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Automatic detection of complex archaeological grazing structures using airborne laser scanning data

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ABSTRACT

The use of Light Detection And Ranging (LiDAR) for archaeological purposes is becoming more prevalent in order to detect and to document remains located in forested areas. One of the main interests of airborne laser scanning is to put the archaeological information in their context, and to allow a better understanding of the relation between each item and its environment. This concept of archaeological landscape generally results in a too large amount of data to permit a manual analysis. This paper describes an approach for the automatic detection of elementary archaeological grazing structures, found in high concentration in some places of Auvergne (France). These elementary structures are generally connected, creating complex archaeological grazing sets. The detection process is based on the design of a model of an elementary grazing structure. The automatic detection is then carried out, based on the evaluation of the matching degree of each element with the model and on their belonging to complex archaeological grazing structures. The efficiency of the method is tested, by comparison with the manual digitalisation of an expert, on a restricted zone, and the results show that the success rate of the automatic detection reaches higher values than classical template matching approaches. The additional criterion, based on the belonging of each elementary structure to a more complex one, improves the detection success: In a complementary way, this approach offers new opportunities: it is also possible to detect complex structures with a template matching approach, if they contain some simple forms, that can be modelled.

1. Introduction

LiDAR, generally known as airborne laser scanning (ALS), is used by archaeologists to detect and map sites and to analyze past landscape since the last ten years (Crutchley and Crow, 2009; Masini et al., 2011; Georges-Leroy et al., 2014). Because of its ability to penetrate certain types of woodland canopy, this technology is a revolutionary tool for archaeologists interested in remains mostly located under forest areas which are still relatively unexplored. Research programs using LiDAR data are becoming more and more frequent. They aspire to explore vast areas, linking scales from micro-regional to regional studies. LiDAR survey exhibits archaeological remains, preserved from destruction by their position in altitude or a protective vegetative cover. Over the past ten years, LiDAR technology permitted to discover unknown or partially identified archaeological sites worldwide even under dense vegetation cover (Devereux et al., 2005; Humme et al., 2006; Doneus et al., 2008; Johnson and Ouimet, 2014; Chase et al., 2014; Ludemann, 2012; Evans et al., 2013; Johnson and Ouimet, 2014; Stark et al., 2015). The majority of published studies examined the possibility of using ALS data for archaeological investigations by visualization and interpretation of high resolution ALS derived-DTMs (Digital Terrain Model) (Kokalj et al., 2011; Bennett et al., 2012; Opitz and Cowley, 2013) after classification procedures of bare-earth elevations (Kraus and Pfeifer, 1998; Vosselman, 2000; Zhang et al., 2003; Zakšek and Pfeifer, 2006; Lasaponara et al., 2011). The ALS ground point clouds are converted to raster DTMs which are used to build derived visualization models. A broad range of models derived from the raster DTMs exist and are used as supplementary tools to detect and differentiate micro-topography and therefore archaeological features, for example, multidirectional oblique weighting hillshade (MDOW), slope, local relief model (LRM), sky-view factor (SVF), positive and negative openness or combination of those methods (Devereux et al., 2008; Hesse, 2010; Challis et al., 2011; Kokalj et al., 2011; McCoy et al., 2011; Bennett et al., 2012; Stular et al., 2012; Doneus, 2013). These DTM treatments belong to the so-called visualization methods, allowing to emphasize anomalies and local details. The archaeologists expertise is then necessary to discriminate only those with an historical interest. The selected structures are then manually digitized, mapped and integrated into GIS-based environment (Doneus and Kühtreiber, 2013). However, the density of archaeological features and the large areas covered by the LiDAR surveys render the manual analysis and interpretation a time-

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consuming and fastidious task (Sevara et al., 2016). The manual visual interpretation is also a subjective process and can have a substantial impact on remains investigations, depending on the level of expertise of people carrying this classification: Non-sites may be identified as potential archaeological sites or on the other hand elements of archaeological relevance may be interpreted as natural (Doneus and Briese, 2006). Specialists may also focus on singular points of their own interest, and may tend to see what they know and unconsciously neglect other elements (Cowley, 2012).

Recently, automatic analysis of satellite images (Lasaponara and Masini, 2014; D'Orazio et al., 2012; Figorito and Tarantino, 2014; Di Iorio et al., 2010) or LiDAR data (Cowley, 2012; Trier and Pilø, 2012; Casana, 2014; Trier et al., 2015; Sevara et al., 2016) were developed. The aim is to automatically extract remains and to offer to archaeologists a pre-selection of potential archaeological features. These methods are especially useful in large areas containing a high concentration of archaeological structures. Several approaches have been proposed recently. Pixel-based classification, based on the identification of high altitudinal gradients in ALS-derived raster DTM like LRM and SVF models, has been applied and compared with object oriented classification (Sevara et al., 2016). The template matching approach has also been tested for archaeological structures with simple forms (Trier et al., 2015; Schneider et al., 2014). The method is then based on a geometrical template, defined from the knowledge of the morphometric characteristics of a targeted archaeological feature. The main problem is that the automatic detection is mostly limited to simple and isolated structures (Kim et al., 2005; Krøgli et al., 2007; Rack et al., 2005; Wan et al., 2012). More recently, rather sophisticated methods involving machine learning algorithms were explored for the automation of the detection process of archaeological remains based on ALS data. Traviglia et al. (2016) summarized papers presented in the session on 'Computer vision vs human perception in remote sensing image analysis: time to move on' held at the 44th Computer Applications and Quantitative Methods in Archaeology Conference (CAA 2016 Oslo 'Exploring Oceans of Data'). Strong advances can emerge from these highly promising approaches. One of the main improvements may lay in the detection and classification processes based on Support Vector Machine or deep convolutional neural networks (CNN) which use a training set to learn to distinguish the archaeological remains from the rest (Robin and Sadr, 2016; Trier et al., 2016). These methods can contribute to avoid the inflexibility of template-matching approaches which can lead to high scores of undetected archaeological features. Beyond ALS data, machine learning approaches can be applied to a wide range of images (Krizhevsky et al., 2012). But, despite promising results, machine learning methods for archaeological detection and mapping need further development as template-matching approaches show higher performance (Zingman et al., 2016).

