A computerized solution for epigraphic surveys of Egyptian temples

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Abstract

Defined as “an auxiliary science to History that studies the inscriptions on enduring substances”, epigraphy calls for very varied methods and disciplines. These all imply a preliminary operation: the survey and copying of the decoration engraved or painted on walls, columns, etc. This stage is essential in understanding and reconstituting ancient monuments, because cartouche friezes and ritual scenes give information on the date of a given temple or on the nature of the activities that took place in it. Nowadays, epigraphic surveys are still for the most part done in a traditional handmade fashion, while computer-aided epigraphic surveying is only used for simple tasks, such as drawing the contour of hieroglyphic signs on scanned photographs. The epigraphy of monuments includes scenes and texts. In both cases, the hieroglyphic signs engraved are made up of complex segments and curves, which must be accurately surveyed and recorded. Each hieroglyphic sign has not only a unique geometrical shape, but also a morphology proper to a given alphabet and a precise sense. What has been mostly done up to now deals essentially with the graphic form of signs and relegates their interpretation to an ulterior analysis. On the contrary, the method proposed here gathers data on the meaning and the geometrical shape of each sign. This will finally lead to statistical studies on the hieroglyphs’ form, to automatic translations of the texts, and to the search for missing elements, based on geometrical as well as textual criteria. Our approach is not only adapted to the treatment of plane surfaces, but for the development of conical surfaces as well, so as to be able to survey the inscriptions of columns. The purpose of this paper is to present the computer tools that we have developed to draw and to record the shape and the meaning of the hieroglyphic inscriptions of walls and columns of temples, using the Egyptian temple of Amun-Ra in Karnak as our case study.

Keywords: Photogrammetry; Archaeology; Cultural heritage; Surveying; Acquisition; Modelling

1. Introduction

Carrying out epigraphic surveys is a very important task in archaeology, particularly in Egyptology because all the monuments contain numerous texts and scenes engraved on their architectural elements. It is a matter of urgency to do such surveys, because the inscriptions are deteriorating at great speed and there is a real risk of losing some important scenes completely.

The main problem at the present time is that the traditional methods carried out to survey the inscriptions are very time-consuming. For example the most common of these methods consists in making facsimiles of the wall to be surveyed, with photographs as background or simply with transparent sheets placed against the surface of the wall (Fig. 1). This method involves numerous checks during the drawing process and is therefore rather tedious, because it requires the collaboration between different drawers.

An other inconvenience of the methods currently used is the fact that the produced results are only visual representations, and not exploitable models. The description is also in the
form of lines and curves: it is not an object that could be used later for various studies.

Unfortunately the computerized methods proposed to archaeologists for surveying epigraphy have rarely been adapted to their needs, at least up to now: they don’t reproduce the relief of the signs accurately, they often don’t take into account the poor state of conservation of the inscriptions. Thus, most archaeologists and epigraphists rely on the traditional methods of surveying, because they think that the complicated interpreting process required for an accurate epigraphic survey of a monument can’t be made by means of a computer.

1.1. Proposition

Our idea is then to propose an original computerized method, which tries to get rid of the problems inherent to traditional epigraphic survey approaches, while considering the needs of the epigraphists and offering them the possibility of controlling various operations during the computerized survey process. Particular emphasis has been put on the fact that the decoration of a monument is indissociable from its architectural support. The drawings must be recorded with all the information necessary to understand their real meaning (i.e. the architectural and archaeological context). The recording format has been normalized so as to be exploitable for research purposes (statistics, restoration of structures, etc.).

