

CYLINDRICAL ORTHOPHOTOGRAPHY COMPLETE COVERAGE OF INSIDE/OUTSIDE CYLINDRICAL SURFACES SUCH AS CASTLE TOWERS

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ABSTRACT

Because we, surveyors, architects and archaeologists, are used to describing objects in planar projections (planimetry, elevation), most orthophoto software have been designed to change a quasi-central projection into a true orthographic projection. This kind of projection is not really suitable for cylindrical surfaces.

To enable the complete study of rotund tower surfaces, a specific process has been designed. The idea is to use the nearest cylinder as the surface of projection. Thanks to a motorised reflectorless total station, an accurate 3D point cloud is scanned. These points are used to calculate the best cylinder of projection (vertical axis co-ordinates, radius) and interpolated to produce a digital model of the real surface. For each digital image, the photogrammetric equations are calculated, derived from control points identified on the photo. It's then easy to link the orthophoto cylindrical co-ordinates to the pixel co-ordinates of the image to rectify it. The rectified images are gathered to produce a general view of the surface, as if the tower were unwrapped on the sheet.

It's now possible to undertake an accurate analysis of cylindrical monuments: stone arrangements, distribution of windows, doors or chimneys. Any orthographic view can be produced automatically by choosing a direction of projection. The digital model can be used to get geometrical data: accuracy of the tower building, shifting of the centre between different floors. This method has already been used for several surveys: the antique tower in the Laudun oppidum, in the south of France, and the towers of the Blandy-les-Tours castle, near Paris.

1. A CYLINDRICAL SURFACE OF PROJECTION

The production of a single orthophoto that allows complete coverage of a cylindrical tower requires the use of a specific surface of projection. This surface must be the nearest cylinder, which means that the distance between the real surface and the mathematical cylinder must be as small as possible. It defines a new cylindrical co-ordinate system for the cartographic representation. By assigning the angular distance along the cylinder perimeter to the horizontal axis, and the elevation height to the vertical axis, the surface is mathematically unwrapped to produce a complete orthographic view.

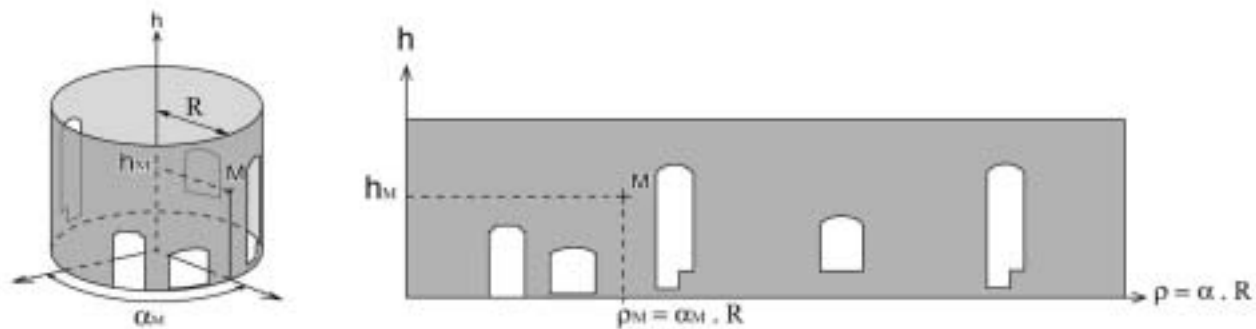


Fig. 1: geometrical unwrapping of a cylindrical surface

In order to obtain geometrical specification about the real surface, to know if a cylindrical projection can actually be used, and to acquire enough data to determine the best cylinder, a 3D point cloud is measured with a motorised reflectorless total station (Leica TCRM or Trimble stations).

Measurement and processing

The determination of a digital model can provide an accurate description of the real surface. First, an irregular 3D point cloud is measured, dense enough to give back information about the tower geometry and its local deformation. The cloud density varies with the surface state: around embossments, fissures and architectural elements, 3d points are closer than in more regular areas.

