Application of Level Set Methods for burned area mapping and evaluation against DLR's TET-1 hotspot data – a case study in Portugal

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Abstract: Automated extraction of fire-affected areas from satellite images is a crucial task for large scale, near real-time damage assessment. The discrimination between burned and unburned pixels is usually done by differentiating pre-/post scenes and categorizing the change rate, or by using empirically derived thresholds on a single scene. These approaches, however, require the setting of a threshold value for the discrimination, which has to be derived empirically for constricted region of interest. It is therefore not well adoptable to different regions of interest, turning this approach inappropriate for automatic extraction of burned areas in large, heterogeneous study areas. The aim of this paper is to test the Active Contour Level Set method, which does not rely on any thresholds, regarding geometric accuracy of burned area extraction.

Keywords: Environmental Science, Remote Sensing, Disasters, Forest Fire, Open Source technology, Environmental monitoring, burned area mapping, Active Contour Level Set, Portugal Wildfires, TET-1

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1. Introduction

A multitude of indices for automatic extraction of fire affected areas from satellite pictures have been proposed over recent decades (e.g. Rouse et al., 1974; Key et. al., 1999). Many of them, such as the Normalized Difference Vegetation Index (NDVI) or the Normalized Burn Ratio (NBR), have shown to be capable of accurately representing the shape and extent of these burned areas (e.g., Chuvieco, 2002, Escuin, 2008; Bastarrika, 2011). To this purpose, indices of pre- and post disaster imagery are calculated, with pixels exceeding a specific threshold being flagged as burnt. This threshold is found empirically, by testing different values and checking the results against validation data, ideally ground truth information. The value received is, however, only ideal for a spatially restricted region of interest and also only for the current point in time. The most appropriate value might change with a differing region of interest, and also when studying a different season for a constant region. These problems become inevitable if the study area is of considerable size, such as continental scale, and if the study period ranges over several months or even years. An active field of research is therefore the development of methodologies for the derivation of dynamic threshold values, which do not focus on the potential burned area pixel alone, but incorporate the surrounding pixels into

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the decision process. These methods feature a high adaptability to changing spatial and temporal conditions.

A very promising approach is the utilization of Active Contour Level Set Methods (Leventon et. al., 2000; Chan and Vese, 2001; Liu et. al., 2014). In this study we apply this method to automatically extract burned area outlines from satellite data regarding the wildfires in Portugal in 2016.

2. Study area and data sources

The studied incident took place in Portugal, on the mainland as well as on the island of Madeira, in August 2016. The fires destroyed an area of nearly 116.000 hectares (cbc.ca, 2016) and caused four fatalities (reuters.com, 2016). More than 515 sources of fire have been determined. The study area is located south-east of the city of Porto and contains the largest continuous burned area, covering 237.8 km2.

Two Landsat-8 scenes have been chosen as reference data. The first one was taken on July, 30th, shortly before the outbreak of the fires. The second one was derived on August 15th. The outline of the burned area was digitized manually from the latter scene. For the automatic derivation of the burned areas, two MODIS MOD09 scenes taken before and after the fires have been selected.

In addition to testing the geometric accuracy of the classification results, the identified areas are also evaluated regarding fire radiative power (FRP). This was done in order to determine the influence of fire intensity on burned area classification. To this purpose, data from four overpasses of the DLR satellite TET-1 was utilized. TET-1 is a micro satellite system targeted at wildfire observation. It is designed to facilitate the detections of low intensity and small fires, and is therefore able to detect temperature anomalies missed by the MODIS sensors onboard AQUA/TERRA.

3. Methodology

The extent and shape of the burned areas within the MODIS imagery is derived by an active contour Level Set algorithm, which is explained in detail below. The results are compared against indices frequently used for burned area classification, specifically the differential NDVI, differential NBR and the differential modified Burned Area Index (BAIm).

Level Set Methods are numerical methods for tracking the evolution of contours and surfaces. They allow for the modelling of arbitrarily complex shapes and handle topological changes, such as merging of features, implicitly.

As a prerequisite, cloud pixels are removed from the source data. Since the analysis relies on change detection , this is a crucial step, given the high temporal dynamic of clouds.

The basis for the level set approach is the calculation and combination of three well known indices. The magnitude of the change vector, as well as the differential NDVI and the differential NBR has to be conducted:

$$\mathrm{CVA} = \sum_{k=1}^{n}[pix|band(k|pre) - pix|band(k|post)]^2,\ \mathrm{NDVI} = \frac{\mathrm{pixNIR-pixRED}}{pixNIR+pixRED},\ \mathrm{NBR} = \frac{\mathrm{pixNIR-pixMIR}}{pixNIR+pixMIR}$$

$$\mathrm{DI} = \mathrm{W_{dNBR}} * \frac{dNBR}{std(dNBR)} + \mathrm{W_{dNDVI}} * \frac{dNDVI}{std(dNDVI)} + \mathrm{W_{CVA}} * \frac{CVA}{std(CVA)}$$

