1 Introduction

The joint research activities mainly concerned Nasca, with particular reference to the study of geoglyphs in an area near Cahuachi where the archaeological mission directed by Giuseppe Orefici operates, the study of Chanquillo, the oldest astronomical observatory of South America.

The laboratory activity consisted in the acquisition and processing of remote sensing data by drone and with geophysical prospecting techniques, processing of satellite remote sensing data, integration and fusion of such data for the purpose of their interpretation.

The scientific investigation methods are listed below:

- Processing of multispectral passive satellite remote sensing data at high resolution applied to the study of geoglyphs, their monitoring and evaluation of state of preservation
- Acquisition and processing of RGB, multispectral and infrared thermal data from drones for the purpose of creating 3D digital models in Nasca and Chanquillo, the identification of archaeological features in Chanquillo
- Processing and post processing with LiDAR data visualization techniques on the Chanquillo
- Geophysical prospections (geomagnetic and georadar) for the characterization of the subsoil and identification of structures of archaeological interest
- Integratione e fusion of heterogeneous data including ancillary data for the extraction of fetures and patterns of archaeological interest

2. Satellite and UAV-based study and monitoring of geoglyphs bewtween Cahuachi and Pampa de Atarco

This report deals with a multiscale, multisensor and multitemporal RS based approach for the analysis, interpretation and monitoring of Nasca geoglyphs which are one of the most impressive and vulnerable examples of cultural heritage throughout the entire world. They are exposed to damage much more than any other cultural heritage, due to their intrinsic fragility but also because they are characterized by very subtle features and strongly threatened by several anthropogenic factors. The area investigated in this paper is located in Pampa de Atarco, selected because it is representative of the most fragile geoglyphs, much more than those already investigated in other sites, such as Pampa de Nasca and Palpa. This is due to the specific engraving techniques based on the use of sand grain, pebbles and gravel of small dimension which make the geoglyphs very difficult to be detected not only on ground but also by satellite and close range view, especially in not optimal illumination condition. This has suggested an investigation strategy based on the integration of multiscale remote sensing passive and active data, including close range imagery, to enhance the visibility of geoglyphs (most of them are very subtle) and to capture the changes due to human induced disturbance affecting them. To cope with these issues, the analyses herein performed were based on statistical indicators computed in both temporal and spatial domains. Multitemporal analysis of VHR satellite imagery using PCA and Skewness allowed us to enhance the visibility of disturbance features and to automatically extract them using unsupervised classifications. In particular, respect to the satellite multitemporal data set which reveals the presence of five off-road vehicle tracks, the enhancement by PCA and Skewness enabled to add other five thinner tracks referable to footpaths or motorcycle tracks. The best

results in terms of enhancement and automatic extraction capability of disturbance features have been obtained by Skewness. The reuse of UAV L SAR-based correlation map, available free of charge from NASA, provided useful information on the state of disturbance from 2013 to 2015, widening the observation time window of the VHR satellite data set from 2002 to 2013. In the spatial domain, the textural analyses mainly based on dissimilarity along with PC1 enabled us to enhance edges of geoglyphs features facilitating their mapping and interpretation. In particular, in areas characterized by the superposition of geoglyphs, thanks also to the contribution of close range UAV photogrammetry, it was possible to reconstruct the relative chronological sequence thus providing an important contribution to archaeological studies. In the future, it is desirable to improve the relative chronological method with approaches and tools for absolute dating. This can be achieved by the analysis of pottery and ceramics close and along the geoglyphs, previously identified using Remote sensing data. As a whole, results from our investigations pointed out that the integration of satellite-based imaging and information with manned and unmanned data have significant potential to contribute into decision making processes for improving knowledge and supporting systematic monitoring and sustainable management strategies as mandatory steps to preserve unique or un-renewable resources as cultural heritage and landscape.

