline{\mathbf{R}}_{ij,r} = mean\left(\mathbf{R}_{ij,r}\right) \qquad \mathbf{R}^2_{ij,r} = variance\left(\mathbf{R}_{ij,r}\right)$$
$$\overline{\mathbf{G}}_{ij,g} = mean\left(\mathbf{G}_{ij,g}\right) \qquad \mathbf{G}^2_{ij,g} = variance\left(\mathbf{G}_{ij,g}\right)$$
$$\overline{\mathbf{B}}_{ij,b} = mean\left(\mathbf{B}_{ij,b}\right) \qquad \mathbf{B}^2_{ij,b} = variance\left(\mathbf{B}_{ij,b}\right)$$

Euclidean distances between the training values and the computed values

$$\mathbf{DM}_{ij} = (\mathbf{D}_{ij,class1}\ \mathbf{D}_{ij,class2}\ \mathbf{D}_{ij,class3})\ ,\ \text{where}$$

$$\mathbf{D}_{ij,class1} = \sqrt{\left(\mu_{ij,r} - \mu_{11,r}\right)^2 + \left(\mu_{ij,g} - \mu_{12,g}\right)^2 + \left(\mu_{ij,b} - \mu_{13,b}\right)^2}$$
$$\mathbf{D}_{ij,class2} = \sqrt{\left(\mu_{ij,r} - \mu_{21,r}\right)^2 + \left(\mu_{ij,g} - \mu_{22,g}\right)^2 + \left(\mu_{ij,b} - \mu_{23,b}\right)^2}$$
$$\mathbf{D}_{ij,class3} = \sqrt{\left(\mu_{ij,r} - \mu_{31,r}\right)^2 + \left(\mu_{ij,g} - \mu_{32,g}\right)^2 + \left(\mu_{ij,b} - \mu_{33,b}\right)^2}$$

$$\mathbf{DV}_{ij} = (\mathbf{DV}_{ij,class1}\ \mathbf{DV}_{ij,class2}\ \mathbf{DV}_{ij,class3})\ ,\ \text{where}$$

$$\mathbf{D}_{ij,class1} = \sqrt{\left(v_{ij,r} - v_{11,r}\right)^2 + \left(v_{ij,g} - v_{12,g}\right)^2 + \left(v_{ij,b} - v_{13,b}\right)^2}$$
$$\mathbf{D}_{ij,class2} = \sqrt{\left(v_{ij,r} - v_{21,r}\right)^2 + \left(v_{ij,g} - v_{22,g}\right)^2 + \left(v_{ij,b} - v_{23,b}\right)^2}$$
$$\mathbf{D}_{ij,class3} = \sqrt{\left(v_{ij,r} - v_{31,r}\right)^2 + \left(v_{ij,g} - v_{32,g}\right)^2 + \left(v_{ij,b} - v_{33,b}\right)^2}$$

Decision rule application

WPS estimated value for the (i, j)-th pixel

$$\Sigma_{WPS} = decision\left(\mathbf{DM}_{ij}\ \mathbf{DV}_{ij}\right)$$

Fig. 1. Processing structure of the WPS method.

(a) – First synthesized RGB image.

(b) – WOS classification of the first synthesized RGB image for three classes.

(c) – WPS classification of the first synthesized RGB image for three classes.

(d) – Second synthesized RGB image.

(e) – WOS classification of the first synthesized RGB image for three classes.

(f) – WPS classification of the first synthesized RGB image for three classes.

(g) – Third synthesized RGB image.

(h) – WOS classification of the first synthesized RGB image for three classes.

(i) – WPS classification of the first synthesized RGB image for three classes.

Fig. 2. Simulation results for the synthesized RGB images.

Figures 2(a), (d) and (g) show the synthesized test RGB scenes. To perform the qualitative study, Figures 2(b), (e) and (h) show the results obtained with the WOS method. Figures 2(c), (f) and (i) show the results obtained with the developed WPS method.

Both, the WOS and WPS methods performs a good qualitative classification, nevertheless, Figure 3 shows some details from the classified synthesized images that probes the performance differences between the techniques.

The quantitative study is performed calculating the classified percentage obtained with the WOS and WPS methods, respectively, and compared with the original class quantities from the original synthesized scenes. Tables 1, 2 and 3 show the quantitative results.

The theory of the WOS method defines that the classification is performed only using one band [1]. The WPS method uses the three RGB bands to analyze the pixel-level means and variances to perform a more accurate segmentation and classification.

