Optimizing multiresolution segmentation for extracting plastic greenhouses from WorldView-3 imagery

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Abstract. Multiresolution segmentation (MRS) has been pointed out as one of the most successful image segmentation algorithms within the object-based image analysis (OBIA) framework. The performance of this algorithm depends on the selection of three tuning parameters (scale, shape and compactness) and the bands combination and weighting considered. In this work, we tested MRS on a WorldView-3 bundle imagery in order to extract plastic greenhouse polygons. A recently published command line tool created to assess the quality of segmented digital images (AssesSeg), which implements a modified version of the supervised discrepancy measure named Euclidean Distance 2 (ED2), was used to select both the best aforementioned MRS parameters and the optimum image data source derived from WorldView-3 (i.e., panchromatic, multispectral and atmospherically corrected multispectral orthoimages). The best segmentation results were always attained from the atmospherically corrected multispectral WorldView-3 orthoimage.

Keywords: Segmentation, Multiresolution algorithm, Object Based Image Analysis, WorldView-3, AssesSeg

1 Introduction

The latest breed of very high resolution (VHR) commercial satellites successfully launched over the last decade (e.g., GeoEye-1, WorldView-2, WorldView-3 and WorldView-4) has marked a turning point in the field of remote sensing. These satellites provide improved capability to acquire impressive high spatial resolution images with ground sample distances (GSD) of 0.5 m or even less, being able to capture four, eight or even more multispectral (MS) bands. VHR satellite images are being increasingly used in remote sensing. Moreover, most of the Land Use/Land Cover (LULC) remote sensing classification research works from this type of satellite images were conducted using object-based image analysis (OBIA) techniques [1,2,3,4,5,6,7].

adfa, p. 1, 2011.

OBIA techniques are based on aggregating similar pixels to obtain homogenous segments (often referred to as objects). Then the image classification is performed on objects (rather than pixels) by using meaningful features related to spectral (e.g. mean spectral values), shape, texture and context information associated with each object, so having a great potential to efficiently handle more difficult image analysis tasks [8,9,10], especially when working on VHR satellite images. The quality of the segmentation significantly influences the final results of OBIA approaches [10, 11] since it is this first stage that generates image objects and determines their corresponding attributes.

Image segmentation is influenced by many factors such as image quality, number of spectral bands, spatial resolution and scene complexity [12, 13]. There exist several types of image segmentation algorithms which largely depend on the specified parameters, so implying that segmentation is not an easy task. Among existing algorithms, multiresolution segmentation (MRS) available in the eCognition software (Trimble, Sunnyvale, California, United States) has been the most widely and successfully employed under the context of remote sensing OBIA applications [9], [14]. Scale, shape, compactness and bands combination and weighting are the main tuning parameters that affect the algorithm performance. More details about MRS can be found in the work published by Baatz and Schäpe [15].

The selection of the optimum MRS parameters is often a tedious trial-and-error process. Fortunately, a few tools have been recently addressed to help the user with this task. For instance, Estimation of Scale Parameters tool for a single band (ESP tool) [16] and for multiband images (ESP2 tool) [12] are being widely applied as an unsupervised method to estimate the optimum scale parameter of MRS algorithm. More recently, Novelli et al. [17] have published a new free of charge command line tool named AssesSeg, thought to assess the quality of segmented digital images. It implements a modified version of the Euclidean Distance 2 (ED2) supervised discrepancy measure proposed by Liu et al. [18]. AssesSeg tool has been already successfully tested to estimate the best segmentation from Sentinel-2, Landsat 8 and WorldView-2 imagery [17], [19]. Moreover, Aguilar et al. [20] tested both ESP2 tool and ED2 method for extracting plastic greenhouses by means of MRS segmentation from an atmospherically corrected MS WorldView-2 orthoimage. ED2 metric was also used by Aguilar et al. [21] to select the optimum MRS parameters from a couple of WorldView-2 MS images geometrically and atmospherically corrected.

In this way, many researches dealing with segmentation within OBIA framework have been conducted on different VHR image sources such as (i) panchromatic (PAN) images [22], (ii) VHR pansharpened images [12], (iii) VHR atmospherically corrected MS images [17], [19,20,21] and, finally, (iv) VHR MS images preserving the original digital numbers [23].