The Nasca Lines are one of the most impressive cultural heritages in the world, dated from 200BC to 600 AD and created by Paracas and Nasca civilizations considered among the richest, most refined, and original cultures of the pre-Hispanic Andean world (Silverman 1990; Masini et al. 2016c). These geoglyphs were obtained using three different engraving techniques by: (i) removal of gravels and sand to evidence the underlay lighter dust, (ii) adding dark color pebbles and sand grains along the lines, (iii) creating slight micro-relief by scraping sand and gravels and adding some darker gravel along the edges of the figures (Eitel 2005; Masini et al.2016a). The impressive geoglyphs shapes, huge sizes (lines longer more than 1 km and biomorphic figures reaching up to 300 m; see Figure 1bcd), and, functions have attracted an extraordinary scientific interest. In the last century, diverse assumptions and numerous theories have been postulated among them the main is the astronomical one, which considers the Nasca lines as a "great book" of astronomy with the function of a calendar (Kosok & Reiche 1949; Aveni 1986). The latest theories are based on the spatial/cultural/religious relationship between (i) the mountains and sacred places (Reinhardt 1988); or (ii) between geoglyphs and settlements (Reindel and Wagner 2009), and Cahuachi ceremonial center (Silvermann 1990; Orefici 2009; Masini et al. 2016a). According to these latest theories, the geoglyphs were sacred spaces used as "venues" for civic ceremonial activities and pilgrimage paths. As a whole, the phenomenon of the geoglyphs has its origin in a profound religious and cultural substratum, strongly influenced by the extreme conditions of the climate and environment where the Nasca used to live. Therefore, the geoglyphs were a cultural expression of the need of adaption, a request of help to the gods, an attempt to create harmonious relationships between man and environment, earth and sky made by ceremonial activities performed in the geoglyphs sacred space (Masini et al. 2016a,c). Geoglyphs were made to please and to be seen by Gods, therefore, only visible from above.
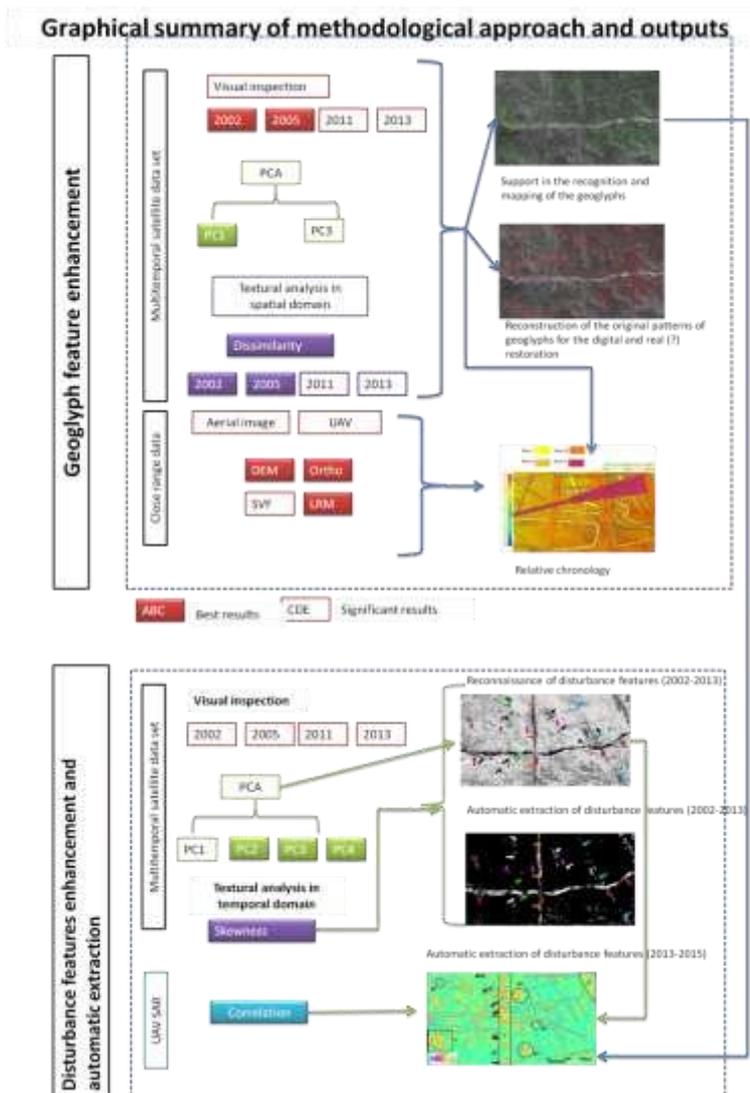
Figure 1 - Graphic summary of the two multiscale, multisensor and multitemporal approaches for enhancing geoglyphs, as well as detecting and automatically extracting disturbance

The area investigated is located in Pampa de Atarco, selected because it is representative of the most fragile geoglyphs, much more than those already investigated in the Pampa de Nasca (Hesse 2015; Comer 2017) and in Palpa (Lambers 2006). This is due to the specific engraving techniques based on the use of sand grain, pebbles and gravel of small dimension which make the geoglyphs very difficult to be detected not only on ground but also by satellite and close range view, especially in not optimal illumination condition.

