Steps Towards a Spatial Information System in a Close Range Archaeological Environment

Ulrike Brüssler, Heinz Rüther
Department of Geomatics, University of Cape Town, South Africa
Email: ulrike@eng.uct.ac.za

KEYWORDS: close range photogrammetry, information systems, archaeology

ABSTRACT

Based on the example of the documentation of the 3.6 million years old hominid footprint track-way in Laetoli, Tanzania, the paper describes the development of a spatial information system for archaeological and conservation sites.

The Laetoli site presents the first physical evidence of hominid bipedalism and because of its fundamental relevance to the history of human evolution, documentation of the site merits an exceptionally high level of detail and completeness. Digital photogrammetric techniques in a close range archaeological environment as a data acquisition tool will be discussed, as well as database design and a spatial information concept.

KURZFASSUNG

Das Dokument beschreibt die Entwicklung eines räumlichen Information Systems für archäologische Fundplätze anhand der Dokumentation der 3.6 Millionen Jahre alten hominiden Fußabdrücke von Laetoli, Tansania.

Laetoli zeigt den ersten Beweis für hominides aufrechtes Gehen und wegen dieser fundamentalen Relevanz für die Geschichte der menschlichen Evolution erfordert die Dokumentation dieses Fundortes ein außergewöhnlich hohen Anspruch an Detailgenauigkeit und Vollständigkeit. Digitale photogrammetrische Techniken für den Nahbereich in einer archäologischen Umgebung sowie Datenbankdesign und räumliche Informations Konzepte werden diskutiert.

1. Introduction

In recent years archaeologists have added digital photogrammetry and Information Systems to the conventional technologies for the surveying and documentation of archaeological sites and artefacts.

The Laetoli project offered an opportunity for a combined application of digital photogrammetry in its close range form and spatial information technology. The objective of the project from the perspective of the geomatic expert is the provision of a permanent record of the oldest available evidence of hominid bipedialsm.

This information must be presented in a format, easily accessible by public and interested researchers. Interpretation of evolutionary evidence tends to be dynamic and interpretations and opinions of scientists vary widely, it is therefore essential for the presentation of the data to retain objectivity and avoid human interpretation at the data acquisition and documentation stages.

Therefore the photogrammetric processing was done in a full- or semi-automated mode, wherever possible. Data were evaluated using analytical and digital photogrammetry and the results of the two approaches were compared to establish the impact of a human interpreter on the data.

A further objective of this interdisciplinary research project was to develop a pragmatic and dynamic model for the management of large amounts of data associated with the conservation and documentation of this and other similar sites.

The design of the Spatial Information System (SIS) is kept as generic as possible in view of the broad range of users including conservation professionals, archaeologists, palaeo-anthropologists and palaeo-ontologicalists, photogrammetrists, students from a variety of disciplines and the general public.

The incorporation of the innovative use of technologies for data acquisition and data processing will be discussed, including aspects of close range photogrammetry such as interest point detection, image matching and visualisation for the subsequent development of virtual reality models.

2. Background

The discovery of the fossilised hominid footprints in Laetoli, Tanzania, in 1978 is widely seen as a conclusive proof for the existence of hominid bipedalism as early as three and a half million years ago. Excavation of the site revealed two parallel tracks of hominid imprints – one with small imprints and one with considerably larger ones - generally attributed to Australopithecus Afarensis. First interpretations suggested that the smaller imprints originated from a small single individual, while opinions varied on the second one, which was interpreted in various ways. A widely held scientific opinions is, like orang-utans and gorilla, the earliest ancestors of human kind were sexually dimorphic, with males much larger than females. Thus the first track-way may have been made by a female and the second by one, possible two males. The imprint of a second big toe in several of the larger imprints suggests that another individual may have walked in the footsteps of the first. However, this area is not within the expertise of the authors of this paper and the dispute is merely mentioned to emphasis the need to acquire the surface data at the highest possible degree of objectivity and precision to provide an unbiased bases for subsequent anthropological research.