Our method is based on photogrammetric procedures, because of their numerous advantages for archaeological tasks:

- Photogrammetry is by definition a non-destructive process (there is no contact with the object to survey) that will not generate further damage on the architectural features to be surveyed.
- Fieldwork becomes easier and faster, since photographic campaigns and surveys are kept to a minimum, generally only to check a few control points.
- The exploitation of data is made entirely with computer tools in the office, and not on site: one can therefore do away with the drawbacks of working in the field (heat, tourism,...) and obtain more durable and exploitable numerical files of the surveyed objects, iconography, epigraphy....
- An analysis can be done at any time later on (for example, if the object is destroyed and should be rebuilt).
- The survey of inscriptions engraved on curved (columns) and not accessible (ceiling) surfaces is made possible.
- Experience has shown that for features to be recorded conventionally during an excavation, several people will intervene. This will result in heterogeneous drawings. If, however, photogrammetry is applied during the whole excavation, the documentation will be standardized.

As proof of this, one only has to look at some application fields of photogrammetry in archaeology: prospecting and landscape archaeology, excavation (examples given by Platzer and Waldhäusl [7,11]), recording of standing remains, caves, mining and cave paintings and recording of finds (examples in Ref. [1]).

Our goal is to take advantage of the various possibilities given by the use of photogrammetry while making the program as user-friendly as possible, since it is intended for archaeologists who are not necessarily well-acquainted with computers. Our epigraphic survey method is exploitable in a graphical software, in this case AutoCAD®, because it is widespread in archaeology. We have up to now aimed at developing two main types of tools (written in the programming language AutoLISP): one for drawing and recording the engravings on a wall, and the other for the treatment of conical surfaces in order to copy inscriptions on columns as well, using the same tools as those developed for the survey of plane surfaces.

This project has been initiated by the Computer Aided Design Research Group GRCAO, University of Montreal, in collaboration with the Photogrammetry and Geomatics Group MAP-PAGE, INSA Strasbourg, at least for the photogrammetric part. It has been carried out within a larger project called “Computer modelling as a means of reflection in archaeology: a new approach to epigraphic and architectural survey applied to the Karnak Temple”. The GRCAO has been able to rely on the technical support of both the French CNRS permanent mission in Karnak and the Karnak Hypostyle Hall Project (KHHP) of the University of Memphis.

1.2. Structuring

The first part of this paper deals with the approach chosen for drawing and recording of hieroglyphic signs on plane surfaces. Three aspects have to be considered: the Bezier curves
and their drawbacks, the strategy used to draw the engravings and the bonding of stones, and the recording and insertion mode of the signs after a first layout.

The second part concerns the adaptation of the method carried out for the epigraphic survey of plane surfaces to conical and cylindrical elements. This requires two steps: the three-dimensional reconstitution of a column and the development of its surface for the two-dimensional surveying of the epigraphy.

2. Drawing and recording of the inscriptions on plane surfaces

The hieroglyphic signs are drawn by means of Bezier curves. Control polygons are grouped and recorded, so as to be able to draw the signs automatically several times over, at different places and scales, and for other exploitations.

2.1. Bezier curves and drawbacks

We have tested several types of bi-dimensional curves to represent the epigraphy of a plane element in a way that stays as faithful as possible to the original drawing. One of the most important criteria has been the simplicity of construction and of modification of the curves by the user:

- real-time display of the curves’ movements with the cursor;
- possibility of inserting at will an inflexion point between two summits;
- possibility of providing a tangency or a dependency between two consecutive summits;
- possibility of inserting new curves and segments if necessary;
- possibility of changing a segment into a curve or inversely;
- possibility of introducing a constraint between two curves or of relaxing it;
- possibility of recording results in the most compact way as possible.

Considering these requirements, we have chosen the Bezier curves because they fulfilled most of these objectives.

The procedure is as follows: a Bezier curve is constructed on the basis of two points (A and B) and of an additional point (C) that allows to trace the tangent to the curve going through the points (A) and (B). The construction method is based on a recurrence principle: from the segments binding the points (A, C, B)—called control polygon of the curve—we choose any ratio between 0 and 1, which is applied on the length of [AC] to obtain the point (X1). The same ratio is applied on [CB] to obtain the point (X2). Next, we repeat the same operation on [X1X2] to obtain the first point of the curve (pm1), and so on to obtain all the points of the curve (Fig. 2).