At this point, it is worth highlighting that this work takes part in a research project aimed at extracting plastic greenhouses from satellite imagery. The segmentation stage is faced by estimating the optimum tuning parameters (i.e., scale, shape, compactness and bands combination) of MRS algorithm in order to delineate plastic greenhouses from a WorldView-3 bundle image (PAN and MS images) under an OBIA framework. To the best knowledge of the authors, this is the first research work headed up to test several VHR image sources (WorlView-3 PAN, MS and atmospherically corrected MS orthoimages) to search for the best segmentation results in the case study of plastic greenhouses.

2 Study Site and Datasets

2.1 Study site

The test area is located in the “Sea of Plastic”, province of Almería (Southern Spain) characterized by the greatest concentration of greenhouses in the world. The study area comprised a rectangle area of about 8000 ha centered on the WGS84 geographic coordinates of 36.7824°N and 2.6867°W (Fig. 1).

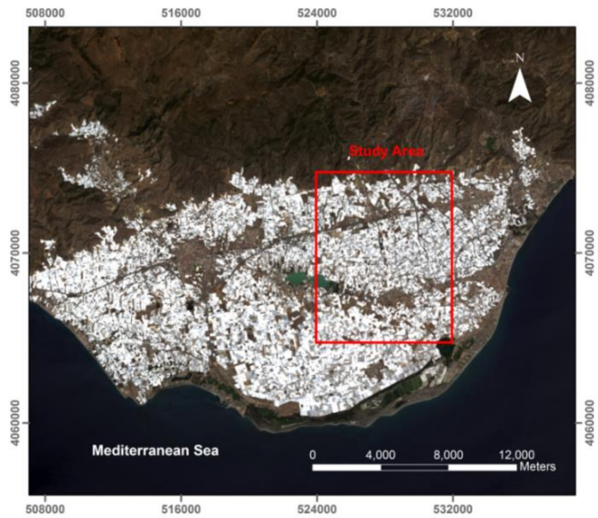

Fig. 1. Location of the study area. Coordinate system: ETRS89 UTM Zone 30N.

2.2 WorldView-3 Data

WorldView-3 (WV3) is a VHR satellite successfully launched on August 13, 2014. This sensor provides optical images with 0.31 m and 1.24 m GSD at nadir in PAN and MS mode, respectively. The MS image is composed by 8 bands: coastal (C, 400-450 nm), blue (B, 450-510 nm), green (G, 510-580 nm), yellow (Y, 585-625 nm), red (R, 630-690 nm), red edge (RE, 705-745 nm), near infrared-1 (NIR1, 770-895 nm) and near infrared-2 (NIR2, 860-1040 nm).

A single WV3 image taken on July 5, 2016 on the study area was acquired. It was collected in Ortho Ready Standard Level-2A (ORS2A) format, containing both PAN and MS 8 bands imagery. This satellite image had a mean off-nadir view angle of 22.2°, mean collection azimuth of 273.6° and 0% of cloud cover. The final product GSD turned out to be 0.3 m and 1.2 m for PAN and MS images, respectively. All delivered products were ordered with a dynamic range of 11-bit and without the application of the dynamic range adjustment preprocessing.

Three different orthoimages were generated from this WV3 ORS2A bundle image by using seven very accurate ground control points and a medium resolution 10 m grid spacing photogrammetric-derived DEM with a vertical accuracy of 1.34 m (root mean square error; RMSE): i) PAN othoimage with 0.3 m GSD and retaining the original digital numbers in its single band; ii) MS orthoimage with 1.2 m GSD and retaining the original digital numbers in all the 8 bands; iii) MS ATCOR orthoimage with 1.2 m GSD and atmospherically corrected (ground reflectance) by using the ATCOR (atmospheric correction) module included in Geomatica v. 2016.

2.3 Reference Greenhouses

This work is focused on optimizing automatic plastic greenhouses delineation from applying MRS algorithm on WV3 satellite imagery, so it has been only considered one land cover or class. Up to 400 polygons representing individual plastic greenhouses were manually digitized on the whole working area onto the WV3 PAN orthoimage, but also using the information provided by the WV3 MS orthoimage so that to have a representative sample of all the greenhouses of the study area. These 400 polygons or reference geometries were grouping in four sets of 100, 200, 300 and 400 greenhouses, all of them presenting an even spatial distribution around the study area. These sets of reference geometries were applied to study the influence of the number of references on the supervised segmentation quality assessment undertaken by using AssesSeg. In this regards, it is important to know that only 30 polygons per class have been considered in previous segmentation quality studies [18], [23].

