

Evaluation of multi-spectral image segmentation algorithms using SITEF (Synthetic Image Testing Framework)

- including adjacency effects

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Introduction

Most Object Based Image Analysis (OBIA) systems start with an image segmentation operation.

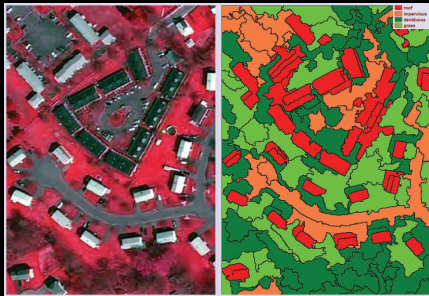
The segmentation stage is a critical part of the process.

If the segmentation fails to identify as an object a given element present in the image, the subsequent stages will generally be unable to recognise or classify this element.

The evaluation of the segmentation process is thus an important aspect of an OBIA system.

However, it is difficult to evaluate the quality of the segmentation result for EOS images, as there are usually no reference values to be used for comparison.

Introduction



Introduction

The quality of the image segmentation result depend on:

Object characteristics

- size
- shape
- spectral signature

Image data

- Spatial resolution
- Radiometric resolution
- Spectral characteristics

Method

- Segmentation algorithm
- Parameter setting

Evaluation of segmentation results

- The standard approach to evaluate a segmentation result is to compare it with a reference segmentation
- Commonly used metrics (e.g. true detection rate, average distance Hausdorff distance) are mostly suitable for the case of a single object

Hammoude metric (H)

$$H = \frac{\#(X \cup Y) - \#(X \cap Y)}{\#(X \cup Y)}$$

X and Y are two segmentations proposed for an object

The Hammoude metric has values between 0 and 1, with a value of 1 occurring when there is no intersection between segmentations (completely dissimilar), and 0 when the two segmentations are equal.

$H' = 1 - H$

$H' = 1$ for a perfect match
 $H' = 0$ for two non-intersecting objects

External similarity indices

The problem of comparing two segmented images can be seen as a comparison between two classifications (data partitions), where each object (or segment) is assigned a class label.

External indices of cluster validity access the degree to which two classifications of the data agree.

The external indices used here are the Rand coefficient (R), the Corrected Rand coefficient (CR) and the Jaccard coefficient (J).

Each image pixel (i) has two class labels, X(i) and Y(i), corresponding to the object numbers assigned by segmentations X and Y.

$$\begin{aligned} a &= \# \{ (i,j) : i \in X, X(i) = X(j), Y(i) = Y(j) \} \\ b &= \# \{ (i,j) : i \in X, X(i) = X(j), Y(i) \neq Y(j) \} \\ c &= \# \{ (i,j) : i \in X, X(i) \neq X(j), Y(i) = Y(j) \} \\ d &= \# \{ (i,j) : i \in X, X(i) \neq X(j), Y(i) \neq Y(j) \} \end{aligned}$$

The four values (a,b,c,d) sum is the number of ordered pairs of pixels: $a+b+c+d=N(N-1)/2$, where N is the total number of image pixels.

External similarity indices

Rand coefficient (R)

$$R = \frac{a+d}{a+b+c+d}$$

Jaccard coefficient (J)

$$J = \frac{a}{a+b+c+d}$$

R and J vary between 0 and 1 (1 is for perfectly matched classifications)

In the Corrected Rand coefficient (CR) the range of values (0 to 1) is adjusted so that a fully random classification would correspond to 0.

Corrected Rand coefficient (CR)

$$CR = \frac{R - R_{exp}}{R_{max} - R_{exp}}$$

R_{max} is the maximum possible value for R ($R_{max}=1$)

R_{exp} is the expected value of R under randomness

To assure that CR has values in $[0,1]$, negative values are truncated to 0.

Multi-spectral synthetic image

The objective is to produce an image that simulates real EOS images, with a number of land cover types, where the land parcel size is known.