Then it is enough to change the ratio \( n/nb \), for \( n \) varying from 1 to nb (where nb is the number of iterations chosen), to obtain a curve of nb + 1 points.

This type of curve suits our needs well (as we will see in the next section), but it has an important disadvantage if we wish to draw it in perspective and to visualize it in front view (for the publication of the drawings, for instance).

In fact, the curve obtained by the straightening of a sign drawn from a shot taken sideways differs from a curve of the same sign drawn with the support of a picture taken perpendicularly to a wall [8]. This is illustrated in Fig. 3.

Thus, to do a rigorous survey of hieroglyphic signs, we have had to develop procedures for the orthorectification of the original photographs. That is to say that we create new pictures from the initial shots, as if they were all taken perpendicularly to the architectural elements to be surveyed (Fig. 4).

Therefore we can draw the hieroglyphic inscriptions by means of Bezier curves on the orthorectified photographs, so as to obtain an accurate drawing “in front view” of the signs (whereas it would have been wrong if we had traced the signs on the original photographs and if we had put them back in a front view afterwards).

2.2. Drawing of the inscriptions and of the bonding of stones

The hieroglyphic signs are then drawn as groups of curves. The construction of a curve is interactive:

- first we click on the two extreme points (A and B) of the control polygon,
- then the third point (C) is inserted with the cursor’s shifting (real-time control of the curve’s movements), in order for the curve to match the sign on the photo as closely as possible.

Two options for the drawing of the next curve are possible:

- to create a curve or a segment (i.e. the points A, B and C are aligned),
Fig. 3. Illustration of a problem of the Bezier curves.

Fig. 4. Orthorectification of a photograph of the pyramidion of an obelisk (from [Parisel C., Rapport de travail sur la construction des orthophotos de surface à partir de photos en format BMP, GRCAO’s internal research paper 17 p (2004)]).
- to create it tangentially to the first curve or to the next that
will be drawn.

When the drawing of a sign is completed, the different
curves are automatically joined so as to make a single curve,
and the same is made with the control polygons. The global
curve can still be modified: the cursor is moved from point
to point on the global control polygon, and the joints are bro-
ken when a curve to adjust is chosen.

Then more choices are available once again:

- to create a tangency or to relax it (with the previous or the
next curve),
- to transform the curve into a segment or inversely,
- to divide the curve into two curves individually modifiable
(for a more accurate drawing of the part of the sign).

This process ends with the re-joining of the curves and of
the control polygons, so as to obtain two individual entities
necessary for the future recording of the drawing.

The survey of the bonding of stones consists simply in the
drawing of several segments, to represent the stones and the
state of conservation of the wall. The segments of each stone
are then joined for the recording too.

This is illustrated in Fig. 5 and [9].

2.3. Recording and insertion mode of the signs
after a first layout

When a complete hieroglyphic sign has been drawn, it is
recorded for future exploitations in a database of the signs sur-
veyed on the wall (at the end, everything must have been re-
corded). This recording process comprises several phases.

Noteworthy is the fact that only the control polygon of the
curve will be recorded. This is particularly handy since it does
not take much computer memory (few points are to be re-
corded), and because the curve can easily be redrawn from
its control polygon (then it is not necessary to record the curve
itself with its numerous points).

Consequently, the first step is the identification of the con-
trol polygons of a sign (the same sign can be made up of sev-
eral curves with their control polygons, as the bird in Fig. 5).
We distinguish between the control polygons that determine
a group of Bezier curves—we call them CTL—from the sim-
ple polygons—we call them POL—that consist of a set of seg-
ments (these are very seldom). The control polygons can be
closed and fit into each other. The biggest that form the exte-
rior contour is numbered 1, and in order of successive inclu-
sion, the numbers 2, 3 and so on.

Finally, we specify if the considered part of the sign is
in sunken relief (indicated by −), in raised relief (indicated
by +), or at the same level (indicated by 0) (Fig. 6).