The next step consists of the weighted combination of these indices, normalized by their standard deviation. As weighting factors for *dNBR, dNDVI* and *CVA*, the following values have

been found suitable: -1.5 for W_{dNBR}, 1.0 for W_{dNDVI} and 0.5 for W_{CVA}. The resulting difference image (DI) is then classified via a two-cluster K-Means classification, separating the images into potentially burned and probably unburned pixels. The former are then used as seeds for the actual Active Contour Level Set algorithm. The ITK (Insight Toolkit) Open Source library is utilized as a basis for the actual Active Contour Level Set (ACLS) algorithm. The algorithm is invoked twice, first with inward and the second time with outward propagation. By that, the outer boundaries of the burned area polygons are returned as well as the inner boundaries (holes) within these features. Both results are then merged and polygonised, to gain an accurate vectorial representation of the burned areas.
The burned areas resulting from ACLS are compared to the results gained by using index thresholding for MODIS and Landsat data respectively. Additionally, the mean value for fire radiative power (FRP) for the classification results are determined using MODIS MOD14 and TET-1 data, to investigate a relationship between missed burned areas and low fire intensity. The results are displayed in table1 and 2.

4. Results and Discussion

As can be seen from tables 1 and 2, the proposed Active Contour Level Set approach performs as well or slightly better than the other tested indices (only *dNBR* shows a high error of commission for Landsat-8). It has to be noted, however, that for these indices, the optimal threshold value regarding the source data was determined and used. Regarding omission and commission misidentifications, it was assumed that these false decisions could be explained by low fire intensity, which would make the differentiation between burned and unburned pixels difficult. This is in fact the case, as can be seen from the correctly classified pixels featuring a FRP three times higher compared to the falsely classified ones.

Table 1. Geometric accuracy for MODIS AQUA imagery, in relation to FRP from MODIS MOD14 and TET-1

	Error of Omission			**Error of Commission**			**Correct classification**		
	%	Mean FRP (MW)		%	Mean FRP (MW)		%	Mean FRP (MW)	
		TET-1	MOD14		TET-1	MOD14		TET-1	MOD14
dNDVI	3.71	7.89	6.33	3.13	7.89	22.22	93.16	16.78	36,33
dNBR	3.66	10.44	12.44	3.36	6.56	18.22	92.98	15.89	34.11
dBAIM	1.56	7.0	5.89	6.68	5.78	14.22	91.76	15.44	31.44
ACLS	3.18	7.11	7.11	3.46	8.11	20.89	93.36	16.56	34.67

Table 2. Geometric accuracy for Landsat 8 imagery, in relation to FRP from MODIS MOD14 and TET-1

	Error of Omission			**Error of Commission**			**Correct classification**		
	%	Mean FRP (MW)		%	Mean FRP (MW)		%	Mean FRP (MW)	
		TET-1	MOD14		TET-1	MOD14		TET-1	MOD14
dNDVI	3.82	18.22	18.78	1.34	4.78	7.89	94.84	13.22	29.78
dNBR	2.91	11,11	14.67	12.98	0.89	1.11	84.11	15.33	30.0
dBAIM	2.36	12.44	16.33	1.72	5.33	6.56	95.92	14.89	29.0
ACLS	1.25	10.44	16.44	3.03	4.22	21.44	95.72	14.89	27.89

The final result can be seen in figure 1. It shows the burned area polygons derived from MODIS data using the Active Contour Level Set approach (red) on top of the manually digitized burned area outlines (yellow), using Landsat-8 as a base image. The figure visualizes the geometric accuracy of 93.3%. Figure 2 again shows the manually digitized burned area outlines, this time

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overlain by TET-1 FRP measurements of four combined overpasses by TET-1 (August 11th – August 14th).

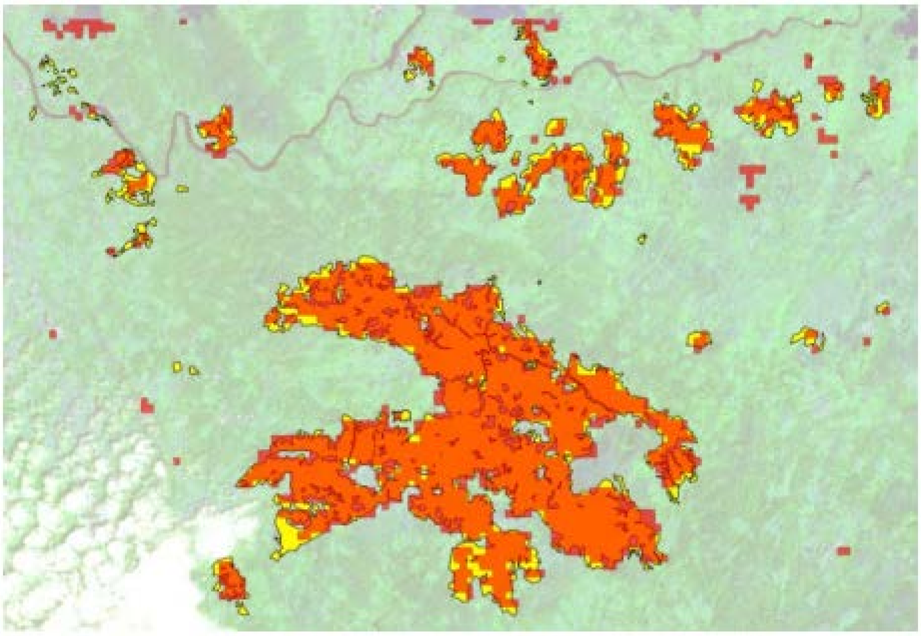

Figure 1. Burned area outlines derived via the Active Contour level Set approach (Yellow: Reference outlines, digitized manually. Red: Results automatically generated by the algorithm).

