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Multi-scale 3D rock-art recording

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ABSTRACT

We present the micro- and mid-scale elements of an integrated multi-scalar solution to the 3D recording of rock-art sites in their landscape contexts. The photogrammetry-based solution integrates 3D models across vastly different scales: individual petroglyph, rock-art panel, site, landscape context. Micro-scale data are acquired with a novel 3D scanner that offers unprecedented radiometric quality at a resolution of 0.1 mm and immediate in-field user feedback while mid-scale data are acquired by unmanned micro-aerial vehicles. At all spatial scales the data are processed in a common Structure-from-Motion environment. Our solution is being tested in Valcamonica in northern Italy. One approximately 400 m^2 panel – Seradina I Rock 12C – is used throughout the paper to illustrate the approach and results. 3D point clouds are provided as digital supplementary material. It is shown that the solution is well-suited to purpose and will be of value to rock-art archaeology more generally.

1. Introduction

Valcamonica – Italy's first UNESCO World Heritage Site (1979) – is home to at least 100,000 petroglyphs, perhaps many more (Anati, 1975; Arcà, 2009). These date mainly to the Iron Age (first millennium BC) but also include examples from prior periods of prehistory and the medieval era. The Alpine valley is situated on the southern edge of the Italian Alps (see Fig. 1a). Formal study of the petroglyphs began in the early 20th century with particularly intense activity in the 1930s and again in the post-World War Two period after the arrival of Prof. Anati in 1956 who, some years later, founded the Centro Camuno di Studi Preistorici (CCSP – a Partner in the project reported here), which – along with other researchers – has published many important works on the petroglyphs (e.g. Anati, 1975, 1994, 2004; Sansoni and Gavaldo, 1995, 2009). With its large number of petroglyphs in various states of preservation and several quite accessible rock-art sites in various parts of the valley, Valcamonica constitutes an ideal testing ground for multi-scale 3D rock-art recording.

The larger context for the research reported here is the EU-funded 7th Framework Project “3D-Pitoti”.[1] The ambitious goals of the 3D-Pitoti project include

1. General requirements analysis and specification of the 3D-Pitoti hard- and software components.
2. 3D recording and registration of petroglyphs, rock-panels and larger-scale landscape for selected sites in Valcamonica.
3. Automated segmentation and classification of individual petroglyphs, based on their 3D structure.
4. 3D immersive, multiuser, interactive visualization at various scales.
5. Dissemination to a wide range of key stakeholders, including archaeologists, surveyors, museums, and schools.

The project's fieldwork is focussed on 5 sites in Valcamonica – Bedolina, Foppe di Nadro, Naquane, Sellero and Seradina (see Fig. 1b) – along with a Chalcolithic statue-stela now housed in the recently opened museum in Capo di Ponte known as MUPRE (Museo Nazionale della Preistoria della Valle Camonica). In this paper, we report results from research related to items 1 and 2 listed above: the requirements analysis; a novel, custom built 3D rock-art scanner; and multi-scale 3D recording in Valcamonica.

2. General requirements and benefits of multi-scale 3D recording

Digital documentation in archaeology already has a solid research record over more than 15 years. The work presented in this paper is mainly related to various aspects of 3D documentation of landscapes at large scales (see e.g. Alexander, 2011; Bewley

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[1] See the 3D-Pitoti project webpage www.3d-pitoti.eu

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2212-0548/

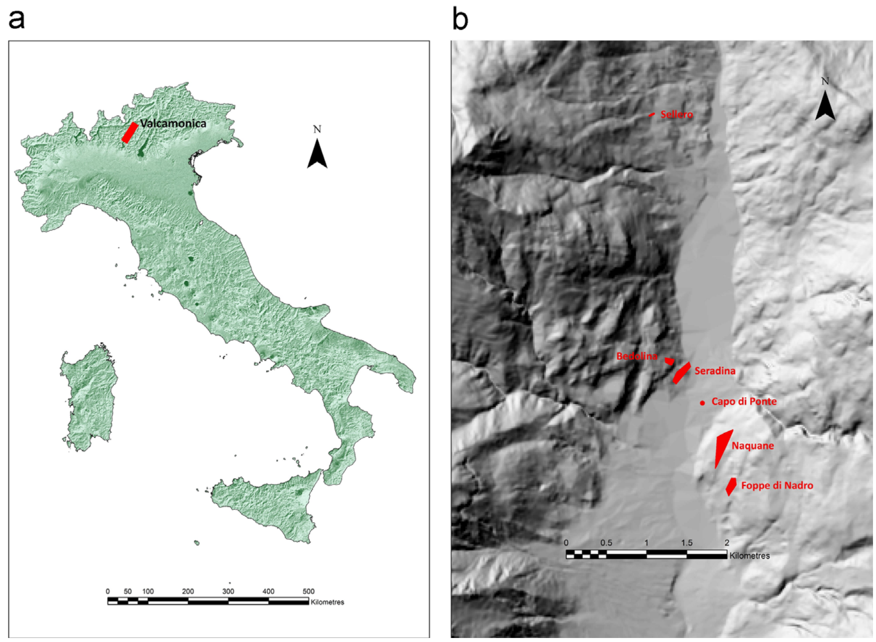

Fig. 1. Valcamonica – Italy's first UNESCO World Heritage Site: (a) Valcamonica in the context of the Italian peninsula and (b) locations and sites mentioned in the text.

