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A novel approach for detecting agricultural terraced landscapes from historical and contemporaneous photogrammetric aerial photos

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ABSTRACT

Terraces are the most distinctive sign of human activity on the shape of the Earth surface. Their construction has increased the soils permeability and reduced the slope gradient of mountains since those territories could be exploited both for agricultural and habitable purposes. Over the last decades, they have been the subject of a quick abandonment due to their scarce competitiveness. This has caused some environmental problems, such as soil degradation and hydrological instability. Minori in Italy is one of the most ancient municipalities in the Mediterranean area characterized by the presence of terraces. This paper intends to develop a method for automatic extraction of terraces from historical and contemporaneous aerial photos using an Object-based Image Analysis (OBIA) approach. Historic photos from 1956, acquired by the Geographical Military Institute (IGM), and a contemporaneous block of RGB and multispectral images, taken in 2017 of the study area have been processed to generate a high resolution Digital Elevation Model (DEM) and detailed orthophotos. Subsequently, the OBIA classification has been applied for producing a binary map of terraced and not terraced landscapes for both datasets. Orthophoto resolution was equal to 240 mm, 7 mm and 15 mm for the historical, RGB and multispectral pictures, respectively. DEM resolution results equal to 480 mm and 0.19 mm for the historical and RGB set of data. The R^2 between the check points and the estimated values, generated during the metric reconstructions of the two obtained DEMs, resulted equal to 0.99 for both datasets (1956 and 2017). The classification accuracy of the generated binary maps (terraced/not terraced landscapes) were equal to 93% and 98%, respectively. The developed approach looks promising for the historical and contemporaneous datasets. That outcome is essential because it allows to detect terraces position and to compare them over the years in order to analyse their evolution and geomorphological changes.

1. Introduction

The Earth surface is being transformed by human activities, considered one of the most remarkable geomorphical agents (Hooke, 2000; Cots-Folch et al., 2006). These processes, such as mining, grading, filling and terracing, moving substantial amount of soil (Haff, 2010), drastically shape the original landscape according to the needs of urban development or for agricultural purposes (Ahnert, 1988). Among these activities, terracing has represented the most significant and characteristic anthropogenic process of land morphology modelling in Mediterranean areas since Neolithic time (Trischitta, 2005). Indeed, their construction has allowed to make mountains or steep slope areas arable and habitable, reducing the slope gradient and increasing the soils permeability thanks to the increase of water infiltration (Sofia et al., 2016a). Therefore, terraces represent an important "monumentum" of the past, providing an old cultural heritage to be conserved and protected. Their defence is important also for preventing hydrological instability, that causes several problems, such as soil erosion, retaining walls, collapse and loss of agricultural lands.

These dynamics have increased considerably over the last few decades since terraces have been subjected to a quick abandonment because of their insufficient competitiveness in terms of agricultural production (Tarolli et al., 2014). Therefore, the European Common Agricultural Policy (CAP) is paying attention to that topic in order to control the issues that could be triggered from the lack of terraces maintenance. To meet that purpose, CAP is considering two different aspects: attracting the farmers interest in keeping agricultural land in "Good Agricultural and Environmental Conditions" (GAEC) and indentifying the Agricultural Land that can be used as "Ecological Focus Area" (EFAs). The first action intends to limit the widespread of some

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phenomena such as soil erosion, loss of soil organic matter and to preserve landscape features. The second one, instead, aims to identify some buffer areas to contain the hydraulic and geomorphological problems. On the other hand, also the Italian national policy is pointing in the same direction: protecting agricultural lands in order to reduce the soil loss to zero (Law n. 2383 of 13/05/2016).

In Italy, terraced landscapes are widespread over its territory: from the Alps to Sicily and both in the interior and exterior areas (Tarolli et al., 2014). Among these, Amalfi Coast in Campania Region, Southern Italy, needs a specific care because of the beauty and the complexity of its territory. It shows a unique well-conserved sight in the world since the terraces model their grades from the top of the mountains until the sea, which draws a lot of tourists each year. Moreover, that place is also soaked of history, it has been inhabited since 950–1250 AD (Caneva et al., 2007). For the above reasons, Amalfi Coast has been included in the UNESCO World Heritage List (year 1997 n. 830). Therefore, a specific management plan needs to be drafted to identify the proper strategy for its preservation. The most important issue to a management plan definition is the scarce knowledge regarding the position and condition of the terraces. Indeed, before the development of a method able to detect and monitor their conservation status over the years, it is necessary to fine tune a specific cost-effective approach for pinpointing their exact location and, consequently, to assess their evolution and geomorphologic changes.