These characteristics will be later used for a symbolic
“pseudo-3D” representation of the hieroglyphic sign, which
consists in the layout of “shadow lines” to simulate the sun-
shade on an engraving (the direction of the sun can be chosen
by the user). This function makes it possible to visualize in-
stantly whether a relief is sunken or raised (Fig. 7).

The second step of the recording process is the grouping of
the control polygons that make up the sign. We make a single
geometrical entity with the different parts of the sign and then
give some information about the meaning of the hieroglyph:
name of the phonogram or of the ideogram, grammatical
meaning, phonetic value, etc. The group has then a proper
identity with a designation, a meaning, a geometrical descrip-
tion and all the characteristics that the user think can be useful
to add.

Two choices are given to the user afterwards: he/she can re-
cord the hieroglyphic sign as a “standard sign” or record it
simply with its original position on the picture (to implement

Fig. 5. Global view of a partial epigraphic survey of the 7th Pylon of the Karnak Temple (on the left). Detail of the drawing of hieroglyphic signs and of stone deterioration (on the right).
The database of the signs surveyed on the wall). In both cases, the information about the group representing the sign is recorded in a text file. We have chosen this type of recording so as to be able to transfer it later on various software (transportable format).

The “standard signs” are intended to save time during the epigraphic survey process. In fact, a hieroglyph can be found several times on the same wall, with just a few morphological differences (Fig. 8). So the insertion of modifiable “standard signs” will make it redundant to draw the same sign several times over: when a hieroglyph comes up that has already been recorded as a “standard sign”, the user only needs to insert the corresponding “standard sign” at the right place and make the necessary adjustments.

The insertion is done through the creation of a rectangle that frames the sign (by identifying the extreme points—top, bottom, left, right—of the biggest control polygon). This rectangle is recorded in the text file at the same time than the other characteristics of the sign. In general, the “standard sign” is recorded for a reading from left to right, but the hieroglyphic texts can be written in several directions. So, at the moment of the insertion, the user can choose the direction (left to right or right to left) in which he wants to insert the sign. The result of the recording process is then a text file that can be of two types depending on whether the drawing is recorded as a “standard sign” or as a simple occurrence with its position on the photograph (Figs. 9 and 10).

Afterwards, the appropriate “standard sign” is searched in the “standard signs” database, in order to insert the sign at a particular place and at a desired scale on the photograph. By simply clicking on the extreme points of the sign to draw to define the edges of the insertion rectangle, it appears along with the “standard sign” at its appropriate spot inside this rectangle. Small modifications can then be added. The insertion of a “standard sign” is illustrated in Fig. 11.

Since the face of a wall can be badly ruined, the damaged parts of a sign can also be recorded. This in turn can be useful for the search of missing elements (blocks) of a wall for example (or for its reconstruction). The process is explained in Fig. 12.

So the missing block will be sought after, through architectural (type of stone), geometrical (shape of block) and textual criteria. If parts of a hieroglyph are still visible on the edge of a stone, we can compare them with the different records that we have at our disposal, and this can eventually lead us to matching several fragments belonging to a same block (Fig. 13).

In conclusion, this part of the paper has presented our method of computerized epigraphic survey used for drawing and recording the hieroglyphic signs of planar architectural elements. This method is user-friendly for archaeologists and epigraphists alike, thanks to the very detailed menus created in the AutoCAD® software. Numerous choices are constantly available during the surveying process, and every operation...
can be undone if necessary. Each surveyed sign is recorded in a database, in the form of a text file, which can later be used for other research purposes: studies on the shapes of hieroglyphs, automatic translation of the texts, search for missing elements, etc.

This method has been carried out for the survey of plane surfaces. We will now turn to a process for the development of conical surfaces, in order to survey the inscriptions of columns as well.

3. Epigraphic survey of conical surfaces

The epigraphic survey of temple columns is essential too, because columns often bear cartouche friezes and ritual
episodes that give information on the date of the temple or on
the nature of the activities that took place in its hypostyle
hall. This part of the article will set out our method carried
out to survey a scene engraved on non-plane surfaces. The
approach is once again based on photogrammetric techniques
and with the ultimate goal of using the tools presented
above for the drawing and the recording of inscriptions on
plane surfaces. To begin with, the column must be modelled
from its photographs (the shots are the only initial data needed,
as was the case with plain walls). After that, the obtained
“virtual cone” must be developed in the form of a plane sur-
face so as to be able to survey it with the same tools as before.