After the first excavation of the tuff surface in 1978 the fragile evidence had to be preserved. The chosen option was the reburial of the entire track, covering it over with layers of sand, plastic sheeting and lava boulders to protect it from damages through plant roots.
A site inspection in 1985 showed that the efforts to protect the footprints from root damage appeared to have backfired. Acacia trees were growing over the buried prints.
As a result of damage from roots penetrating into the tuff layer the track lost some of its scientific value and suffered more deterioration in 10 years than in the 3.6 million years beforehand. (Johnson, 1989)

3. The Project

The Laetoli Project is a collaborative conservation project between the Getty Conservation Institute and the Government of Tanzania to conserve the Laetoli hominid trackway.
In order to produce a permanent record of the hominid trackway site the Getty Conservation Institute entrusted the Department of Geomatics at the University of Cape Town with the digital / analytical photogrammetric documentation and conservation of the site as well as the development of a Spatial Information System.
As it was considered as essential by conservation experts to rebury the site after removal of roots and insect damage and chemical conservation treatment, it became obvious that the trackway would not be accessible for the public and scientists. It was therefore necessary to device an alternative means to allow the public "access" to the track. The conventional way of providing such access was given through the casts prepared by Mary Leakey. The original casts can be seen in the museum of Olduvai, Tanzania, while duplicates are distributed to numerous museums around the world.
Most scientists refer to these casts when discussing the footprints. The modern alternative to casts is a highly precise and detailed digital surface model (DSM) consisting of dense point clouds describing the imprints with the possibility of detailed dimension analysis and 3D visualisation.

The conservation project including re-excavation, conservation, photographic and photogrammetric recording, scientific restudy, and reburial was completed in two field campaigns in 1995 and 1996. The photogrammetric team from University of Cape Town joined both field campaigns and produced a complete photogrammetric coverage of the individual footprints as well as the surrounding track.

4. The Photogrammetric Recording Process

The photogrammetric field campaign was designed to allow for a comparison of different photogrammetric techniques and to provide for a broad range of imagery. Photography was therefore taken with three different camera types, a conventional metric camera (UMK 10), a conventional non-metric camera (Hasselblad), and a non-metric digital camera (DCS 420). A control-point field was established, which provided full control for each of the photogrammetric models.
Control points were determined with sub-millimetre accuracy to enable the generation of DSMs with contour intervals of 5mm for the track-way and 0.5mm and 1mm for the individual footprints.

4.1 Control-Point Survey

The site is 27m x 5m in extent. There are 69 footprints, separated in a G1 and G2/3 track.

Since some of imprints were incomplete or damaged by roots or insects only 60 footprints were captured individually. 107 control points were temporarily attached to the tuff surface and determined in a precise triangulation survey and least squares network adjustment.

The adjustment resulted in standard deviation of better than 0.5mm for the XYZ-co-ordinates of the control points.

The photogrammetric control points were triangulated from a previously established external network.

The height was established by vertical angle measurements and subsequent adjustment.

4.2 Photogrammetric data acquisition

The Photogrammetric data acquisition was split into two parts:

- the photogrammetric survey of the track-way
- the photogrammetric survey of the individual footprints

4.2.1 Photogrammetric data acquisition for the track-way

The photogrammetric survey was designed to provide complete dual stereo cover for conventional and digital photography. The cameras were positioned over the track in 28 base lines separated by intervals of 45 cm, resulting in 50% longitudinal and 80% lateral overlap. For each set of images a camera support bar was positioned over the track at an elevation of approximately 1.6m to allow for the camera to be centred over the pre-designed base line. To cover the whole track-way, ' 148 UMK photographs, 302 DCS images, and 156 Hasselblad photographs had to be taken.

4.2.2 Photogrammetric survey of each individual footprint

After completion of the track-way survey, each hominid footprint was photographed individually at a lower camera height to obtain a more detailed map of the imprint. For this photography a separate set of co-ordinate control-points surrounding each footprint was required. This was achieved by means of a portable control point frame with 71 retro- reflective targets at two elevations, which was placed over each of the imprints prior to the photography. Four points of the control frame were surveyed from the surrounding survey network and the remaining 66 points were transformed by means of a 3D transformation, into the site co-ordinate system for each footprint. Image capture was done with the cameras at an elevation of approximately 0.9m.