Given the importance of that topic, several authors have proposed different methods for identifying agricultural terraces at large scale (Demoulin et al., 2007; Clarke et al., 2010), nevertheless these approaches are not sufficient to characterize and describe the complexity of terraced landscapes. This shifted the focus on the detailed scale, even if that topic has been explored just in few studies, many of which are based on a visual and manual interpretation of (digital) orthophotos (Faulkner et al., 2003; Martínez – Casasnovas et al., 2010; Agnoletti et al., 2011). These approaches are time consuming and their accuracy depends on operator's ability to interpret the images. On the contrary, the definition of a methodology suitable for the automatic extraction of terraces are even less common and, mostly, time consuming and expensive (Karydas et al., 2005; Li et al., 2012; Sofia et al., 2014; Diaz-Varela et al., 2014). To go beyond these limits, Diaz-Varela et al. (2014) proposed a new method characterized by the combination of unmanned aerial vehicles (UAVs) and photogrammetric technique for accurately describing the morphological surface through a high-resolution Digital Elevation Model (DEM) and a fine orthophoto. Photogrammetry was proposed by Rieke-Zapp et al. (2001) as a valid alternative to the traditional method applied until that moment for obtaining a high resolution DEM. Indeed, it allows to generate a comparable DEM with ones produced by laser scanner or Laser Imaging Detection and Ranging (LIDAR) in term of resolution and accuracy but reducing the time and cost of data acquisition (Rieke-Zapp et al., 2001). Although the approach proposed by Diaz-Varela et al. (2014) is innovative, it introduces some new issues, such as, the inability to analyse historical series, causing the impossibility to evaluate terraces evolution and morphological changes, or to investigate large areas in a short time. In the last few years, UAVs have gained more and more opportunities in agricultural and environmental monitoring (Colomina et al., 2007; Nex and Remondino, 2014; Capolupo et al., 2015b, 2018) introducing many benefits, such as the increase of spatial resolution of the aerial photos based on a reduced flight altitude or the decrease of the time and cost of image acquisition over a small area of interest. Nevertheless, they are not suitable to fly over large areas because their batteries last no longer than 10–15 minutes and they have limitations in the maximum values of altitude that can be achieved. In these cases, taking aerial photos by a manned plane could be more appropriate because it allows to combine the high resolution thanks to the introduction of new sensors and the possibility to cover wide zones in short time.

Contrary on the traditional classification approach (pixel-oriented), the object-oriented analysis (OBIA) combines the information extracted both from orthophotos and DEM: each pixel is classified on the base of the image textures and information context (Burnett and Blaschke, 2003). Indeed, the images are discretized in "regions", commonly defined "objects", internally coherent but completely different from their surroundings (Castilla and Hay, 2008). Each object is subsequently classified.

Therefore, the objective of this study is to introduce an innovative method for the automatic identification and extraction of terraced landscapes from photogrammetric aerial photos in order to go beyond the limits of the traditional approaches. Indeed, after assessing the ability of the photogrammetric technique in describing the complexity of terraces morphology, a novel universal methodology for automatically detecting the terraces has been developed, combining photogrammetry and OBIA classification. Subsequently the method has been applied for two periods over time and the difference between two terrace location maps is evaluated and implications for management identified.

2. Material and method

2.1. Study area

The Amalfi Coast site (40.38° - 40.40° longitude; 14.29° - 14.44° latitude, with an area of 112.3 km^2) is located in Salerno province, Southern Italy (Fig. 1). It is characterized by a peculiar landscape, consisting of an altitudinal gradient branded by a high floristic richness: the vegetation varies over the steep slopes from the typical Mediterranean greenwood and scrublands to temperate forest in the upper part (Caneva et al., 2007; Pindozzi et al., 2016). The coastline site consists of 13 municipalities. Although each of them is branded by a specific history and morphological features, they are characterized by some lower common denominators, such as the presence of terraces, agricultural economy and Mediterranean climate. Among these, Minori (40° 39″ 00″ N 14° 37′ 35″ E) (Fig. 1) is the most ancient municipality since it was founded in Roman period, as shown by some archaeological ruins detected in the area (Caneva et al., 2007). It extends over an area of 2.56 km^2. The area is mainly characterized by a Mediterranean climate, except for the upper part that has a temperate climate. Also the rainfall is particular, because it is higher than the other Southern Italian coastal zones: the mean annual rainfall average is higher than 1000 mm and, often, higher than 1400 mm (Caneva et al., 2007).

The study area is not so large but it is intensely terraced. It is bigger than the study considered in other studies, as Diaz-Varela et al., (2014) (1.2 km^2) and, taking into account the amount of terraced patches and the complexity of the landscape mosaic, the study area is comparable to the study of Cots-Folch et al., (2006) (28.96 km^2 of which 2.91 km^2 are terraced), Sofia et al (2016 b) (about 4.5 km^2), Modica et al., (2017) (24 km^2 of which 0.828 km^2 are terraced).

To make Minori territory arable and habitable, human influence started modelling its shape since 950–1025 AC, building some first terraces (Caneva et al., 2007). Nevertheless, the real transformation of the area started in the Middle Ages, when it was made over through terrace systems in order to exploit the fertility of its land for growing gainful crops, such as chestnuts, lemons and grapes (Tarolli et al., 2014). Two kinds of terraces can be distinguished: terraces with retaining walls in "dry stone" and terraces with retaining walls of stone bound by a lime mortar. The former consists of the older "macerere" or "murecine" terraces, as called in the local dialect, built without the use of binders (Tarolli et al., 2014). In that case, the drainage of excess infiltration water is ensured through the gap among the stones. The latter, instead, includes the terraces built with stones held together by a mortar, characterised by a high concentration of pozzolana, a lithic sediment deposition located in the volcanic area. That technique is dated to the XIX century or even later. Both terraces were built following the contour line shape, using different kind of stones according to different historical period and the economic situations of the zone