

Visualisation and GIS-based Analysis of the Nasca Geoglyphs

Armin Grün, Martin Sauerbier and Karsten Lambers

Institute of Geodesy and Photogrammetry, ETH Hönggerberg, CH-8093 Zürich, Switzerland
www.photogrammetry.ethz.ch
{agruen, msb, lambers}@geod.baug.ethz.ch

Abstract. On the south coast of Peru, the famous geoglyphs carved into the desert surface of the Nasca region constitute a dominant feature in the prehistoric landscape. In a joint archaeological-geodetic project we used photogrammetry to map more than 1 000 of these ground drawings around Palpa, to the north of Nasca, which we later on revised in detail in the field. In this article we describe the visualisation of the geoglyphs and the landscape they are found in. Furthermore, we present the outlines of a GIS which we are currently establishing for the spatial analysis of the geoglyphs within their natural as well as cultural environment.

Keywords. Nasca, geoglyphs, photogrammetry, visualisation, GIS

1 Introduction

The famous geoglyphs of Nasca, Peru are currently the focus of a joint archaeological-geodetic project which aims at their 3D recording and visualisation as well as their analysis and interpretation within the context of the Nasca Culture (200 BC – AD 600). The lines, cleared areas and biomorphic figures in the desert around the town of Nasca are of great interest for the public ever since they were first reported in the late 1920s. Although the ground drawings have, for a long time, been interpreted as astronomic-calendric markers (Reiche 1993), today it is widely agreed that the geoglyphs served as pathways or sacred spaces in the framework of a water or fertility cult (Aveni 1990, 2000; Lumbreras 2000; Silverman, Proulx 2002).

Moreover, some of these investigations so far remain unpublished, as do the recent archaeological surveys in most tributaries of the Nasca drainage. As for the geoglyphs, their sheer size and number as well as the difficult terrain they are found in have so far prevented their effective recording, so that only a few important sites have been mapped in detail.

Therefore, the main goal of the Nasca-Palpa Project, initiated in 1997 and largely funded by the Swiss-Liechtenstein Foundation for Archaeological Research Abroad (SLSA, Zürich/Vaduz), was the complete and accurate 3D recording of two major geoglyph concentrations around the town of Palpa, to the north of Nasca (Fig. 1). This was accomplished by a photogrammetric analysis of aerial images of the area of investigation (Grün, Bär, Beutner 2000; Grün, Lambers *forthcoming*). An extensive settlement survey along the Grande, Palpa, and Viscas rivers (Reindel, Isla Cuadrado, Koschmieder 1999) and major excavations at two important Nasca sites (Reindel, Isla Cuadrado 2001) as well as of several small stone structures on the ground drawings (Reindel *et al.* 2001) provide the cultural background for the analysis and interpretation of the geoglyphs (Reindel, Lambers, Grün *forthcoming*). In this article we describe the visualisation of the geoglyphs and the surrounding terrain. Furthermore, we present the architecture of a Geographic Information System for the archaeological analysis of the geoglyphs that we are currently implementing. The GIS will be based on a commercial GIS software package and customised according to the user requirements.

2 Photogrammetry

Given the high number of geoglyphs to be mapped within the area of investigation, at the outset of the project it was decided that only a photogrammetric mapping procedure based on the stereoprocessing of aerial images would make a complete and highly accurate 3D recording of the Palpa geoglyphs feasible. The details of data acquisition and processing have been presented in previous articles (Grün, Bär, Beutner 2000; Grün, Lambers *forthcoming*) and will not be repeated here (on the principles of photogrammetry see Kraus 1993). The basic steps included: the acquisition of aerial images suited for stereoprocessing, the establishment of ground control points using differential GPS, the aerotriangulation and later on the scanning of the aerial images, the generation of a DTM as well