360 DCS images and 240 Hasselblad photographs covered the individual footprints.

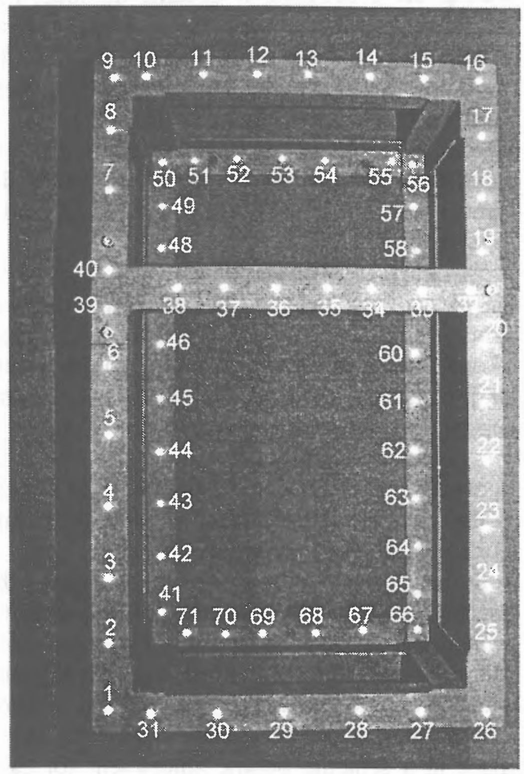

Figure 1: Footprint Frame

5. Data Processing

After the photogrammetric survey of the Laetoli site, the acquired data had to be processed. The analogue photography taken with the UMK camera, were processed in a TOPOCART analytical plotter and a digital surface model was created in form of a contour plot.

The procedure for the digital images for the individual footprints taken with the DCS camera differed and the following procedure was adopted:

1. Camera calibration

There are two options for the calibration of the camera.

- pre-calibration of the camera
- self-calibration for each model

It was originally planned to adopt the pre-calibration approach for the digital photogrammetry. This meant that the camera focal setting had to be retained by taping the lens focus ring into position to prevent movement during the image capture process. It was intended to pre-calibrate the camera and adopt the calibration values for the entire process. During the processing it became obvious, that the calibration had not remained constant (focal length changed by up to 1.1 mm). This can be attributed to chip movement in the DCS camera combined with instability of the lens.
It was therefore decided, to abandon the pre-calibration approach and instead calibrate the camera in a self-calibration for each model separately.

2. Control point measurement:
On each of the images the control points were identified on the computer screen and the image co-ordinates of the control points were automatically measured in pixel co-ordinates using in-house software.

3. Image Orientation
In order to establish the orientation of all images in object space the elements of the interior and exterior orientation were determined.
Following the self-calibration concept the interior orientation parameters of the camera, principal distance, principal point and lens distortion parameters, were determined together with the exterior orientation parameters, location and orientation of the camera set-ups in object space in a separate bundle adjustment for each model, consisting of six images using in-house software.
Semi-automated target identification and automated target centring were employed to determine control point positions for the bundle adjustment and provisional values for the exterior orientation parameters were determined by means of a direct linear transformation.

4. Interest point extraction
In order to produce a dense cloud of surface points in an automated mode it is necessary to detect identifiable points on one image of the set and then to find conjugate points on all other images. This is achieved by an interest point extraction algorithm, which detects image points on the bases of changing texture / grey-value with a subsequent matching algorithm.
For the footprints a maximum gradient interest operator was employed.

5. Surface reconstruction
The surface was reconstructed by means of Multi-Photo-Geometrically-Constrained-Matching, in which epipolar line geometry is used to provide a search range (Wong, 1986) for subsequent least squares, grey-scale matching (Grün, 1988) to determine conjugate on all images. The matching algorithm is combined with the bundle adjustment in an iterative process to determine XYZ co-ordinates in object space of all matched points (In-house software).

6. Generation of a grid-DSM
The surface modelling was done using height interpolation by finite elements with the software package HIFI 3.2 (Photogrammetry GmbH Munich).

7. Contour map and Ortho-image
After having derived the orientation parameters and the DSM, ortho-images were produced with commercial software written by Grün/ Baltsavias, University of Zürich and in-house software of the Department of Geomatics, UCT.
The contour maps were produced with the software HIFI and ArcInfo.