This suggested an investigation strategy (see figure 1) based on the integration of multiscale remote sensing passive and active data, including close range imagery, to enhance the visibility of geoglyphs (most of them are very subtle) and to capture the changes due to human induced disturbance affecting them. To cope with these issues, the analyses herein performed were based on statistical indicators computed in both temporal and spatial domain. In particular, multitemporal analysis of VHR satellite imagery using PCA and Skewness allowed us to enhance the visibility of disturbance features and to automatically extract them using unsupervised classifications. In particular, respect to the satellite multitemporal data set which reveals the presence of five off-road vehicle tracks, the enhancement by PCA and Skewness enabled to add other five thiner tracks referable to footpaths or motorcycle tracks. The best results in terms of enhancement and automatic extraction capability of disturbance features have been by Skewness.

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Textural analyses mainly based on dissimilarity along with PC1 enable us to enhance edges of geoglyphs features facilitating their mapping and interpretation. In particular, in areas characterized by the superposition of diverse ground drawings, thanks also the contribution of close range UAV photogrammetry, it was possible to reconstruct the relative chronological sequence (see figure 2) providing an important contribution to archaeological studies.

Figure 2 Relative chronology of execution phases of geoglyphs

3. Chankillo investigations

Chankillo is an ancient monumental complex in the coastal desert of Peru, in the Casma valley, Ancash department dating back to the 4th century BC. The preserved ruins are related to a solar observatory, a fortified temple and a complex of structures with an administrative function.

The solar observatory is made up of Thirteen Towers aligned on a ridge arranged in the NW-SE direction which form a slightly curved toothed horizon. The observation points were placed in such a way that during the winter and summer solstices, the sun would rise and set on the towers at opposite ends

The fact that this observatory operated throughout the year and still functions today makes it unique in the world Archaeological data suggests that observations at sunrise and sunset served to regulate a social and ritual calendar, while strengthening a solar cult that helped give legitimacy and authority to a rising warrior elite. Recent archaeoastronomic work by Gezzi and Ruggles have identified a wider range of potentially significant alignments, possibly including some lunar, visible from places accessible to the public rather than

just a few high-level individuals. The site and its interpretation also illustrate some fundamental issues of archaeoastronomic methodology and practice that have a broader meaning.

The research project is divided into the following activities

• Processing of remote sensing data of different characteristics and resolutions such as multispectral satellite images, LiDAR data, multispectral and thermal aerial images acquired by drones aimed at identifying archaeological proxy indicators

• Ground validation of archaeological proxy indicators and interpretation through geophysical surveys (georadar) and ground reconnaissance.

• Map of features of cultural interest

The most important results were obtained from the elaboration of digital models from LiDAR (fig. 3, see methodological appendix) with particular visualization techniques (fig. 4) which emphasized microtopographic traces relating to walls, platforms and structures, some of the which refer to a complex of food stores (fig. 5). The latter have been indirectly verified with georadar surveys (figure 6) that show in greater detail these features that are located at a depth varying between 20 and 80 cm.