3 Methodology

3.1 Image segmentation

The image segmentation method tested in this research was the MRS algorithm included into the OBIA software eCognition v. 8.8. The outcome of MRS algorithm is controlled by three main factors: (i) scale parameter (Scale), determining the maximum allowed heterogeneity for the resulting segments, (ii) weight of color and shape criteria in the segmentation process (Shape), and (iii) weight of the compactness and smoothness criteria (Compactness). The users also have to decide the bands combination and their corresponding weights to be applied in the segmentation process.

This segmentation approach is a bottom-up region-merging technique starting with one-pixel objects or seeds. In numerous iterative steps, two smaller objects are merged into larger one [15] if the corresponding fusion factor results to be less than the square of scale factor, given that local mutual best fitting is true. This heuristic based on mutual best fitting allows finding the best fitting pair of objects in the local vicinity of a seed object following the gradient of homogeneity.

Fusion factor (f) is computed from the weighted combination of shape and color heterogeneity (equation 1), while Δh_{color} expresses difference in spectral heterogeneity (equation 2).

$$f = w_{color} \Delta h_{color} + w_{shape} \Delta h_{shape} \quad (1)$$

$$\Delta h_{color} = \sum_{c} w_c \left(n_{merge} \sigma_{c,merge} - \left(n_{Obj1} \sigma_c^{Obj1} + n_{Obj2} \sigma_c^{Obj2} \right) \right) \quad (2)$$

Where n_{merge}, n_{Obj1} and n_{Obj2} being the number of pixels in the merged object, object 1 and object 2, respectively. The terms $\sigma_{c,merge}$, σ_c^{Obj1} and σ_c^{Obj2} would represent standard deviations of the merged object, object 1 and object 2, while w_c being the weight chosen for the c spectral band.

Thousands of segmentations from applying MRS algorithm were computed by means of a semi-automatic eCognition rule set characterized by a looping process varying the aforementioned MRS tuning parameters. From the results provided in Aguilar at al. [20], the tested Shape values ranged from 0.1 to 0.5 with a step of 0.1, whereas Compactness was fixed to 0.5 in all cases. Regarding Scale parameter, it ranged from 175 to 250, 30 to 95 and 1050 to 1200, always setting a step of 1, for the cases of MS orthoimage, MS ATCOR corrected orthoimage and PAN orthoimage, respectively. According to Novelli et al. [17], the bands combination for MS and MS ATCOR corrected orthoimages was fixed to Blue-Green-NIR2 bands equally weighted. In the case of PAN orthoimage, only the PAN single band was used.

3.2 Segmentation assessment

Although there are several supervised methods and metrics to quantitatively asses segmentation quality, the ED2 measure proposed by Liu et al. [18] has provided very good results working on plastic greenhouses [20]. In a nutshell, ED2 aims to optimize, onto a two dimensional Euclidean space, both the geometrical discrepancy (potential segmentation error (PSE)) and the arithmetic discrepancy between image objects and reference polygons (number-of-segmentation ratio (NSR)).

In this work, the selection of the best three MRS parameters for each WV3 image data was carried out through a modified version of ED2 including in a command line tool named AssesSeg. Full details about the modified ED2 measure as well as the standalone command line tool (AssesSeg.exe) can be found in a recently published work by Novelli et al. [19]. As a supervised segmentation quality metric, the modified ED2 works with a set of reference objects (i.e., those reference greenhouses or geometries explained in section 2.3) to evaluate segmentation goodness.

It is important to note that a modified ED2 value of zero would indicate an optimal combination of both geometric and arithmetic match. An optimum geometric match would be related to the absence of over-segments or under-segments. The best arithmetic match would occur when a reference polygon only matches a calculated object MRS. The ideal segmentation will be pointed out by the minimum value of modified ED2 measure.

4 Results and discussion

The optimum segmentations for each image data (i.e., PAN, MS and MS ATCOR orthoimages) were based on the minimum value of the modified ED2 metric computed for each set of reference geometries (i.e., 100, 200, 300 and 400 polygons). The modified ED2 presented a very good agreement with the visual quality of the greenhouse segmentations for all the studied cases. For instance, Figure 2 depicts the values of modified ED2 computed for each segmentation extracted from the WV3 MS ATCOR orthoimage against the 100 reference geometries set. The fixed parameters were band combination (Blue-Green-NIR2) and Compactness (0.5), while Shape and Scale were kept variable. In this case, the minimum value of modified ED2 was obtained for Shape and Scale values of 0.4 and 50, respectively (Fig. 2).This figure also allows to appreciate the importance of testing a wide range of parameters to find out the ideal segmentation. Notice that ESP tool or ESP2 tool [16, 17] only search for the optimum scale parameter of MRS algorithm.