Our study is based on the LiDAR survey of the central part of the Chaîne des Puys (fig. 1) (volcanic chain located in Auvergne, France), held in winter 2011. It revealed, for the first time in the Dome Mountains, the presence of typical grazing structures locally called "tras". The discovery of an important concentration of these structures (225 elementary structures for 2 square km) in an area covered by the LiDAR was the opportunity to develop and to test an automatic detection tool. As several thousands of them are present in different sectors of the Massif Central, the method will be easily deployable on a much larger scale and will assist archaeologists and the archaeological services to map these grazing structures.

These archaeological grazing structures are very interesting for automatic detection, because they are composed of similar elementary parts from one to each other, a priori easy to model. The challenge is that these elementary parts are not found isolated, as it is the case for pits or charcoal (Trier and Pilø, 2012; Schneider et al., 2014), but rather highly connected. So, a classical template matching approach may not be sufficient to detect them. The elementary structures arrangement can be another identification indicia, but as these groupings can have various sizes and shapes, they can't be identified by classical morphometric criteria. The method described in this paper uses information on both elementary and complex archaeological structures to achieve the automatic detection: an elementary structure is defined by its morphometric characteristics, but also by its belonging to a complex structure. The automatic detection process uses a combination between pixel-based classification and template matching, in order to detect the elementary parts of complex archaeological structures.

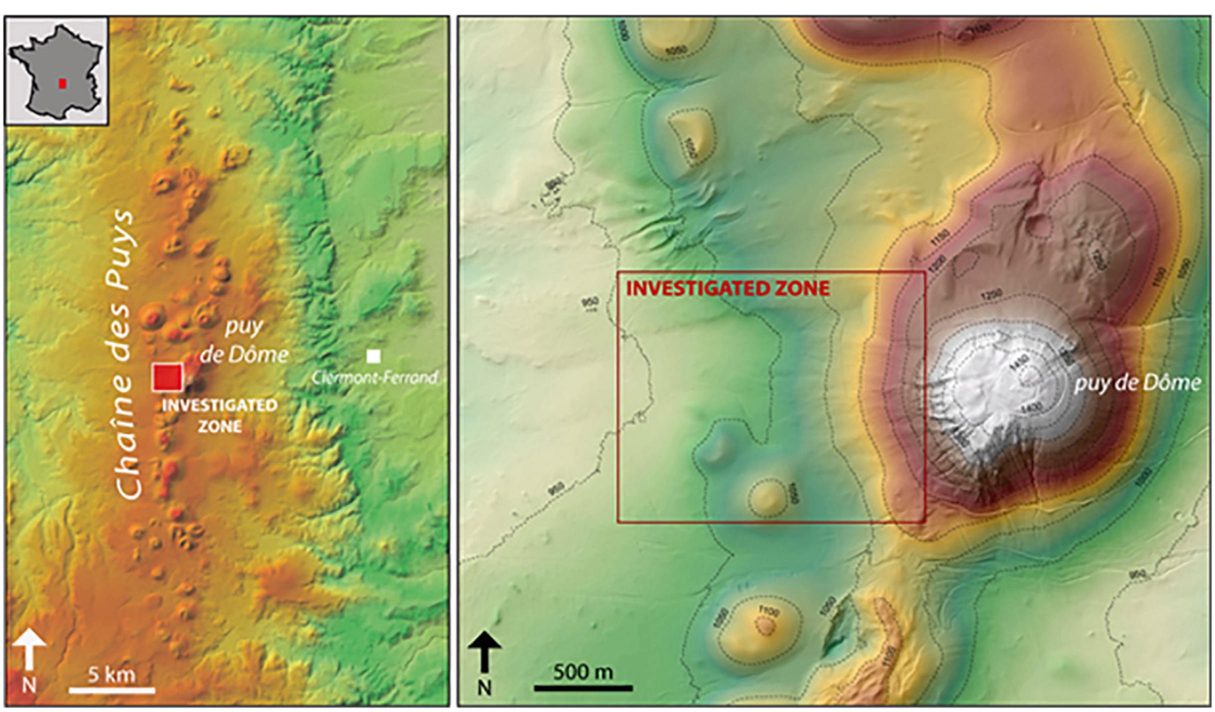

Fig. 1. Study site location in the French Chaîne des Puys and localisation of the investigated zone.