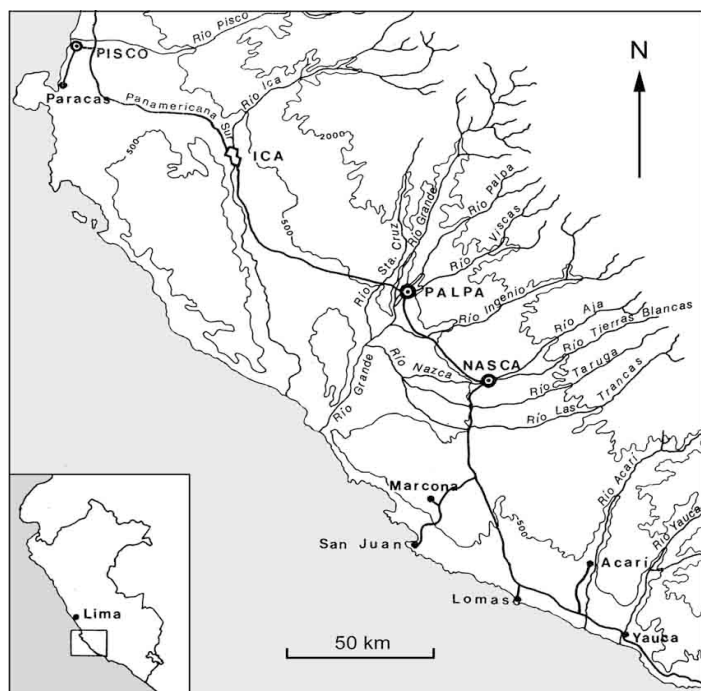


Fig. 1. The Nasca region in the coastal desert of southern Peru

However, this hypothesis is largely based on analogies with cultural contexts known from other regions and epochs of the Andes. In the Nasca area itself, the archaeological database is scant. Scientific excavations have been limited to only a few

as of orthoimages used for texture mapping, and finally the extraction of all geoglyphs in 3D vector form. Preliminary maps of the geoglyphs were revised in the field during an extensive ground survey of the geoglyph sites which also included the detailed description of more than 1 000 geoglyphs as well as the collection and classification of associated archaeological finds such as ceramics. Later on, the corrections made in the field were integrated into the 3D-vector dataset. This last step is currently being concluded. The result of the photogrammetric work is a highly accurate 3D model of our area of investigation around Palpa, which includes vector as well as descriptive data of all the existing geoglyphs of this specific region, and the related orthomosaic.

3 Visualisation

The visualisation of the produced 3D model is the next important step. Although our main emphasis is on the digital 3D model, the visualisation of data by the means of conventional 2D paper maps is equally important for archaeological work. This is especially the case in the Nasca area where only very few detailed and accurate maps of archaeological contexts are available and where even the quality of topographic maps leaves much to be desired.

3.1 2D Maps

The 3D vector data of the geoglyphs as well as contour lines derived from the DTM (both in DXF format) can easily be combined into maps and provided with coordinates using for example ArcView 3.2. By this means, any desired part of the dataset can be shown at different scales according to the purpose at hand (fieldwork, museum presentation, printed publication). A general map of the geoglyphs of Cresta de Sacramento, the ridge immediately to the north of Palpa, will be published in the near future (Reindel, Lambers, Grün *forthcoming*). This is the first map of a certain part of the Nasca area which shows not only the most important or easiest visible, but all surviving geoglyphs (in this case 611), with detailed descriptions available for all ground drawings. An enlarged detail of the map of San Ignacio, the plateau to the south of Palpa, is shown in Fig. 2.

3.2 3D Models

For the visualisation of digital 3D models, tools and software are available in manifold forms. For example, in http://www.tec.army.mil/TD/tvd/survey/survey_toc.html we can access a list of about 550 software packages just for terrain visualisation. For the uninitiated user it is very difficult to select a program of choice, and it needs a lot of testing and practical work with different kind of datasets before a critical assessment and acquisition decision can be made. Although the conceptual aspects of computer graphics algorithms are quite straightforward, it is always the implementation and the quality of the key components of the computer platform which define the performance. When analysing visualisation software a major consideration is whether real-time performance is required or not. For many analysis applications real-time performance is just a must for the sake of economy and efficiency of operation.