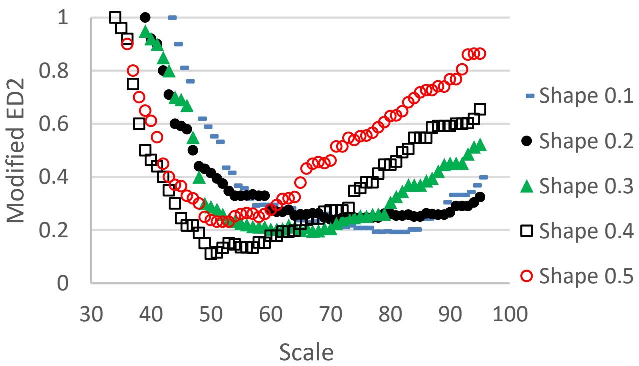

Fig. 2. Modified ED2 computed by using AssesSeg for all MRS outputs (MS ATCOR orthoimage and 100 reference geometries). Best estimated segmentation: Scale = 50 and Shape = 0.4

Table 1 depicts the best MRS parameters according to the final values of modified ED2 obtained for each image source and reference geometries set. We can make out that regarding the best plastic greenhouse segmentations, the WV3 MS ATCOR orthoimage turned out to be the best image source with modified ED2 values ranging from 0.112 to 0.146. The WV3 PAN orthoimage yielded modified ED2 values between 0.178 and 0.203, clearly worse than those provided by MS ATCOR corrected orthoimage in spite of presenting higher spatial resolution. Finally, the WV3 MS original orthoimage, with 1.2 m GSD, produced modified ED2 measures slightly worse than PAN image data (0.193 - 0.221). In addition, the optimum Shape parameter seems to be related to the image data source. Because of that, the recommendations by Aguilar et al. [20, 21] about Shape parameter selection for plastic greenhouses segmentation should be taken carefully.

Table 1. Optimum MRS outputs (i.e., minimum ED2 values) for the different image data tested and every set of reference geometries.

Image Source	No. Reference Geometries	Segmentation Parameters			Modified
		Scale	Shape	Compactness	
MS (bands: Blue-Green-NIR2)	400	210	0.5	0.5	0.205
	300	221	0.5	0.5	0.207
	200	220	0.5	0.5	0.193
	100	195	0.5	0.5	0.221
MS ATCOR (bands: Blue-Green-NIR2)	400	60	0.4	0.5	0.141
	300	68	0.3	0.5	0.146
	200	68	0.3	0.5	0.129
	100	50	0.4	0.5	0.112
PAN (band: PAN)	400	1152	0.4	0.5	0.183
	300	1150	0.4	0.5	0.178
	200	1099	0.4	0.5	0.179
	100	1101	0.4	0.5	0.203

Regarding the number of polygons involved in computing the modified ED2 metric to be applied in plastic greenhouses, MRS parameters keeps stable as from 200. It points out to the necessity to count on a high number of reference geometries bearing in mind that only 30 references have been considered in previous segmentation quality studies [18], [23].

Figure 3 depicts a visual comparison restricted to a detailed area between the optimum segmentations attained by using the 100 reference geometries and modified ED2. Figure 3a shows the reference geometries (red polygons), each one representing a single plastic greenhouse. Figures 3b, 3c and 3d display the corresponding PAN, MS and MS ATCOR derived segmentations, respectively. We can see that the reference geometry marked with an orange ellipse represents a greenhouse which is showing strong strip shapes corresponding to ventilation roof windows. These windows resulted to be individually segmented when PAN orthoimage, with high spatial resolution (0.3 m) and pixel values given as digital numbers ranging from 225 to 2366, was used as image source (Fig. 3b). These strips were only partially segmented when using the MS orthoimage (Fig. 3c), having worse geometric resolution (1.2 m) but also presenting pixel values given as digital numbers (ranging from 201 to 2154 in the case of the Green band). Finally, the roof windows were completely ignored when employing the MS ATCOR corrected orthoimage (Fig. 3d) with 1.2 m GSD and pixel values expressing ground reflectance ranging from 0 to 100%. It is worth noting that the application of atmospheric correction in the ATCOR corrected orthoimage involved a substantial reduction in the quantitative range of values or pixel relative mapping positions available for assigning pixel content (from 1 to 100% in the case of ground reflectance). This numerical effect, together with the mathematical formulation of the fusion factor or threshold employed for grouping pixels in the MRS algorithm (see equation 2), would imply that the higher the range of the pixel mapping content the larger the number of objects would be segmented for a certain Scale parameter. In fact, increasing heterogeneity, measured through standard deviation of neighboring pixels/objects, can be expected when dealing with images presenting higher relative differences in pixel content values. This effect would also explain why the optimum Scale parameters result to be significantly higher in the case of MS orthoimages as compared to MS ATCOR corrected ones (Table 1). In this sense, the WV3 MS ATCOR product achieved a more realistic segmentation of the individual greenhouses, avoiding the over-segmentation due to the existence of roof windows.