3.1. Three-dimensional reconstitution of a column

The only data required to create a 3D model of a column’s
part are eight photographs covering its entire surface and
some control information (i.e. points) to be located on these
photographs. The photos must have a relatively high overlap
between themselves. A minimum of six homologous points
between two consecutive overlapping photographs is required,
and three more common points between three overlapping pho-
tographs. This task has likewise been done in the graphical soft-
ware AutoCAD®. The photographs with the points can be seen
in Fig. 14. For a better visualization, we have drawn polylines
that connect the different homologous points between the shots.

From these initial data, the planar coordinates of the points
on the photographs are integrated into photogrammetric for-
mulae to obtain their 3D coordinates [3,4]. We have also de-
veloped computer tools for an automatic computing of the
3D coordinates of the column’s points.

Thanks to these 3D points, we are able to draw a vectorial
model of the column, which will represent the theoretical col-
umn’s surface.

Since the theoretical surface of Egyptian columns is a cone
(with a very acute angle at the summit), we have drawn a 3D
polyline to obtain the vectorial view of the column, based on
the points describing the cone geometrically. The parameters
of the cone have been calculated by a mathematical algorithm,
which carries out the surface matching of a cone [10].

These parameters are:

- the director vector of the cone’s axis,
- one axis point,
- the summit angle,
- the distance between the axis point chosen and a generatrix
  of the cone.
A solution is found through an iterative modification of the cone’s parameters. The calculation ends when the average distance between the cone’s points and the calculated surface stops decreasing.

It is then worth determining the cone that fits the column best, indeed the column might have suffered a slight subsidence or inclination in time and its axis may not be necessarily vertical.

The drawing in Fig. 15 represents the calculated 3D points and the 3D polyline describing the best cone based on these points.

For better 3D visualization, we have also drawn on this layout one of the polylines joining the homologous points between two snapshots.

This model of the column is a “virtual model” (independent of any coordinates system), which can be scaled down to proportion by measuring a length on the real column, or replaced in the 3D space while measuring just three points in the field.

Thanks to this vectorial representation of the column, we are now able to develop the obtained 3D polyline on a plane, so as to survey the hieroglyphic signs on a two-dimensional surface.

### 3.2. Development of the column surface for the two-dimensional surveying of the epigraphy

As mentioned above, the cone that best approximates the points, can be at an angle. So, the first step of the development is to make the previously obtained cone vertical, for the simplicity and the accuracy of the development’s calculation.

A change of reference has been carried out so as to move the summit of the original cone to the zero point (of the AutoCAD drawing) and to put the axis in a perfect vertical position.

The transition from one coordinates system to the other is possible through three non-coplanar homologous points in each system. We choose these three points at random among the seven points of the previous 3D polyline.

Knowing that the summit must be translated into the point (0, 0, 0), the coordinates of the two other required points are easy to deduct. Afterwards, all the cone’s points can be transferred from one system to the other and be placed exactly “on” the theoretical surface of the new vertical cone by means of an orthogonal projection.

We have thus been able to develop the vertical cone: the points of the 3D polyline have been put on a same plane. The points of the vertical cone (previously projected on the theoretical surface) have also been located on the development. This is illustrated in Fig. 16.

To be able to draw the hieroglyphic inscriptions, it is now necessary to orthorectify the original photographs of the column and to insert these pictures in the development (the principle and the aim are the same as those carried out to obtain Fig. 4).

For the pictures to be developed, these must be transformed into orthophotographs [2]. The epigraphy will thus be surveyed on this “front view” of the column.