The processing of LiDAR data and subsequent post processing with visualization techniques also highlighted some topographical elements relating to possible buried structures and sanctuaries (huacas) around Chankillo, some of them verified with targeted reconnaissance in the field
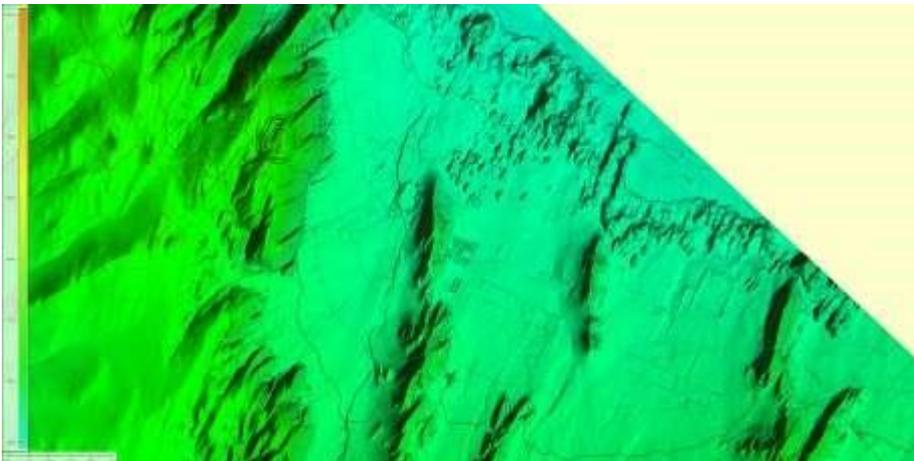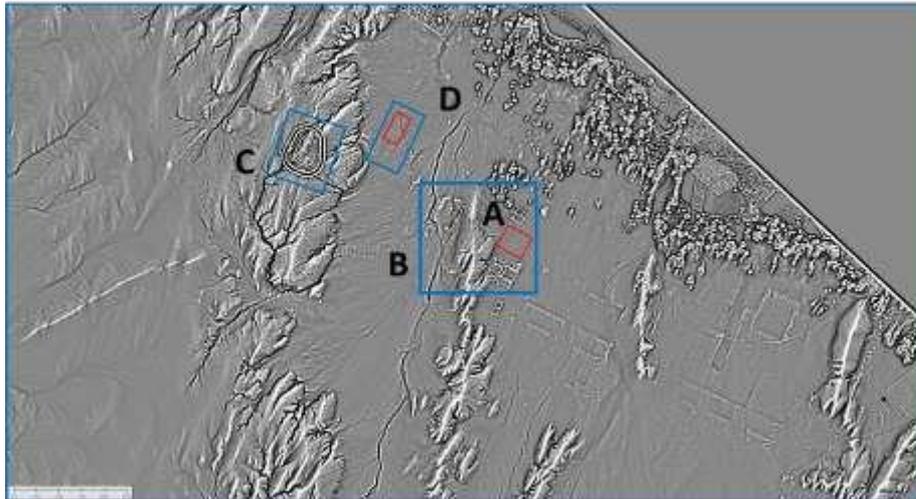

Figure 3 - DTM obtained from LiDAR survey

Areas to be investigated by GPR and Drone: priorities

A: possible eastern
osservation center (GPR
profiles x1m, in both
directions; area= 50 x
50m)
B: 13 Towers + western
osservation center (600
x 600 m ca
C Templo fortificato
(300 x 370m) m
D: Site of archaeological
interest (40 x 70 m GPR;
Drone: 170 x 280)

☐ UAV survey

☐ GPR survey

Figure 4 - Result of the visualization method based on the Local Relief Model (LRM). The letters A, B, C and D indicate the archaeological areas of interest to be investigated with other remote observation techniques such as the georadar and the drone. Among these D refer to an unknown site (see also figure 5)