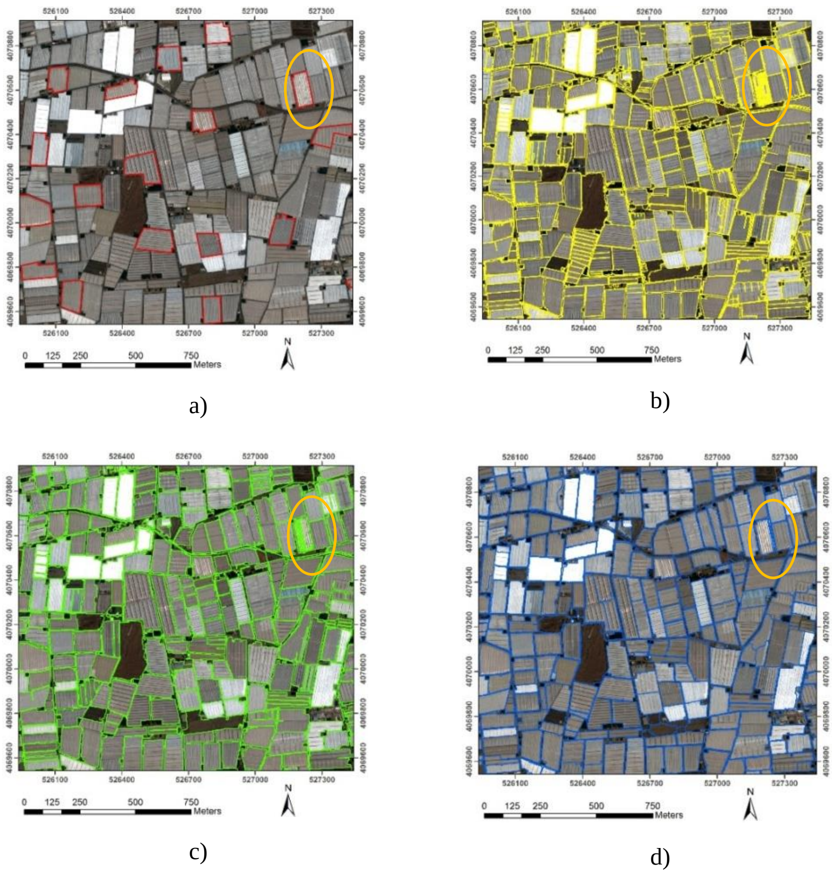

Fig. 3. Visual comparison over the RGB WV3 MS ATCOR orthoimage of the best seg-mentations (100 reference geometries): a) Reference geometries (Red polygons); b) Optimum segmentation from WV3 PAN orthoimage (Yellow polygons); c) Optimum segmentation from WV3 MS orthoimage (Green polygons); d) Optimum segmentation from WV3 MS ATCOR orthoimage (Blue polygons).

5 Conclusions

As far as the authors knowledge, this work is the first attempt to identify the optimum image data source derived from VHR bundle satellite imagery (e.g., GeoEye-1 and WorldView-2/3/4) to perform MRS algorithm on a plastic greenhouse area.

In this regards we found that the WV3 MS ATCOR corrected orthoimage was the best image data source to attain the best greenhouses segmentation according to the modified ED2 metric. This image product presented a geometric resolution of 1.2 m and digital values expressed as ground reflectance.

Modified ED2 metric presented a very good agreement with the visual quality of the greenhouse segmentations. Moreover, the command line tool AssesSeg allowed easily checking a high number of MRS parameters combinations.

Finally, the number of reference geometries to compute ED2 should be much higher than 30. In fact, when the class to be segmented is very heterogeneous, as in our case dealing with plastic greenhouses, sets of references between 200 and 300 should be considered in order to obtain reliable results.

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