The cylinder of projection directly derives from the cloud. From the n measured points $(M_i)_{i=1 \text{ to } n}$, its radius R and its centre C (X_c , Y_c) are calculated in such a way that the difference between horizontal distances CM_i and R is as small as possible. The $(X_c$, Y_c , R) parameters are calculated with successive approximation, using the least-square method.

It is now possible to estimate the horizontal distance between the cylinder and the real surface (each measured point). This first diagnostic is imperative to eliminate errors and to refine the determination of the surface of projection.

Exploitation and cartographic complication

To show the deformation of the tower, an interpolation of the digital model can be undertaken. In the cylindrical system, the contour lines show the radial difference between the cylinder of projection and the real surface.

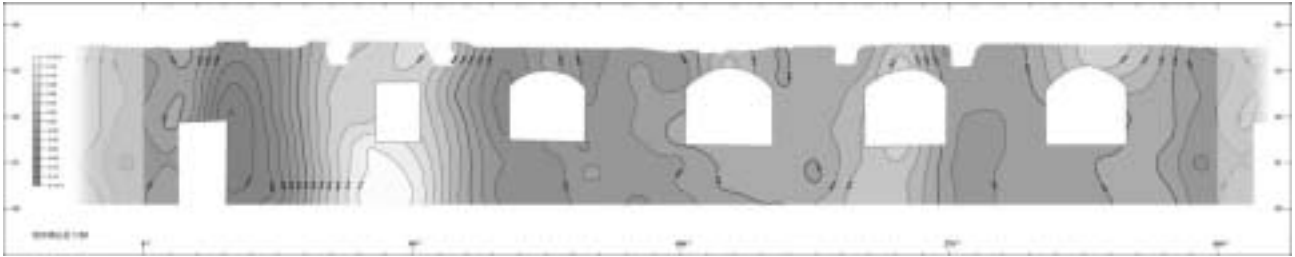


Fig. 2: an unwrapped representation of a digital elevation model (contour interval: 2 cm)

The peculiarity of the reference surface (a cylinder) must be considered for the contour line interpretation. This peculiarity also complicates the cartographic relation between several cylinders. In the case of different cylindrical levels, the radius and the centre of each cylinder can be different: for a radius of 3.1m, the perimeter of a cylinder is 0.63 m longer than for a radius of 3.0m. In the case of a constant angular distance scale, special graduation must be set in order to enable the cartographic correspondence between each level.

2. CYLINDRICAL ORTHORECTIFICATION

The basis of the rectification is the same as for usual orthophoto. It uses the photogrammetric equations to make the relation between field and raw photo co-ordinates. An intermediary function is joined to convert cylindrical co-ordinates into rectangular ones.

Determination of the mathematical model

For each scanned photograph, the unknown parameters (principal distance, principal point co-ordinates, field position and orientation of the camera) of the photogrammetric equations are determined from known control points, whose co-ordinates are obtained from surveying. This simultaneous orientation is achieved using the bundle method. The calculation uses matrix procedures designed with Starcalc, the Sun StarOffice spreadsheet software.

Rectification

It's now possible to calculate the photo co-ordinates of any field point. The real surface of the tower is assimilated to the cylindrical DEM. For each pixel of the cylindrical orthophoto (P_i), the rectification consists in :

- Translating the cylindrical co-ordinates of P_i into its rectangular field co-ordinates, using the mathematical definition of the cylinder of projection and the DEM (radial difference),
- Calculating the photo co-ordinates of the corresponding point in the raw photo, using the photogrammetric equations,
- Getting the RGB values of the corresponding pixel colour,
- Assigning these values to P_i .