(a) – Detail of the second synthesized RGB image.

(b) – Detail of the obtained WOS classification for the second RGB image.

(c) – Detail of the obtained WPS classification for the second RGB image.

(g) – Detail of the third synthesized RGB image.

(e) – Detail of the obtained WOS classification for the third RGB image.

(f) – Detail of the obtained WPS classification for the third RGB image.
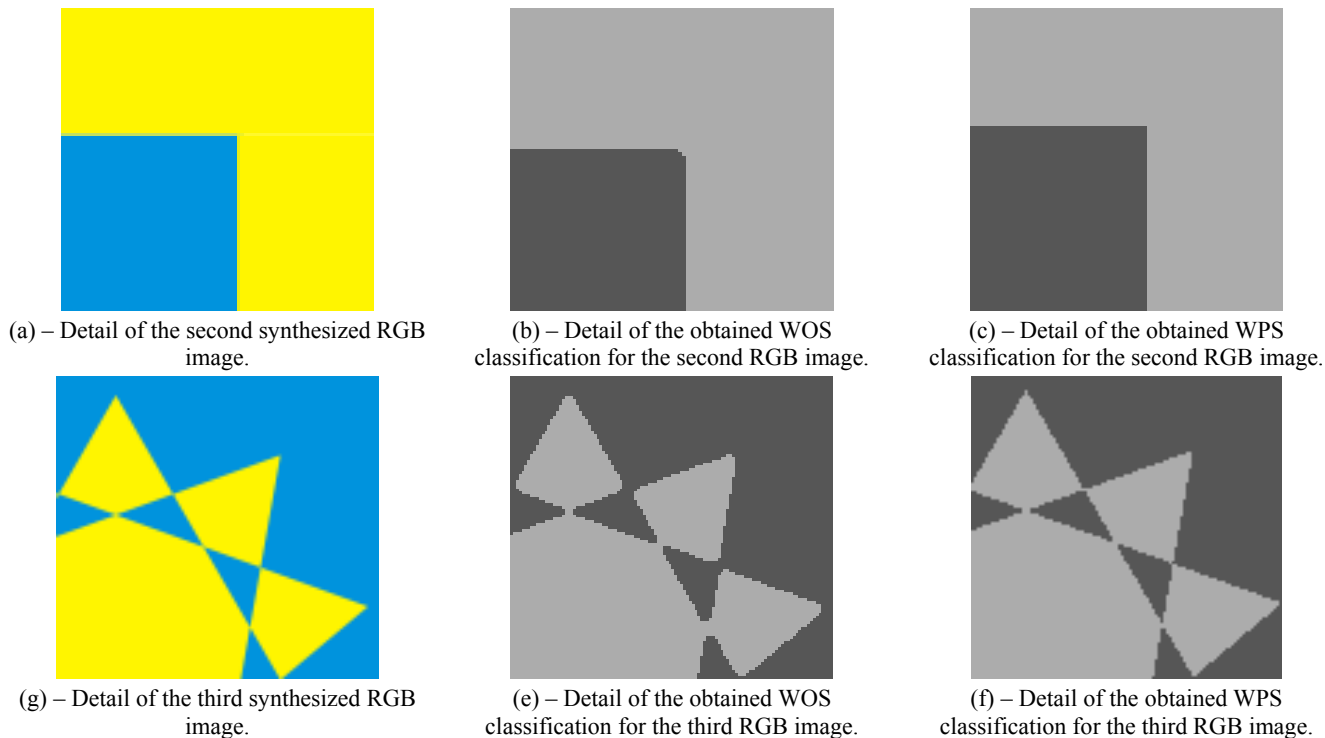
Fig. 3. Qualitative comparison of classification details.

TABLE 1
COMPARATIVE TABLE OF THE CLASS PERCENTAGES OBTAINED BY THE CLASSIFICATION METHODS – FIRST SYNTHESIZED IMAGE

Method →		WOS method		WPS method	
	Original Image	%	Difference	%	Difference
Class 1	23.17	22.96	+0.20	24.74	-1.58
Class 2	30.65	29.96	+0.69	29.46	+1.19
Class 3	46.18	45.33	+0.85	45.80	+0.38
Unclass.		1.75	+1.75	0.00	+0.00
Percentage Points Difference →		3.50%		3.15%	