The resolution of the DCS camera (1524 by 1012 pixels over a chip area of 13.8 by 9.2mm) proved satisfactory for the automated DSM generation and was acceptable with respect to definition of detail. However, to improve the visual quality of the ortho-images, the Hasselblad photographs were scanned at 7.5micron resolution and ortho-images were produced using the original derived DSM and orientation data.
In the interest of maximum flexibility the data were produced in different output formats, such as ASCII, dxf, e00, tif, kon.
Altogether 1800 files were produced, including DSM files, images files and general information files. It became obvious that in order to manage the vast amount of data and to present the information in a user-friendly and meaningful way, an Information System was needed.

6. Spatial Information System

The field of Information Systems is relatively new and rapidly developing. To design an Information System, which will be accepted by its users, awareness of possibilities, trends and limitations are essential. This chapter aims to provide a definition and to derive the fundamental principle on which Information Systems are based.

6.1 Definition of Information System

An Information System is a system for capturing, storing, checking, manipulating, analysing and displaying data. It is typically implemented as a computer-based system for handling spatial data which is composed of four major sub-systems (Marble, 1984):

- A data entry subsystem for handling problems connected with the translation of raw or partially processed spatial data.
- A data storage and retrieval subsystem which accepts the input stream of spatial data and structures the database for efficient retrieval
- A data manipulation and analysis subsystem which takes care of all data transformations initiated by the user
- A data visualisation and reporting subsystem which returns the results of queries and analyses to the user.

To design an Information System, its purpose, the tasks it is supposed to perform and the people who will use the system must be clearly identified. Not all of the above mentioned four components will have the same impact in a specifically designed Information System. It must be established if the Information System will be designed as a transaction processing system, where the emphasis lies on recording and manipulating, or as a decision support system, with the emphasis on manipulation, analysis and particularly, modelling for the purpose of decision makers. In this respect it is important to define the Information System in detail, because the design of the IS, i.e. the structure of the database and querying possibilities, will be different for a transaction processing system and a decision support system.

6.2 Extent and Content of Information Systems

Information systems have a number of important general attributes. The information in the system must be organised to be meaningful when retrieved; access to information in the system must be managed and carefully regulated; there must be continued support and maintenance of the information and technology within the system over time; and users must be trained and encouraged to use the system.

Information Systems - and especially GISs, with their emphasis on geographical reference - are seen by an increasing number of archaeologists as being the optimum information technology to be adopted for location analysis, spatial data management and spatial modelling. GIS systems represent reality as a series of geographically referenced features. The geographical data element is used to provide a reference for the attributes in GIS. The geographical element is consequently seen as more important than the attribute element and this is one of the key features, which differentiates GIS from other Information Systems.

Strictly speaking the term 'geographical' refers only to locational information about the surface or near surface of the earth at real-world scales and in real-world space.

While in the archaeological/conservation context data will be spatially referenced, this reference is not necessarily geographic. Instead, a local site co-ordinate system defines the spatial datum.

In general, the use of the term 'spatial' in the IS context refers to data linked to a location derived from primary or secondary remote sensing and/or surveying operations.

Historically, spatially referenced ISs were based on geographic co-ordinates in a pre-designed geographically based data structure. Commercial software has retained the term 'Geographic', although applications have moved to a wider and more flexible use of data base structures in a general spatial environment. In the archaeological context the term 'spatial' is thus preferable to 'geographic'.

Many researches have concentrated on the limitations of IS rather than seeking complementary technologies to strengthen it. To overcome limitations faced by the current state of technology, flexibility in the design of the Information System has to be emphasised.

For example, experience–based archaeological knowledge is required for the classification of artefact types. Such experience–based decisions may in future be supported by advanced computing techniques, e.g. neural networks or hybrid neural expert systems.

In general it is important to guard against the development of an Information System as a mere tool. This would be underrating the potential of Information Systems and ignoring the need for the simultaneous development of an IS culture.

7. Design of Information System

To design the SIS for archaeological and conservation sites, a strategic plan was developed. The purpose of the strategic plan is to create a framework within which the complexity and interdependence of the IS design and implementation can be managed.