Actually one can classify visualisation software on the basis of its real-time performance, given a certain computer configuration. In this context one can distinguish high-end, middle class and low-end systems (e.g. Skyline, Erdas IMAGINE

VirtualGIS and Cosmo Player, in this order). While low-end software is increasingly available as freeware over the Internet, the other levels of quality can only be reached by paying, in some cases dearly, for the product. On the other hand, due to the dramatic increase in computer power and graphics board performance over the last years one can nowadays expect even from laptops a rendering performance that was unheard of only 2-3 years ago. High-end performance of photo-textured 3D models can be obtained on laptops if the software supports that. One critical parameter here is the Level-of-Detail (LoD) property. LoD capability ensures that at each and every frame of an image sequence only the foreground portion of the 3D model is represented at highest resolution. Other zones of model depth are represented at lower resolution. This reduces the amount of computations substantially, an advantage, which becomes the more prominent the bigger the model is. This LoD property applies both to vector and image raster data. The interested user should also pay attention to the fact whether the different resolution layers can be produced effortlessly by himself or whether a major economic effort is needed.

Currently our two datasets of Sacramento (to the north of Palpa) and San Ignacio (to the south of Palpa) encompass 13 MB of vector data and 3 GB of image raster data at the highest resolution level. After all data is collected we even expect about 20 % more. This requires high-end visualisation software to be used. In our case we employ Skyline from IDC AG, Luzern, Switzerland. The visualisation was realised using the two blocks of the DTM with a mesh size of 2 m and orthoimages with ground sample distances of 0.28 m (Sacramento) and 0.25 m (San Ignacio), resp. The 3D vector data of the measured geoglyphs is integrated as an additional layer that can be faded in or out while navigating in real-time mode. The Skyline software allows the integration of the 3D vector data in DXF format in two different ways: 1) maintaining the height attributes of the vectors or 2) mapping them to the DTM. In our case, the vector data had already been integrated as breaklines into the DTM.

Furthermore, important locations have been stored as view-points, which allows to directly fly to them, and different routes for synthetical flyovers have been defined. These routes can be viewed in real-time mode or exported as a sequence of images, e.g. in AVI or MPEG format. The Skyline visualisation software offers the full functionality of a web browser, which enables the integration of the project's website and a geo-referenced map in a separate overview window (Fig. 3). It is also possible to place labels into the 3D model which contain information about important locations not only in textual form but also as hyperlinks and images or video sequences (mime type data).

To create synthetical flyovers of smaller subsets of our data we also employ Erdas IMAGINE VirtualGIS 8.4. However, this software is mainly suited for the production of static images (Fig. 4) because of its manifold regulation capabilities regarding the LoD control. This allows finding the optimal settings for any observation point. Unlike the Skyline software, IMAGINE VirtualGIS offers some basic analysis tools, especially the possibility to calculate and visualise lines of sight for arbitrary points and viewshed analysis for one or more points, including the display of overlapping zones. Therefore, the Erdas software can also serve as a module of the GIS.