Procedure:

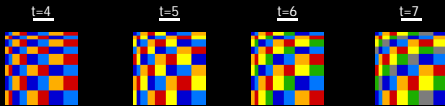
- Create a base image, with the geometric properties and class types
- A multi-spectral image is used as reference to obtain signatures (multi-spectral pixel values) for each land cover class
- The final multi-spectral synthetic image is created, using the Base image and the reference

The base image is used to create an image with labels assigned to the various land parcels, which is then used as reference segmentation.

Multi-spectral synthetic image

Base image (parameters): t – number of land cover types
u – size of the smallest unit
s – range of sizes
r – repetition parameter

Example of a Base image with u=4, s=4, r=2.

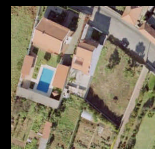


- there are r^2 single unit parcels (of u by u pixels)
- generally r^2 parcels of i^j units, with $i,j=1,\dots,s$
- two neighbouring parcels always belong to different classes

Multi-spectral synthetic image

Example

Reference image:
airphoto, RGB color



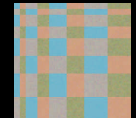
Training areas for 4 land cover types



Base image:

u=4 ; s=4 ; r= 2 ; t=4

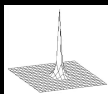
Synthetic image (ideal sensor)



Multi-spectral synthetic image

Including adjacency effects (realistic sensor model)