TABLE 3
COMPARATIVE TABLE OF THE CLASS PERCENTAGES OBTAINED BY THE CLASSIFICATION METHODS – THIRD SYNTHESIZED IMAGE

Method →		WOS method		WPS method	
	Original Image	%	Difference	%	Difference
Class 1	14.17	14.94	-0.77	15.82	-1.65
Class 2	73.90	72.47	+1.43	72.82	+1.08
Class 3	11.93	10.83	+1.10	11.36	+0.57
Unclass.		1.75	+1.75	0.00	+0.00
Percentage Points Difference →		5.05%		3.30%	

TABLE 2
COMPARATIVE TABLE OF THE CLASS PERCENTAGES OBTAINED BY THE CLASSIFICATION METHODS – SECOND SYNTHESIZED IMAGE

Method →		WOS method		WPS method	
	Original Image	%	Difference	%	Difference
Class 1	31.33	31.22	+0.12	32.83	-1.50
Class 2	31.24	30.89	+0.35	30.88	+0.35
Class 3	37.43	36.15	+1.29	36.29	+1.14
Unclass.		1.75	+1.75	0.00	+0.00
Percentage Points Difference →		3.50%		2.99%	

From the details shown in Figure 3, the WPS method performs a more accurate and less smoothed identification of the classes.

Tables 1 to 3 show the quantitative performances. From this analysis, the WPS classified image provide a lower percentage points difference from the original synthesized RGB image than the WOS classified image. Moreover, the WOS provide some unclassified zones due to its decision rule application [4]; the WPS method classifies all the pixels due to the use of pixel-based statistical training data. These qualitative and quantitative results probe the overall performance of the developed WPS technique.
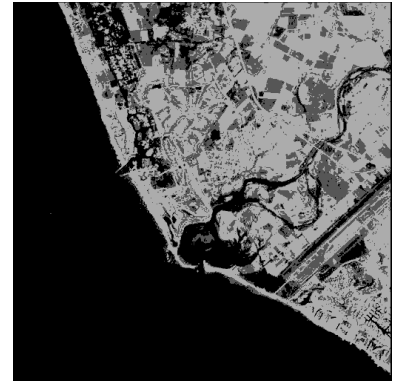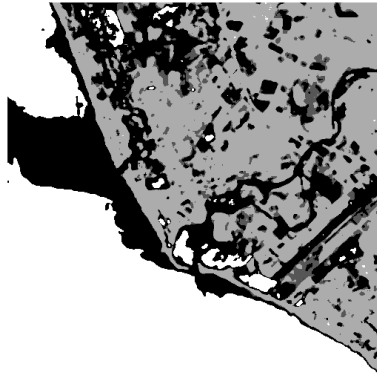
| (a) – Original high-resolution MRS image. | (b) – RSS map extracted with WOS. | (c) – RSS map extracted with WPS. |

Fig. 4. Preliminary simulation results for RSS maps extraction from MRS imagery.

V. RSS SIMULATION EXPERIMENT

In the reported here simulation results, a RSS electronic map is extracted from the MRS high-resolution image using the WOS and WPS methods. Three level RSS are selected for this particular simulation process, moreover, unclassified zones must be also considered (2-bit classification) as

■ – RSS relative to the wet zones of the MRS image.
▨ – RSS relative to the humid zones of the MRS image.
▧ – RSS relative to the dry zones of the MRS image.
□ – Unclassified zones of the RSS map.

Figure 4(a) shows the MRS high-resolution *1024x1024*-pixels RGB image in TIFF format borrowed from the real-world [7] corresponding to the Banderas Bay in the city of Puerto Vallarta in Mexico. Figure 4(b) shows the RSS map obtained applying the WOS method for the adopted ordered weight vector. Figure 4(c) shows the RSS maps obtained applying the WPS method.

The WOS method employs only one band to perform the classification [1], for this simulation the G band was used. The resulting RSS map shows a large unclassified zone, this is due to the color gradient present on the original MRS image and the lack of supervised data [4]. The WPS method employs all three RGB bands; therefore, using the statistical pixel-based information the RSS map obtained shows a high-accurate classification without unclassified zones.

VI. CONCLUDING REMARKS

From the simulation results one may deduce that the WOS classifier generates several unclassified zones; while the developed WPS classifier provides a high-accurate classification without unclassified zones because it uses more robust information in the processing (several image spectral bands).

The reported here simulation results shows the qualitative analysis of the overall performance of the WPS method, the quantitative analysis is a matter of further studies.

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