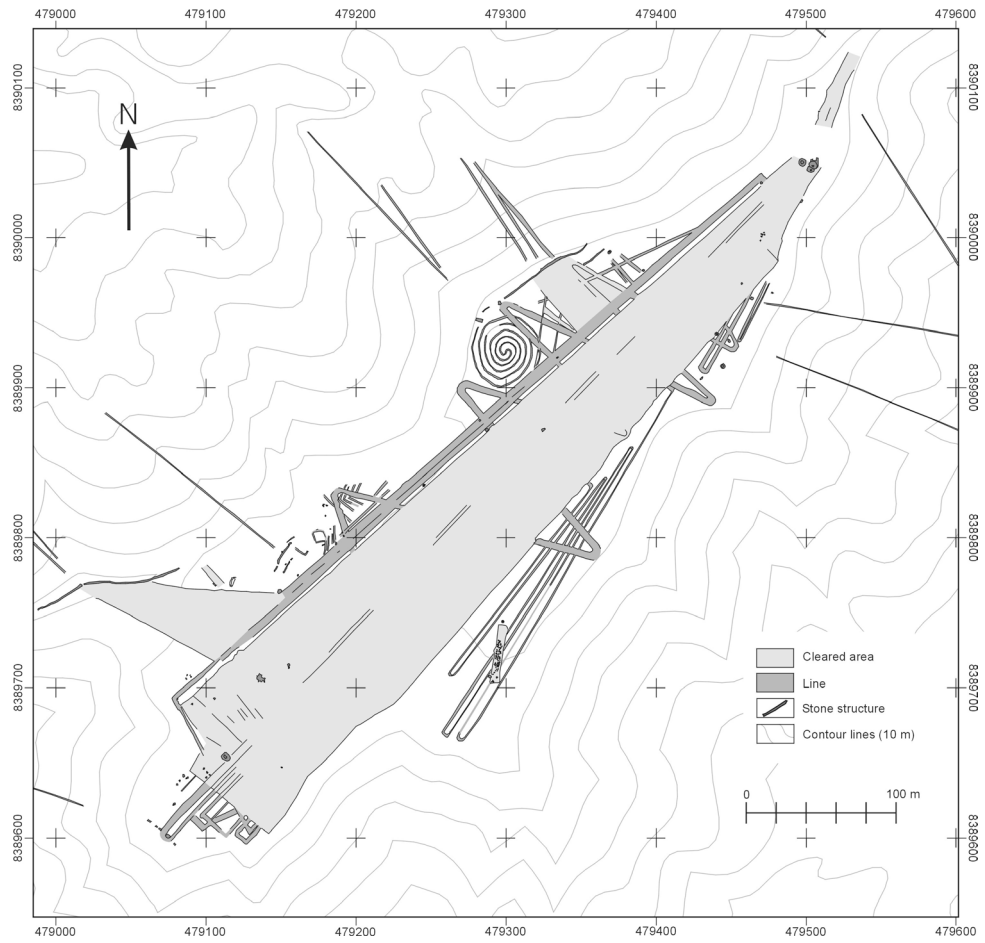


Fig. 2. Map of site PAP 379 (to the south of Palpa) with a central trapezoid and various lateral geoglyphs (compare Fig. 3).

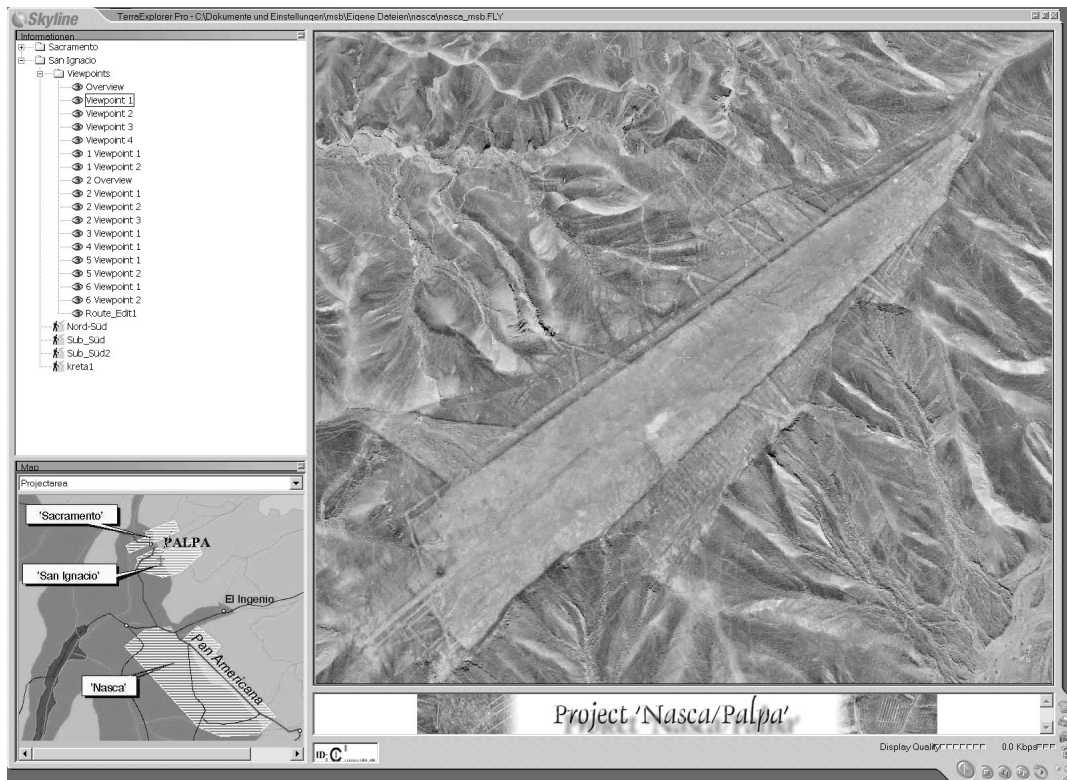


Fig. 3. Screenshot showing the Skyline Terra Explorer visualisation tool including 3D model, website, and geo-referenced map.