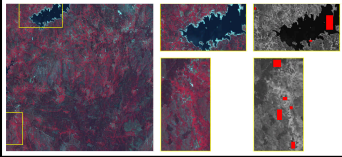
- Point Spread Function



0.000	0.000	0.001	0.002	0.004	0.007	0.011	0.016	0.022
0.000	0.001	0.003	0.007	0.014	0.024	0.037	0.054	0.077
0.001	0.003	0.009	0.019	0.034	0.056	0.089	0.136	0.200
0.002	0.005	0.016	0.034	0.064	0.119	0.194	0.294	0.424
0.004	0.011	0.036	0.084	0.164	0.304	0.504	0.774	1.124
0.007	0.016	0.056	0.134	0.284	0.544	0.944	1.444	2.144
0.011	0.024	0.084	0.204	0.444	0.844	1.444	2.144	3.044
0.016	0.034	0.114	0.284	0.604	1.204	2.144	3.044	4.244
0.022	0.044	0.164	0.404	0.844	1.604	2.844	4.244	6.044
0.024	0.056	0.194	0.484	1.004	1.944	3.444	5.044	7.244
0.034	0.084	0.284	0.704	1.404	2.844	5.044	7.244	10.044
0.044	0.114	0.404	1.004	2.004	4.044	7.244	10.044	14.044
0.056	0.164	0.564	1.404	2.844	5.644	10.044	14.044	19.044
0.077	0.244	0.844	2.004	4.044	8.044	14.044	19.044	26.044
0.100	0.344	1.204	2.844	5.644	11.244	19.044	26.044	35.044
0.136	0.484	1.844	4.044	8.044	15.644	26.044	35.044	47.044
0.184	0.704	2.844	5.644	11.244	22.044	35.044	47.044	63.044
0.244	1.004	4.044	8.044	15.644	30.444	47.044	63.044	84.044
0.304	1.404	5.644	11.244	22.044	42.444	63.044	84.044	110.044
0.374	1.944	8.044	15.644	30.444	58.444	84.044	110.044	142.044
0.454	2.644	11.244	22.044	42.444	80.444	110.044	142.044	180.044
0.544	3.444	15.644	30.444	58.444	110.044	142.044	180.044	234.044
0.644	4.444	22.044	42.444	80.444	142.044	180.044	234.044	306.044
0.754	5.644	30.444	58.444	110.044	180.044	234.044	306.044	396.044
0.884	7.244	42.444	80.444	142.044	234.044	306.044	396.044	516.044
1.044	9.044	58.444	110.044	180.044	306.044	396.044	516.044	666.044
1.244	11.244	80.444	142.044	234.044	396.044	516.044	666.044	856.044
1.484	14.044	110.044	180.044	306.044	516.044	666.044	856.044	1104.044
1.784	18.044	142.044	234.044	396.044	666.044	856.044	1104.044	1428.044
2.144	23.044	180.044	306.044	516.044	856.044	1104.044	1428.044	1836.044
2.564	29.044	234.044	396.044	666.044	1104.044	1428.044	1836.044	2340.044
3.044	36.044	306.044	516.044	856.044	1428.044	1836.044	2340.044	2952.044
3.584	44.044	396.044	666.044	1104.044	1836.044	2340.044	2952.044	3684.044
4.204	54.044	516.044	856.044	1428.044	2340.044	2952.044	3684.044	4548.044
4.904	66.044	666.044	1104.044	1836.044	2952.044	3684.044	4548.044	5556.044
5.684	80.044	856.044	1428.044	2340.044	3684.044	4548.044	5556.044	6720.044
6.544	96.044	1104.044	1836.044	2952.044	4548.044	5556.044	6720.044	8052.044
7.484	114.044	1428.044	2340.044	3684.044	5556.044	6720.044	8052.044	9564.044
8.504	134.044	1836.044	2952.044	4548.044	6720.044	8052.044	9564.044	11268.044
9.604	156.044	2340.044	2952.044	5556.044	8052.044	9564.044	11268.044	13176.044
10.784	180.044	2952.044	3684.044	6720.044	9564.044	11268.044	13176.044	15288.044
12.044	206.044	3684.044	4548.044	8052.044	11268.044	13176.044	15288.044	17604.044
13.484	234.044	4548.044	5556.044	9564.044	13176.044	15288.044	17604.044	20124.044
15.004	264.044	5556.044	6720.044	11268.044	15288.044	17604.044	20124.044	22848.044
16.604	296.044	6720.044	8052.044	13176.044	17604.044	20124.044	22848.044	25872.044
18.284	330.044	8052.044	9564.044	15288.044	20124.044	22848.044	25872.044	29208.044
20.044	366.044	9564.044	11268.044	17604.044	22848.044	25872.044	29208.044	32856.044
21.884	404.044	11268.044	13176.044	20124.044	25872.044	29208.044	32856.044	36816.044
23.804	444.044	13176.044	15288.044	22848.044	29208.044	32856.044	36816.044	41088.044
25.804	486.044	15288.044	17604.044	25872.044	32856.044	36816.044	41088.044	45672.044
27.884	530.044	17604.044	20124.044	29208.044	36816.044	41088.044	45672.044	50568.044
29.944	576.044	20124.044	22848.044	32856.044	41088.044	45672.044	50568.044	55776.044
32.084	624.044	22848.044	25872.044	36816.044	45672.044	50568.044	55776.044	61296.044
34.304	674.044	25872.044	29208.044	41088.044	50568.044	55776.044	61296.044	67128.044
36.604	726.044	29208.044	25872.044	45672.044	55776.044	61296.044	67128.044	73272.044
38.984	780.044	32856.044	29208.044	50568.044	61296.044	67128.044	73272.044	79728.044
41.444	836.044	36816.044	32856.044	55776.044	67128.044	73272.044	79728.044	86496.044
43.984	894.044	41088.044	36816.044	61296.044	73272.044	79728.044	86496.044	93576.044
46.604	954.044	45672.044	41088.044	67128.044	79728.044	86496.044	93576.044	100968.044
49.304	1016.044	50568.044	45672.044	73272.044	86496.044	93576.044	100968.044	108776.044
52.084	1080.044	55776.044	50568.044	8052.044	93576.044	100968.044	108776.044	116992.044
54.944	1146.044	61296.044	55776.044	8848.044	100968.044	108776.044	116992.044	125616.044
57.884	1214.044	67128.044	61296.044	9712.044	108776.044	116992.044	125616.044	134648.044
60.904	1284.044	73272.044	67128.044	10656.044	116992.044	125616.044	134648.044	144088.044
64.004	1356.044	8052.044	73272.044	11680.044	125616.044	134648.044	144088.044	153928.044
67.184	1430.044	8848.044	8052.044	12784.044	134648.044	144088.044	153928.044	164168.044
70.444	1506.044	9712.044	8848.044	13968.044	144088.044	153928.044	164168.044	174808.044
73.784	1584.044	10656.044	9712.044	15232.044	153928.044	164168.044	174808.044	185848.044
77.204	1664.044	11680.044	10656.044	16576.044	164168.044	174808.044	185848.044	197288.044
80.704	1746.044	12784.044	11680.044	18000.044	174808.044	185848.044	197288.044	209128.044
84.284	1830.044	13968.044	12784.044	19504.044	185848.044	197288.044	209128.044	221368.044
87.944	1916.044	15232.044	13968.044	21088.044	197288.044	209128.044	221368.044	234008.044
91.684	2004.044	16576.044	15232.044	22752.044	209128.044	221368.044	234008.044	247048.044
95.504	2094.044	18000.044	16576.044	24496.044	221368.044	234008.044	247048.044	260488.044
99.404	2186.044	19504.044	18000.044	26320.044	234008.044	247048.044	260488.044	274328.044
103.384	2280.044	21088.044	19504.044	28224.044	247048.044	260488.044	274328.044	288468.044
107.444	2376.044	22752.044	21088.044	30208.044	260488.044	274328.044	288468.044	302908.044
111.584	2474.044	24496.044	22752.044	32272.044	274328.044	288468.044	302908.044	317648.044
115.804	2574.044	26320.044	24496.044	34416.044	288468.044	302908.044	317648.044	332688.044
120.104	2676.044	28224.044	26320.044	36640.044	302908.044	317648.044	332688.044	348028.044
124.484	2780.044	30208.044	28224.044	38944.044	317648.044	332688.044	348028.044	363668.044
128.944	2886.044	32272.044	30208.044	41328.044	332688.044	348028.044	363668.044	379608.044
133.484	2994.044	34416.044	32272.044	43792.044	348028.044	363668.044	379608.044	395848.044
138.104	3104.044	36640.044	34416.044	46336.044	363668.044	379608.044	395848.044	412388.044
142.804	3216.044	38944.044	36640.044	48960.044	379608.044	395848.044	412388.044	429228.044
147.584	3330.044	41328.044	38944.044	51664.044	395848.044	412388.044	429228.044	446368.044
152.444	3446.044	43792.044	4					