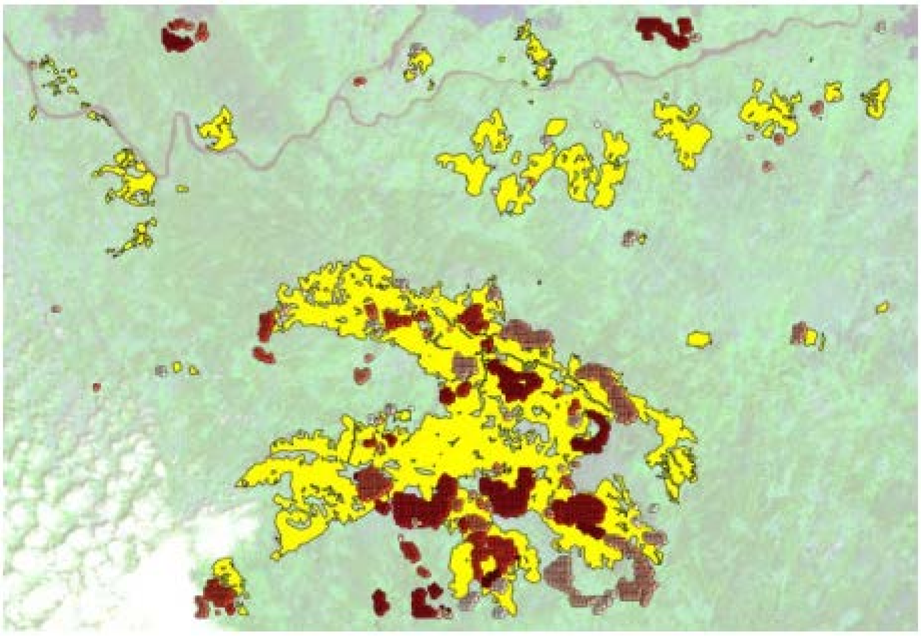

Figure 2. Yellow: Reference outlines, digitized manually. Reddish dots: Hotspots (with available FRP) detected by TET-1 on the 11., 12., 13., and 14. of August.

5. Conclusions

For the test area, the Active Contour Level Set approach was proved to be a valuable means for completely autonomous derivation of burned areas. It was applied to data from two different sensors with differing spatial as well as temporal resolution, and performed with the same or even slightly better quality than the reference indices using optimized, fixed thresholds.

6. References

Bastarrika, A., Chuvieco, E. and Martín, M. P., 2011, Mapping burned areas from Landsat TM/ETM+ data with a two-phase algorithm: Balancing omission and commission errors. Remote Sensing of the Environment, Volume 115, Isuue 4: 1003-1012.

Chan, T. and Vese, L., 2001, Active contours without edges. Image Processing, IEEE Transactions Volume 10, Issue 2: 266–277.

Chuvieco, E., Martin, M. P. and Palacios, A., 2002, Assessment of different spectral indices in the red-nearinfrared spectral domain for burned land discrimination. International Journal of Remote Sensing, Volume 23, Issue 23: 5103-5110.

Escuin, S., Navarro, R., and Fernandez, P., 2008, Fire severity assessment by using NBR (Normalized Burn Ratio) and NDVI (Normalized Difference Vegetation Index) derived from LANDSAT TM/ETM images. International Journal of Remote Sensing, Volume 29, Issue 4: 1053-1073.

Key, C. H. and Benson, N. C., 1999, The Normalized Burn Ratio (NBR): A Landsat TM radiometric measure of burn severity. U.S. Department of the Interior, Northern Rocky Mountain Science Centre.

Leventon, M.E., Grimson, W.E.L. and Faugeras, O., 2000, Statistical shape influence in geodesic active contours. In Proc. Conf. Computer Vis. and Pattern Recog., Hilton Head Island, SC, Volume 1: 316–323

Liu, Y., Dai, Q., Liu, J., Liu, S., Yang, J., 2014, Study of Burn Scar Extraction Automatically Based on Level Set Method using Remote Sensing Data. PLoS ONE 9(2): e87480. doi:10.1371/journal.pone.0087480.

Rouse, J. W., Haas, R. W., Schell, J. A., Deering, D. H. and Harlan, J. C., 1974, Monitoring the vernal advancement and retrogradation (Greenwave effect) of natural vegetation. Greenbelt, MD. USA: NASA/GSFC.