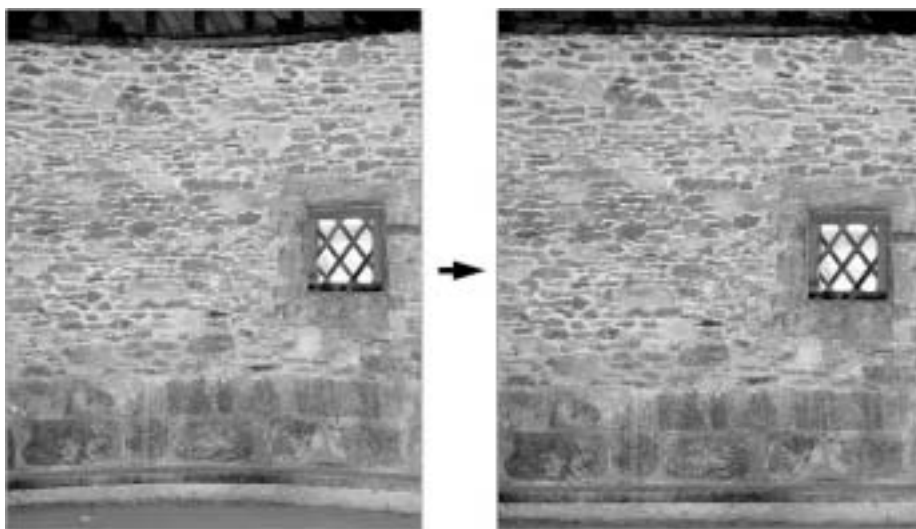


Fig. 3: the raw photo of a cylindrical surface and the result of its rectification

Pixel by pixel, the portion of the cylindrical orthophoto corresponding to the raw photo is built. The gathering of all the rectified images results in the full coverage of the cylindrical surface. To provide a real cartographic document, the orthophoto is completed with a grid which sets its geometrical boundary.

Application

Cylindrical orthophotos provide the same advantages as classical ones: they allow the study of a monument along its whole surface, offering the detail copiousness of a photograph. Indeed they enable the archaeologist and the architect to face details that can be 20m overhead. They produce a stone to stone cartography and provide the means to measure accurate geometrical characteristics of cylindrical monuments. They are the appropriate technical documents.

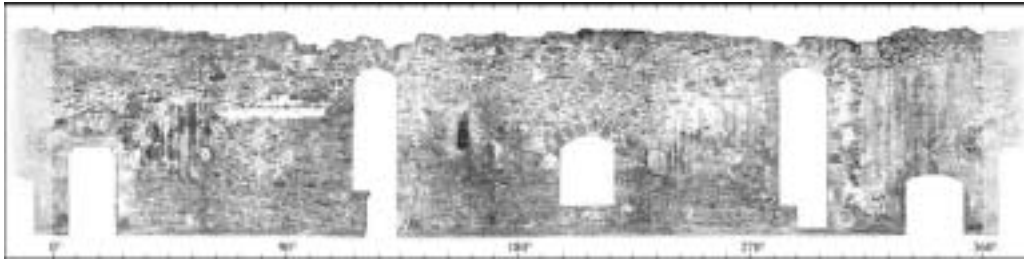


Fig. 4: cylindrical orthophoto of the inside surface of a tower level

The transition from cylindrical to rectangular co-ordinates is a simple mathematical transformation. From the cylindrical orthophoto, it's possible to choose any direction of projection, to automatically produce a side view that can be associated to orthophotos of bordering plane elements (such as a rampart).

The orthophoto can be used as texture to produce truthful 3D models of cylindrical objects.



Fig. 5: a side view automatically derived from a cylindrical orthophoto.



Fig. 6: a simple 3D model using a cylindrical orthophoto as texture.

3. EXAMPLES

The antique tower of Laudun: outside surface

The pre-roman and roman site of the "Camp de Cesar", covering a surface of 18 ha, dominates the French Rhone valley, an important transit way for the ancient civilizations in the South of Gaul. This oppidum maintained strong ties with the Mediterranean people, especially with Marseille. Just before the Christian era, the final romanisation brought deep modifications to the urban plan. A new rampart, of little defensive value, was built directly on the limestone hill-rock, to define the high quarters of the roman inhabitation. It is enhanced by a prestigious tower of exceptional dimension : 8m high and 9m in diameter.

