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Semi-automatic detection of linear archaeological traces from orthorectified aerial images

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ABSTRACT

This paper presents a semi-automatic approach for archaeological traces detection from aerial images. The method developed was based on the multiphase active contour model (ACM). The image was segmented into three competing regions to improve the visibility of buried remains showing in the image as crop marks (i.e. centuriations, agricultural allocations, ancient roads, etc.). An initial determination of relevant traces can be quickly carried out by the operator by sketching straight lines close to the traces. Subsequently, tuning parameters (i.e. eccentricity, orientation, minimum area and distance from input line) are used to remove non-target objects and parameterize the detected traces. The algorithm and graphical user interface for this method were developed in a MATLAB environment and tested on high resolution orthorectified aerial images. A qualitative analysis of the method was lastly performed by comparing the traces extracted with ancient traces verified by archaeologists.

1. Introduction

Since the end of the nineteenth century, aerial images have largely been used to study archaeological features. Particularly, oblique and vertical photos have been used for the identification of ancient remains, invisible on the ground, but which can be recognized in aerial views as "soil marks" and "crop marks" (Evans and Jones, 1977). In the last years, satellite imagery (Agapiou et al., 2012; Lasaponara and Masini, 2012), also integrated with ground or aerial laser scanning data (Lasaponara et al., 2012; Pirotti et al., 2013a,b; Pirotti et al., 2013a,b), have demonstrated a great potential for archaeological investigations, producing improvements in scientific research, reducing costs and risk associated with excavations, and providing new strategies for conservation and preservations. Acquiring these images during the most advantageous days and transforming them into interpretable and understandable information can be rather challenging. Yet, since multitemporal satellite image datasets are often unavailable for many geographic locations and change detection analysis is not generally applicable, aerial data continue to be a primary source of information, mainly in documenting the dynamics of archaeological excavations.

Many automatic algorithms can be applied for the extraction of structured objects (roads, buildings, trees, etc.), as identifiable portions of an image that can be interpreted as a single and clearly visible unit (Ahmadi et al., 2010; Gülgen and Gökgöz, 2011; Santoro et al., 2013; Tarantino and Figorito, 2011). Unfortunately, traces on imagery are often only partially visible due to their bad state of preservation as well as to spectral similarities between archaeological remains and surrounding entities (De Laet et al., 2007).

In literature there are image processing methods mainly based on visual interpretation, as in the cases of radiometric enhancement (Parcak, 2009), spatial filters (Alexakis et al., 2009) and spectral indexes (Lasaponara and Masini, 2007). Automatic trace detection would be an ideal tool for archaeologists, but many issues related to image resolution, image degradation or presence of obstacles such as trees and man-made objects make these automations difficult to achieve (Masini and Lasaponara, 2007). In this context, image processing algorithms simply do not have the same ability as human eyes to pick out subtleties in remotely sensed images and therefore automatic algorithms provide many false positives that have to be manually corrected.

Conventionally, the work of aerial archaeologists does not require an objective process open to automated application, but a subjective interpretation of probabilities and a skill rather than simply a technique (Aqdus et al., 2012). Operator knowledge remains indispensable for a reliable archaeological interpretation of imagery and for this reason in the last years the attention of the research community has turned to semi-automatic solutions (Bucha and Ablameyko, 2007), also testing the reliability of the approach in different contexts (D'Orazio et al., 2012)

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The aim of this paper is to propose a semi-automatic approach based on multiphase active contour model (ACM) segmentation (Cao et al., 2008; Vese and Chan, 2002) for linear archaeological trace detection and extraction. The method consists in a region-based segmentation and does not utilize image gradients to identify object boundaries, but rather the statistical information inside and outside a contour line to control the region evolution. Region-based methods may perform better on images without edges or with weak edges and may be less sensitive to the location of initial contours. As a result, they could be less sensitive to noise. For this study, a graphical user interface (GUI) was designed for streamline user interaction and to support the segmentation algorithm. By using the GUI, a straight line was drawn for each archaeological object. The lines produced were then used to create sub-images around target objects and to obtain information on the approximate orientation of the target object for filtering tasks. Such method allows to verify archaeologists' assumptions on input lines and create a GIS layer with geometric and radiometric attributes for further analysis.

More details on this study are presented in the following sections: Section 2 introduces the study area; Section 3 describes the sample data set used and the method proposed to detect positive crop marks; results are presented in Section 4 and discussed in Section 5 together with concluding remarks.