A strategic plan consists of the situational analysis, the project plan, the design specifications, the implementation and the operation and maintenance stage for the development of an Information System.
The Situational Analysis – by defining the 'philosophical', technical and resource situations – represents a crucial part of the Strategic Plan, since the IS has to be successfully implemented into an existing situation.
The Project Plan establishes what is needed and required on the basis of the Situational Analysis, to guarantee the successful implementation of the IS.
The design specifications of the Information System must be guided by considerations of technical, financial and institutional feasibility as well as by the specific IS application.

7.1 Project Plan

The Project Plan represents the first operational step of the strategic plan. It defines the fundamentals for the design of the Information System in the context of its environment. Based on the situational analysis, data requirements, needs analysis and user specifications have to be analysed to design the database.

Since the cost of the direct acquisition of digital data and the conversion of existing data to digital form by far exceeds the cost of any other component of the system, it is important to verify that each data item is in fact essential. Thus, the determination of the data items needed in an IS must be more than a 'wish list', it must involve a systematic study of the relevance of each data item for the potential user. This process must contain the rating of data within the overall functionality of the IS to ensure an efficient, dynamic and optimised system. The accumulation of vast amounts of data, simply because they are available, must be avoided.

Every computer based Information System uses digital data. These data have to be collected and, if necessary, converted into digital form, in order to organise the data in the database of the IS.
Organising data in a structure is one of the crucial tasks in the development of an IS.
A record of all the data included in the system has to be kept. Therefore it is helpful to develop a Data Input Sheet reflecting the important details of the input data. In general, a data input sheet must contain information about the data format, where the data can be found or who is holding the data, the date of acquisition, and an indication if the data is to be included in the database.
To ensure that the acquired data is compatible with the database and to establish a system of standardisation for the data being used in the database, the development of a Data Standardisation Catalogue_is essential. It should include standards, definitions and references, spatial data transfer specification, digital data quality and cartographic features.

7.2 Design Specifications

The design requirements determined through the situational analysis, data requirements, needs analysis and user specification must be translated into technical specifications to be used to structure the database, select software, write custom programs and select and configure hardware.

Definition of a data base:
A database is an organised collection of information. Each record in a database is composed of the important elements of information related to a particular item. Each record is represented by a set of fields, which contain the individual elements of information. The data model of an IS describes entities and attributes, their relationship to one another, how they are used, and the processes used to manage them. Once defined, the logical data model is translated into a structure that can be implemented on a computer.

A database defined by data describing the real world has to be as dynamic as the real world. Therefore these dynamics should be reflected in the database for it to remain useful in the decision making process.

7.3 Feasibility of the Information System

The feasibility study investigates the practical aspects of the Information System. This part of the Strategic Plan aims to avoid the development of an Information System, which is impractical with respect to financial resources, technical compatibility and institutional ethos.

- Financial Feasibility
  Financial aspects of the IS should be re-adjusted throughout the planning and implementation stages of the IS, to

accommodate dynamics of the situation and financial resources throughout the project.

- Technical Feasibility
  Of greatest significance for the planning stage is the definition of criteria by which to select the most appropriate technology.
  The technical feasibility study should therefore investigate:
- Balancing complexity with capability and need
- Providing different levels of technology to different users depending on need
- Ensuring ongoing technical support

Computing resources should consist of distributed, interconnected platforms ranging from high-performance parallel processors at the central processing facility to PCs at user sites. While most users will employ desktop PCs, the master system is likely to employ broad range of platforms ranging from the desktops to UNIX workstations, mainframes, and high-performance graphics processors. The most flexible design would incorporate laptop PCs and palm readers for data capturing in the field.

8. Implementation of Information System

Information system projects have failed for many reasons. Some examples of the more common causes for failures experienced by organisations are:

- resources are diverted from an IS system development project, making it impossible to complete the IS;
- development costs and time greatly exceed original estimates;
- the intended users ignore the operational system;
- the system produces disappointing results;
- a system falls into disuse as soon as its original users are transferred elsewhere;

To avoid such failures great emphasis must be placed on factors, such as implementation planning, the enactment of organisational processes, and obtaining of informed commitment of all system's participants.

9. Visualisation of Data

The value of visualisation and multi-media technology in presenting complex issues allowing the user to interact with the system and to explore the connections between data is widely accepted (Allen, 1990).