Test images

Three base images: $u=3$; $s=8$; $r=5$; $t=8, 6, 5$



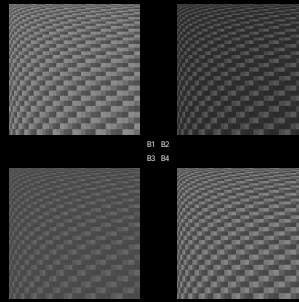
SPOT HRG
satellite image
used as reference

A - Irrigated permanent semi-natural mountain meadows
B - Non-irrigated permanent semi-natural mountain meadows
C - Evergreen forest
D - Deciduous forest
E - Communitarian pastures
F - Annual crops
G - Sand (*)
H - Water (*)

- All 8 classes
- 5 most similar / different
- Only the 6 veg. classes
- All subsets (6) with 5 vegetation classes

(*) Non-vegetation class

Test image (example)



Sensor: SPOT HRG

Unit size ($u=3$) - 3×3 pixels

Scale range ($s=8$)
parcels of 1×1 to 8×8 units

Repetition parameter ($r=5$)
5 rows and 5 columns each

Number of classes ($t=5$)
5 land cover classes

- 540×540 pixel images
- 1600 parcels
- 36 parcel sizes
- 25 or 50 of each size

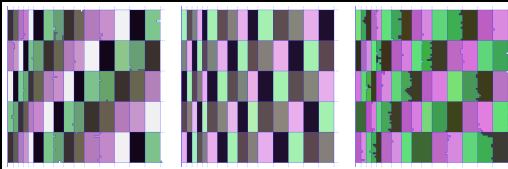
Results - Detail

Small section of the SPOT test images, with parcels of:
6 by 1, 6 by 2 and 6 by 3 units (25 parcels of each size)