Fig. 4. *Overview of the plateau of San Ignacio (to the south of Palpa), generated with Erdas IMAGINE 8.4.*

4 GIS

The main purpose of the planned GIS of the Nasca-Palpa Project is the archaeological analysis of the geoglyphs of Palpa within their natural as well as cultural environment. It may therefore be considered an explanatory GIS following the classification of Wheatley and Gillings (2002: Fig. 12.1). At the same time, however, it should enable the effective integration, management, and manipulation of different kinds of data (vector, raster, and textual data), as well as the interchange of data between the users. The GIS will have a modular structure based on commercial software packages, which have to be customised according to the user requirements.

4.1 GIS Functionality: User Requirements

The geoglyphs constitute a dominant feature in the arid landscape of the Nasca region. Whatever their specific purpose, they clearly integrated the uninhabited desert plains into the cultural landscape of the valley-based Nasca society. However, how this was accomplished exactly, what principles and concepts guided this process, and what kind of order might underlay the vast array of ground drawings in the desert is still poorly understood. A GIS-based analysis is expected to provide clues for a better understanding of these topics (Silverman, Proulx 2002:179).

The GIS of the Nasca-Palpa project is designed to enable a systematic investigation of the spatial relations of the ground drawings to their environment. One important aspect here is the distribution of the geoglyphs. Unlike on the Nasca pampa, the topography at Palpa allows to distinguish more or less clearly delimited geoglyphs sites. As the settlements along the valley

margins have also been recorded by our project, the distributional pattern of both kinds of contemporaneous sites can be compared to reveal possible correlations. In the case of Los Molinos and La Muña, two important regional centers of Nasca times that were partially excavated, certain geoglyphs that formed an integrated part of these settlements could already be identified in the course of our fieldwork (Reindel, Isla Cuadrado 2001). The GIS-based investigation of site catchment areas, visibility between settlements and geoglyph sites and accessibility of geoglyph sites in a difficult terrain will probably help to establish similar relations for other sites as well.

On the level of individual geoglyphs, their location and orientation seem to be guided to a certain degree by local topography. Specific types of geoglyphs are apparently found only on certain types of terrain, e.g. human figures and small trapezoids only on slopes, spirals, large trapezoids and animal figures only on plateaus etc. Furthermore, the orientation of the large trapezoids as well as their accompanying lines seem to follow local geomorphology, whereas single lines (on slopes as well as on plateaus) often crosscut these given orientations and in many cases seem to be directed toward remote landscape features like mountain tops or the farthest visible regions of the valleys (up- and downriver). These and other preliminary observations made during our fieldwork at Palpa can be tested and revised performing a systematic investigation of spatial relations within a GIS environment. This will also include a test of the recent hypothesis that the geoglyphs map underground water sources.

To investigate these and other topics, well established techniques will be employed, among others: the calculation of slope and aspect, buffering, the cell-based definition of a cost surface,

line-of-sight and viewshed definition, and others (for an overview see Wheatley, Gillings 2002). The photogrammetrically generated, highly accurate DTM of the area of investigation will serve as the geometric basis for these analyses.

The current work at Palpa also includes a cooperation with geoscientists who investigate the geomorphology, geology, hydrology, and climatic history of the Nasca region. The corresponding data and results will be integrated into the GIS where they will serve as background information for the archaeological analysis and as the base for independent geoscientific analysis as well. The international and interdisciplinary cooperation within the project requires the easy interchange of data as well as analytical capabilities between scholars based in different countries and with different research interests.

4.2 Structure of the GIS

The structure of the GIS follows from the aforementioned user requirements. Based on these it is necessary to design a data model suitable for providing the required functionality, especially to permit all kinds of desired queries. A conceptual data model for the Nasca-GIS has already been developed using the object-oriented Unified Modeling Language (Visnovcova 2000).

Two different groups of GIS users can be distinguished: local and external scientists (Fig. 5). Both of them are mainly interested in the basic data such as the DTM, aerial images and orthoimages, but also in the vector data including the geoglyphs, topographic features (e. g., rivers) as well as modern man-made objects like roads and houses. As the external users should be able to access the data from different locations, it is necessary to decide how this may be realised in a practicable way.