The orthorectification process is divided up into two phases:

- the first consists in drawing, on the original shot, the edges of the column’s shaft (generatrix), and in obtaining their equivalent on the development, so as to obtain the limits of the orthophotograph to be produced,
- the second carries out the transfer of the colour values of the pixels from the original photograph to the development.

We have thus created a new picture by assembling these pixels inside the previously drawn limits.
The result is shown in Fig. 17 for one of the shots. After orthorectifying all the shots, a single photomontage is made, on which the hieroglyphic inscriptions are drawn.

The montage of the orthophotographs is not as easy as it may at first appear, because the exact positions and the scale of the different pictures must be strictly respected. Moreover, there are differences in light exposure from one original shot to the other (see Fig. 14), which requires image processing, in order to obtain a homogeneous picture of the entire surface of the column’s shaft (see below).

With these requirements in mind, once the photomontage is done, we obtain a “photograph” of the developed surface of the column’s shaft. This picture represents a plane surface, on which the hieroglyphs can be drawn (Fig. 18).

We have made the drawings of the hieroglyphic signs on this picture by using the same tools and procedures as those described in Section 1 of this paper: the signs are traced, recorded, inserted, etc. exactly in the same way as the inscriptions of a wall. As the column’s surface is now “planar”, the “standard signs” can be inserted directly on the picture. The adaptation of the pre-recorded signs may require a small rotation to fit them exactly with the inscriptions of the column, but this task is quite simple to do.

In this respect, the quality of light exposure during photographic campaigns determines to a large extent the success of a computerized epigraphic survey. Sunbeams should hit the walls or columns sideways, in order to emphasize shady areas. Ideally, it is best for pictures to be taken in mid-morning and in mid-afternoon, when the sun lights up the wall from two distinct angles. Depending on the hour of the day, either the vertical lines or the horizontal lines of the epigraphic signs stand out. The one and the same inscription can thus be read under different light (see Section 2.3 and Fig. 7), which enables epigraphers to choose from a range of various pictures of a wall in order to obtain what they deem to be the most accurate reading of any given text.

If a segment of a wall were to remain in the shade for a long period of time (say, during wintertime, when the sunrays would not be able to reach some hidden architectural features), it would be of course necessary to go on the field during the season when the above-mentioned segment is eventually lit. One can overcome such nuisance by using at all times a set
of mirrors, and placing them in strategic places, in such a way that they would reflect the light on the wall from different angles. Taking shots at night, with the help of strong projectors, or obviously to take them with a good flash, are other possible solutions.

However, if choosing the right time or season to take pictures is a key ingredient for a reliable survey, using these photographs as the basis for the creation of a digital 3D model can be done at any time, which leaves the user free from the temporal constraints mentioned above. Moreover, the technology of image processing software is advancing at a very fast pace, a fact that makes it increasingly easier with time to improve the quality of digital shots. Nothing is really definitive at the moment of the photographic campaign (at a lighting level) and image enhancements are always possible, what adds to the simplicity of use of our method. On the other hand, the geometric arrangement of the shots has a great importance on the field and cannot be changed later. It is then significant to watch over to take a minimum of three photographs of each plane archaeological element (for the conical elements, the procedure is explained in Section 3.1): one shot taken from the left, one in front of the wall and one from the right, with a relatively high overlap between themselves.
4. Conclusions and extensions

This paper has dealt with a computerized epigraphic survey solution for all planar, but also conical and cylindrical architectural elements of Egyptian temples. This approach is of course adaptable to the survey of other types of temples (Greek for example). The simplicity and flexibility of its use makes it accessible for epigraphists, and more widely for archaeologists. One of its advantages is to save time for tasks other than the survey per say. Moreover, various exploitations (reconstitution, palaeography, ...) are possible, thanks to the fact that all the signs drawn are recorded in a universal format. The publication of the texts can still be made in paper form, but can now be in numerical form too, which in turn leads to other possibilities such as data exchange.

The different types of exploitation have not really been fully tested yet, but this is our next goal.

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Fig. 18. Montage of the orthorectified photographs with the layout of some hieroglyphic signs.