SPOT 8

SPOT 5d

SPOT 5s



For this section, there is a perfect match between the segmentation of SPOT 5d and the reference segmentation

Results - General view

Average values for the whole image (1600 parcels)

	SPOT8	SPOT5d	SPOT5s	Ideal case
No. objects	1563	1596	1545	1600
H	0.0430	0.0025	0.0820	0
H'	0.9570	0.9975	0.9180	1
R	0.9977	0.9998	0.9941	1
CR	0.9767	0.9977	0.9549	1
J	0.9623	0.9962	0.9348	1

Results - Parcel size and shape

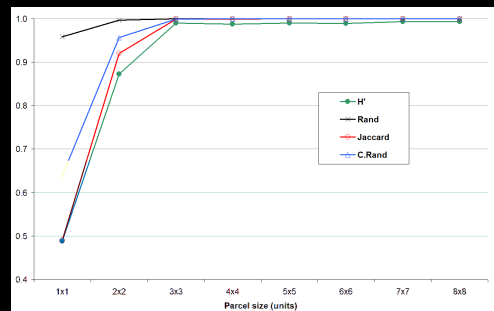
6 classes (vegetation land cover)

PSF, without pixel offset (0,0)

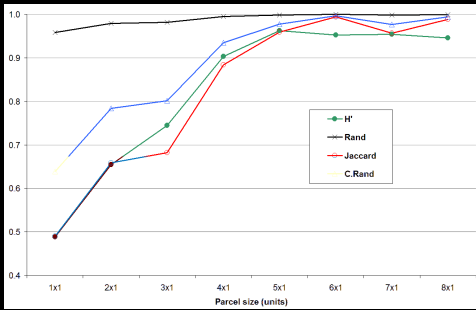
Average H values for square parcels

Ham.	1	2	3	4	5	6	7	8
1	0.5115							
2	0.3453	0.1273						
3	0.2555	0.0423	0.0101					
4	0.0964	0.0385	0.0181	0.0121				
5	0.0378	0.0293	0.0127	0.0122	0.0100			
6	0.0478	0.0168	0.0170	0.0113	0.0094	0.0106		
7	0.0460	0.0159	0.0150	0.0136	0.0077	0.0101	0.0064	
8	0.0539	0.0151	0.0134	0.0095	0.0076	0.0089	0.0063	0.0068

Results - Parcel size and shape



Results – Parcel size and shape



Results – Set of land cover classes

Average Hammoude metric (H) for each land cover class

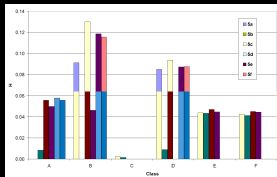
Class ID	SPOT8	SPOT5d	SPOT5s
A	0.0279	0.0047	0.0445
B	0.1142	(*)	0.1504
C	0.0080	0.0016	(*)
D	0.0944	0.0063	0.1083
E	0.0526	(*)	0.0522
F	0.0468	(*)	0.0546
G	0.0000	0.0000	(*)
H	0.0000	0.0000	(*)

(*) Class not used

Results – Set of land cover classes

Class	5a	5b	5c	5d	5e	5f
A	(*)	0.0083	0.0558	0.0498	0.0578	0.0557
B	0.0912	(*)	0.1301	0.0462	0.1187	0.1157
C	0.0023	0.0016	(*)	0.0000	0.0000	0.0000
D	0.0850	0.0089	0.0938	(*)	0.0873	0.0877
E	0.0438	0.0435	0.0469	0.0447	(*)	0.0000
F	0.0424	0.0412	0.0450	0.0445	0.0000	(*)