et al., 2005; Chase et al., 2011; Harrower et al., 2014), particular sites at medium scales (see e.g. Alexander, 2011; Harrower et al., 2014; Knabb et al., 2014; Lambers et al., 2007; Robinson, 2006; Romero and Bray, 2014), and individual pieces, often at highly detailed, sub-millimetre scale (see e.g. Barber et al., 2014; Domingo et al., 2013; Gonzalez-Aguilera et al., 2011; Grosman et al., 2008. In terms of technological and algorithmic development, many solutions available today can be considered to be quite mature and there are reasonably standard workflows and processing pipelines for 3D surveying, site reconstruction, and the documentation of objects. One strand of research is related to reconstruction from images using bundle adjustment and related methods (see e.g. Agarwal et al., 2010, 2011; Frahm et al., 2010; Gherardi et al., 2010). This photogrammetric approach is definitely the most versatile as it can be applied at all spatial scales, provided the observed scene shows sufficient texture to allow automated feature correspondence analysis and the matching of corresponding points between images. Special care is needed in the photogrammetric acquisition process to be able to recover the correct scale of the 3D model, and to avoid drift. Therefore, to provide the highest quality 3D models, expert photogrammetrists and surveyors are required to work closely on-site with archaeologists (see e.g. Nocerino et al., 2014). Other work builds on specialized hardware that provides true metric scale and avoids model drift and distortions, e.g. laser scanners (Doneus and Neubauer, 2005; Castagnetti et al., 2012) and structured light scanners[2] (McPherron et al., 2009), or combines photogrammetric reconstruction with other sensors (Remondino, 2011), e.g. inertial sensors on mobile phones (Tanskanen et al., 2013). For special applications in archaeology, heritage, and the documentation of sculptural art, highly specialized scanners have been developed (Weinmann et al., 2011), but they require operation under very controlled conditions, for instance inside a dark room, and objects that can be brought to the scanner.

What are the specific challenges and benefits of 3D documentation of rock-art sites at all relevant scales, as addressed by the 3D-Pitoti project? A seamless transition between vastly different spatial scales requires an excellent spatial registration of the various recordings. Interactive 3D visualization and analysis requires radiometric surface properties beyond photo-texture, because the 3D content will be viewed under varying artificial illumination conditions. Therefore, at least the micro-range scans should be free from artefacts that are specific to the recording date and time, for instance the direction of the sunlight illuminating the rock-art or shadows cast on the scene. Potential benefits of such multi-scale 3D data are many, for instance intervisibility analysis between and within sites; enhanced visibility and contrast of petroglyphs by varying the (simulated) position of the sun; possible development of completely new 3D petroglyph segmentation and classification algorithms; shape analysis; comparisons between sites; and multiuser interactive experience of the rock-art in a detailed rendering of its natural surroundings.

In an initial project phase, one of the partners of the 3D-Pitoti consortium[3] used their existing technology to acquire a ground-truth dataset of the various Valcamonica sites targeted, including satellite images, aerial photogrammetry (manually captured digital photography using a motorized paraglider), laser scanning, structured light scanning (SLS), and close-range photogrammetry (manually captured digital close-up photographs). A thorough evaluation showed that photographs taken by expert photogrammetrists provide the best data quality in terms of spatial resolution and colour. Therefore, we have developed a single *common Structure-from-Motion (SfM) pipeline* that constitutes a purely photogrammetry-based solution to multi-scale rock-art recording. In addition to the superior resolution and radiometry of photographs, this approach is especially well suited for rock-art because natural rock surfaces and the rock-art itself constitute very well-textured scenes that provide excellent and unique point matches, which are a prerequisite for successful photogrammetric reconstruction.

However, multi-scale photogrammetric 3D reconstruction is quite demanding, even for experts. To be deployed by field archaeologists with limited training in photogrammetry the existing technology needs substantial improvement. In particular, we

[2] cf. Commercially available products, e.g. http://www.david-3d.com/en/

[3] ArcTron3D, a company involved in 3D documentation of archaeological sites.