Area D

Orthophoto   Multishading   Local Relief Model
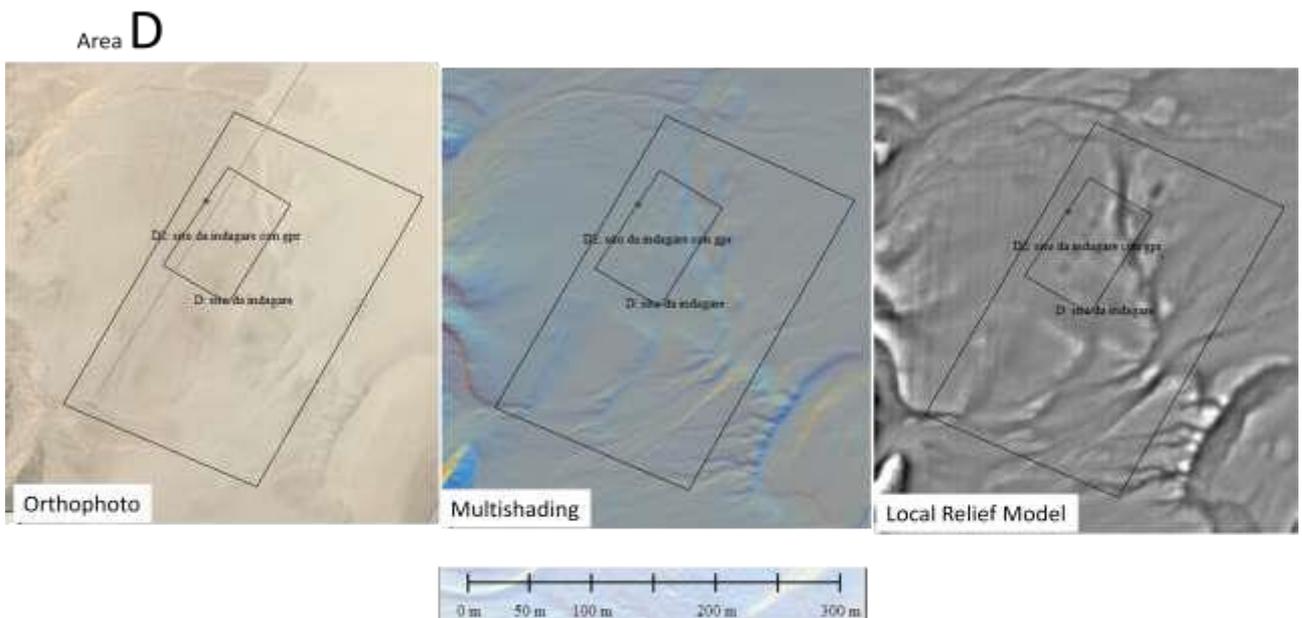
0 m   50 m   100 m   200 m   300 m

Figure 5 - From left to right, orthophoto, multishading and Local relief model of a sector named with the letter D. In particular, the result of the LRM highlights micro-reliefs relating to a rectangular platform and a complex of smaller square-shaped elements , probably related to underground food stores
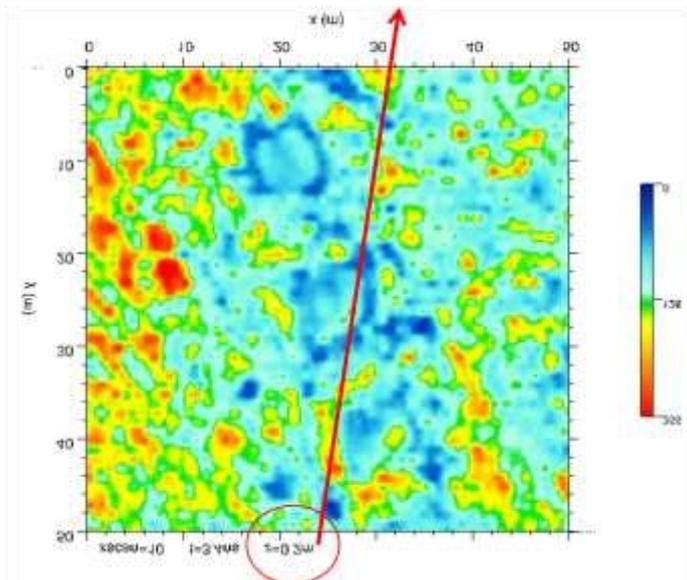
Figure 6 - Georadar map confirming the presence of the pattern of archaeological interest highlighted by the LRM calculated on the DEM derived from the LiDAR survey

4. Scientific outputs

Publication

Masini, R. Lasaponara (2020). Satellite and close range analysis for the surveillance and knowledge improvement of the

Nasca geoglyphs. *Remote sensing of environment*. Volume 236, January 2020, 111447 Conferences

Nasca (Peru), 25.08.2018. Lecture dal titolo "La "Re-descubierta " de los geoglifos de Pampa de Atarco: Nuevas informaciónes sobre los geoglifos y la relación entre el hombre y el medio ambiente a los tiempos de los Nascas" nell'ambito del III SIMPOSIO DE ARQUEOLOGIA "Avances de las investigaciones arqueologicas de las misiones Italiana y Japonesa

Il responsabile scientifico