2. The study area

The test site is located to the south of Foggia, a town of Apulia in Southern Italy, in the centre of the region's Tavoliere plain. From a structural point of view, the Tavoliere is part of an alluvial basin (Fossa Bradanica) whose formation dates back to the Lower Pliocene period. Situated between the Southern Apennines chain and the Apulian Dinaric foreland (De Santis et al., 2010), the Tavoliere plain started to be inhabited in the Holocene and was densely settled between the Neolithic and the Middle Ages. Optimal geomorphological, geological and strategic conditions (great visibility, infrastructure facilities, etc.) were the driving forces for its anthropization (Eramo et al., 2004) and led to a notable presence and variety of settlements (Gallo et al., 2009; Oldfield, 2005). Today, the plain's landscape is characterized by agricultural uses (cereals, vegetables, olives) and an increasing number of wind turbines and photovoltaic panels for energy production. Historical images often represent the only data sets to detect and preserve its archaeological heritage.

The Tavoliere was selected as study site because it shows a lot of clearly visible crop marks in historical aerial images. Crop marks are due to differences in plant height or colour and surface density (Hejcman and Smrž, 2010). Depending on the type of feature, plant vitality may be enhanced or reduced by buried archaeological features (Evans and Jones, 1977). Features that inhibit root penetration, such as buried walls, will provide less ideal growing conditions for vegetation resulting in negative crop marks. On the other hand, features that contain additional moisture, such as road ditches, increase plant growth resulting in positive crop marks (Lasaponara and Masini, 2007).

In this work we focused on positive crop marks appearing as dark tones in the RGB imagery. Target objects included ancient drainage ditches, Roman centuriations and agricultural allocations. These traces usually have a dimension that prevails over others, with an average width of 1.5–3 m and a length up to 300 m. Archaeological traces often appear fragmented due to human actions or meteorological agents.

3. Data and methods

3.1. The sample data set

The digital aerial image used in this work has Ground Sample Distance of 0.5 m, and was acquired on May 8th, 2008, using a Leica ADS40, digital aerial scanner (Cramer, 2006; Sandau et al., 2000). The method presented in this paper is based on the study of orthorectified RGB images. A potential issue of this approach is that many pixels corresponding to archaeological traces in agricultural fields have values similar to those of other pixels in the same fields (Fig. 1). Moreover, in this context, identifying and separating clear and prominent edges can be rather challenging: the higher the magnification, the higher the ambiguity.

3.2. The segmentation algorithm

Segmentation is a fundamental process in computer vision. The goal of segmentation is to divide the image into regions that belong to distinct objects in the depicted scene. Curve evolution methods are widely used to cope with image segmentation problems. These methods drive one or more initial curves, based on gradient and/or region information in the image, to the boundaries of objects in the same image. In this study, the active contour model (ACM) was used to partition aerial images into homogeneous regions. Chan–Vese algorithm (Chan and Vese, 2001) searches for the position of the minimum by adjusting each point on the closed curves during iteration to a lower energy position amongst its eight local neighbours. This is closely related to Mumford–Shah algorithm (Mumford and Shah, 2006). Further aspects and details of this algorithm can be found in the studies under references (Cao et al., 2008; Vese and Chan, 2002). The main ACM assumption is that homogeneous regions are required, or rather that every region can be distinguished from its global statistics. In the case of large remotely sensed images, the method produces poor results, because it is impossible to reduce spatial heterogeneity into few homogeneous regions. For this reason a multiphase ACM was applied to solve such inconvenience (see Appendix A). A multiphase approach is a generalization of the above single active contour model that searches more regions (Vese and Chan, 2002) in one run. Furthermore, the segmentation task can also be implemented recursively and does not need a priori knowledge on the object structure. The main purpose of this paper is to detect regions (objects) and their boundaries for individual component extraction. The algorithm proposed aims at supporting manual extraction of interesting traces from a limited number of segments.

3.3. Processing methods

The procedure for trace extraction consists of four-steps (Fig. 2a): (1) initialization; (2) data preparation; (3) ACM multiphase application; and (4) class assignment and filtering of spurious objects. A *description* of each step follows.

3.4. Step 1 – initialization

In this step, the operator uses the GUI to draw straight lines (Fig. 2b), one for each archaeological trace to be extracted (Fig. 3a). The initial placement can be executed coarsely by drawing straight lines in approximate vicinity of the traces. In order to improve the segmentation and reduce computation time, a subimage is created around each input segment. Afterwards, the algorithm processes each sub-image independently.