(*) Class not used



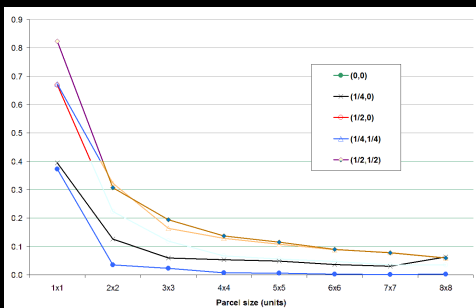
Average Hammoude metric (H) for each land cover class

Results – Pixel offset

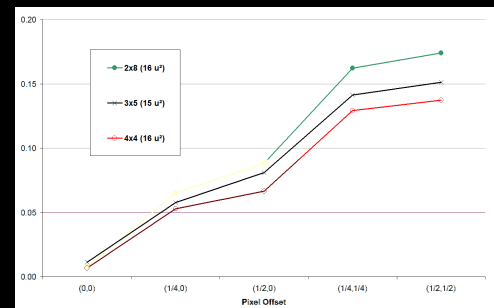
- Test image – 5d
- 5 offset values between the ideal and real grid (+ PSF)
- Hammoude metric (H)

Class	(0,0)	(1/4,0)	(1/2,0)	(1/4,1/4)	(1/2,1/2)
A	0.0498	0.1365	0.1665	0.2211	0.2453
B	0.0462	0.0513	0.0818	0.1415	0.1687
C	0.0000	0.0404	0.1005	0.1382	0.2042
E	0.0447	0.1193	0.1755	0.2498	0.2397
F	0.0445	0.0531	0.0862	0.1425	0.1490
Average	0.0370	0.0801	0.1221	0.1786	0.2014

Results – Pixel offset



Results – Pixel offset

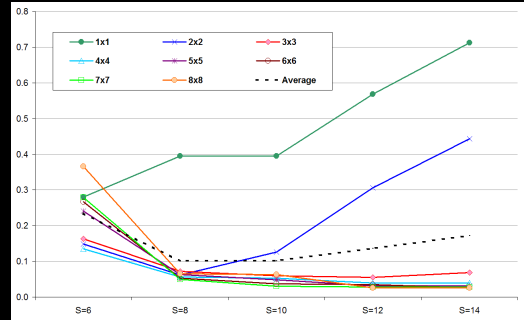


Results – Segmentation parameters

- Test image – 5D
- PSF with pixel offset (1/4,0)
- 5 values for the Segmentation Parameter SCALE

Class	S=6	S=8	S=10	S=12	S=14
A	0.1350	0.1300	0.1365	0.1502	0.1812
B	0.1915	0.0485	0.0513	0.0780	0.1203
C	0.1073	0.0644	0.0404	0.0276	0.0256
E	0.1205	0.1177	0.1193	0.1327	0.1716
F	0.3887	0.0605	0.0531	0.0782	0.1218
Average	0.1886	0.0842	0.0801	0.0934	0.1241

Results – Segmentation parameters



Conclusions

The Synthetic Image TEsting Framework (SITEF) permits to overcome the lack of a reference segmentation, by creating multi-spectral synthetic images with controlled spatial and spectral characteristics.

Various aspects can be evaluated, such as:

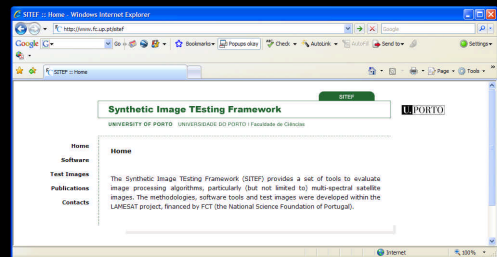
- Parcel size and shape
- Land cover type and set of land cover types
- Segmentation algorithms / parameters

The SITEF software is freely available.

It can be used to fine tune the parameters of a segmentation algorithm to a specific dataset and application.

Synthetic Image TEsting Framework (SITEF)

www.fc.up.pt/sitef



Evaluation of multi-spectral image segmentation algorithms using SITEF (Synthetic Image TEsting Framework) - including adjacency effects

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