Due to the size of high resolution images and terrain data it is not feasible to provide the basic data via the Internet. Thus, the external users will have to store it locally. This approach is reasonable because of the persistence of the basic data. Other information such as vector data, analytical functions and results of queries are frequently affected by updates, while their transfer times are much lower compared to the image data. This kind of data will therefore be made available for remote access by authorized users. The exchange of information is designated to be a bidirectional operation supervised by the administrator: the integration of the results (e. g., thematic maps, typologies, chronologies) and functionalities produced by the users will provide this information to any other interested scientists in the network.

The multiple tasks of the administrator (a geodesist) and the local user (an archaeologist) at IGP not only comprise technical support and data provision, but also on the archaeological side the analysis, validation, administration and integration of results into the database. On the photogrammetric and geodetic side, apart from the administration of the existing data, the administrator also has to develop additional analysis functionalities, to customise the commercial GIS platform, to verify the integrity of data and to maintain the system. Furthermore, the administrator and the local user need to cooperate in additional tasks such as validation of analysis results.

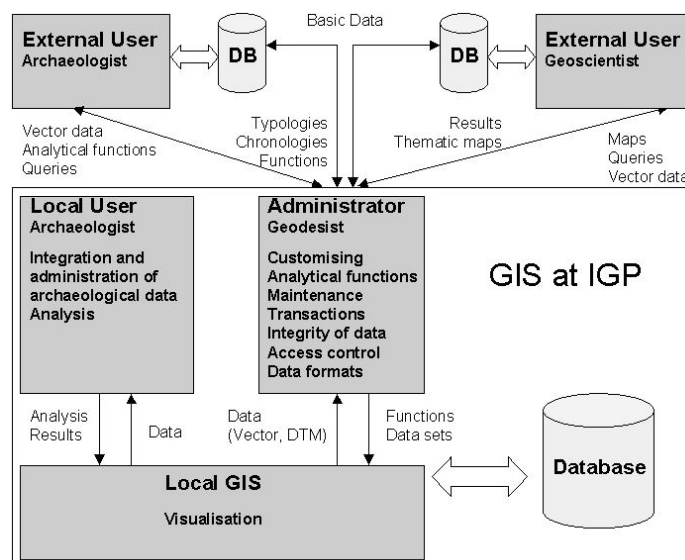


Fig. 5. Basic structure of the planned GIS.

We are currently evaluating several commercial GIS software packages in order to decide on which one to build our GIS. The important criteria can be summarised as follows:

- The software should support widely used data formats to ensure data exchange without loss of information.
- The definition and editing of objects must be possible in an efficient way.
- An interface to common database management systems has to be provided, as well as data manipulation and query using standardized languages such as SQL.
- The software functionality should be customisable using common programming languages such as C++ and Java or internal languages and existing scripts.
- The integration of raster and vector data is essential.
- A 3D visualisation tool for spatial analysis should be included.
- A comfortable tool for the creation and design of 2D maps and plans is desirable.
- The supported hardware platforms as well as the operating systems should enable data transfer to Microsoft Windows systems as well as UNIX platforms.
- Finally, the cost factor has to be kept in mind.

Although the evaluation process has not yet been concluded, we will most probably employ different software packages for different tasks according to the special capabilities of each.

5 Conclusions

The photogrammetric 3D recording, the visualisation and the GIS-based analysis of the geoglyphs of Palpa present novel approaches in Nasca archaeology. For the first time, two of the most important concentrations of these still enigmatic ground drawings are systematically documented and analysed. The complete mapping of all surviving geoglyphs of a given region has considerably altered our conception of the ground drawings. Not just the quantity, but also the diversity of the geoglyphs is much greater than expected. The accurate recording of each geoglyph in its individual shape and context allows detailed insights into the construction process and the use of the ground drawings. Without the application of photogrammetry the acquisition of adequate data would not have been possible.

The analytical capabilities of the projected GIS are likely to provide further insights into the role and function of the geoglyphs, while the excavations at important Nasca settlements as well as of small stone buildings on the geoglyphs and the regional study of settlement patterns will provide the cultural background for a new attempt to interpret the geoglyphs within their cultural context. All in all, the current project, while far from being completed, can already serve as a reference example to demonstrate the synergy which results from a good cooperation between archaeology, natural and engineering sciences.

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