IS software in general, does not support multi-media data types. Most developers only offer a 2.5D visualisation and the current software tools lack power for the integration of a multi-media Information System.
Therefore an "IS in Multimedia" (Moreno-Sanchez, 1997) approach was chosen for this particular project. Instead of using the inherent visualisation and multimedia tools of existing IS software packages, independent high-level visualisation tools are combined with IS software for the Laetoli project.

The design of the visualisation tools was based on four aspects:

1. Purpose – It is important to establish the usefulness of available tools before implementing them simply because they are available. While the idea of walking or flying through a simulated landscape is clearly attractive, it is less clear if it is of any real advantage to take a virtual stroll through an abstract 3D graphic.
2. Degree of Interactivity – The scientist interested in posing 'what if?' scenarios will typically demand an interactive capability. Interactivity depends, however, on hard- and software developments in the IS environment. Data models and display forms have to be able to explore interactively the IS data set, which has, therefore, to be designed with a highly efficient data storage and data extraction system.
3. Degree of Abstraction – Abstract representation may be largely unfamiliar to an individual not trained in visualisation tool use. For the non-scientific audience abstraction should be minimised, and the information content maximised. The whole visualisation tool must be user-friendly and non-threatening. This suggests the use of a visual realism approach, which shows the user what will or might happen under a variety of conditions. Those not trained in interpretation of abstract information should be able to work with the tool on an intuitive level.

Aspect of phenomena – 'The aspect of phenomena concept' requires the data representation visible to the user to match the phenomena for which it provides a model. The displays have to meaningfully represent the project. Therefore symbols and classification have to be chosen in a way, that the display becomes self-explanatory in the context of the project.

The dynamic models of the visualisation are being programmed in Inventor C++ and Cosmo World by SILICON GRAPHICS and will linked to the Spatial Information System.

Figure 2: Visualisation tool

Concluding Remarks

The advance and combination of digital photogrammetry and Information System technology has expanded the traditional role of surveying and photogrammetry in the archaeological and conservation domain significantly. From providing a valuable but limited recording capability Photogrammetry/ Geomatics has grown into a general documentation /management/analysis technology for archaeological and conservation sites. The Laetoli project has shown that it is important for the photogrammetrist to be integrated into the overall project as supposed to forming an isolated service provider.

The use of new techniques and an interdisciplinary approach offer a wide range of possibilities to analyse and interpret archaeological finds. The integration of photogrammetric and archaeological analyses through the employment of spatial information systems permits precise documentation and rapid access to data.

The project lands itself to design a generic recording/information management system for archaeological and conservation sites.

Acknowledgement

The photogrammetric survey of the Laetoli site and the subsequent establishment of the SIS are funded by the Getty Conservation Institute. The authors specifically wish to express their gratitude for the support and advice received both in Laetoli and at the GCI in Los Angeles from Neville Agnew, Martha Demas and Gaetano Palumbo. All in-house software used for the project was generated during research projects supported by the South African Foundation for Research Development (FRD), the University of Cape Town and the Deutscher Akademischer Aussendienst (DAAD). The software used was produced by Graeme van der Vlugt, Julian Smit and Henty Waker. A special thank you must go to Manos Baltsavias who assisted with the ortho-image generation during a visit to the University of Cape Town. The commercial software HiFi was made available by the Photrogrammetrie GmbH, München.

Bibliography

Johnson, D., Shreeve, J.: 1989, The Primitive Wonder. In: Lucy's Child: The discovery of Human Ancestors. New York. pg.184-209

Grün, A.W., Baltsavias, E.P: 1989, Geometrically constrained multiphoto matching. Photogrammetrie Engineering and Remote Sensing, , Vol. 54, No.5, pp 633-641

Wong, K.M., Ho, W.:. 1986, Close Range Mapping with a Solid State Camera. Photogrammetrie Engineering and Remote Sensing, Vol.52, No.1, pp. 67-74

Moreno-Sanchez, R., Malczewski, J.: 1997, Design and development strategy for multi-media GIS. Transaction in GIS

Allen, K., Green, S., Zubrow, E.: 1990, Interpreting Space: GIS and archaeology, London