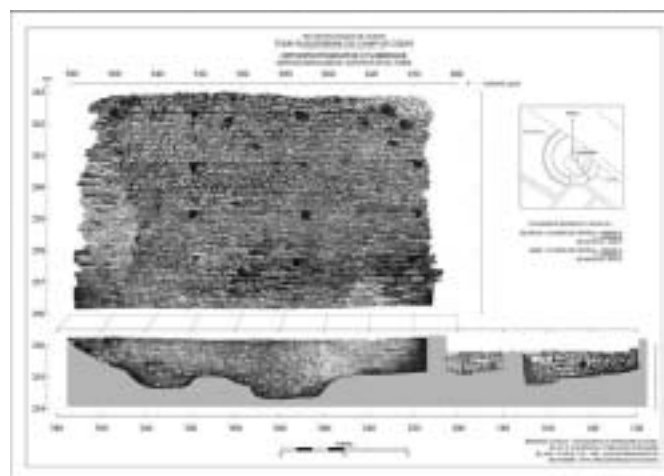


Fig. 7: Laudun - cylindrical orthophoto of the tower extrados.

Built in a dominating position above the oppidum, this tower was probably more a monument of prestige than of military use. It is composed with a big round foundation on which the elevation has been raised. This elevation has been partly destroyed, probably to

enable the building of a roman theatre below the rampart. The D.E.M, interpolated from 3D points measured on the extrados of the stones, has revealed the accuracy of the tower cylindricity, 2000 years after it was built.

The cylindrical orthophoto has developed the outside surface of the foundation and the elevation. Thanks to the image registration, it is possible to measure the stone and putlog hole distribution, to compare it to the rampant or to obtain geometrical data to try to understand building techniques. A projection of the cylindrical orthophoto was produced in the projection plan of the rampart orthophoto, to provide a full elevation view of the two monuments.

The mediaeval castle of Blandy-les-Tours: inside surfaces



Owned by the French department of Seine-et-Marne, this castle lies 45 km south east of Paris. It's one of the best preserved seigneurial monuments in the Ile-de-France area. Its restoration was undertaken in 1989. I've been asked to provide the complete coverage of the monument with orthophoto methods, including the cylindrical surfaces of five towers. The inside surfaces of the three biggest towers were surveyed in the year 2000. Each tower has several floors and the determination of the cylinders of projection has shown that the radius of each level increases with the height.

The towers' differing uses and their relative degree of preservation have particularly complicated their survey. The "Tour des Gardes" (guardians tower) is a five floor round tower, but the wooden floorboards of the first three floors have fallen through. With the aim of minimising perspective deformation, climbing equipment was used to reach the inside 22m elevation in order to be able to put in the control point targets, and to photograph the inside surface from directly opposite it. The Dungeon is a six-floor, 30 m high round tower which has been restored in part. Contiguous stairs allow access to almost every level. The whole inside surface has been photographed, using a home made pole to lift the camera when the elevation was too high. Control points have been measured inside and outside the tower, in order to register each level in the same Cartesian co-ordinate system. The calculation of the six cylinders of projection in this system has revealed the systematic

shifting of the centres. The inside cylinders are tangent to the inside of the castle, whereas the whole outside surface seems to be a single vertical cylinder. This geometrical configuration results in the walls of the tower being thicker the lower down they are, which is probably an indication of a military use.

Two series of documents have been produced. First, for each level, a cartographic document has been produced to scale 1:50, gathering the unwrapped orthophoto (300 dpi), the contour lines of the corresponding unwrapped DEM, geometrical information about the cylindrical surface of projection and statistics about the 3D point cloud. All these data have been set in different layers that can be overlaid. They make possible the reconstitution of the real surface.

Then, for each tower, all the cylindrical orthophotos have been gathered in a new document, to provide a full coverage of the whole unwrapped elevation. Cartographic correspondence between each level has been set. It's then possible to analyse the distribution of architectural elements, the variation of stone size, the appearance of fissures.

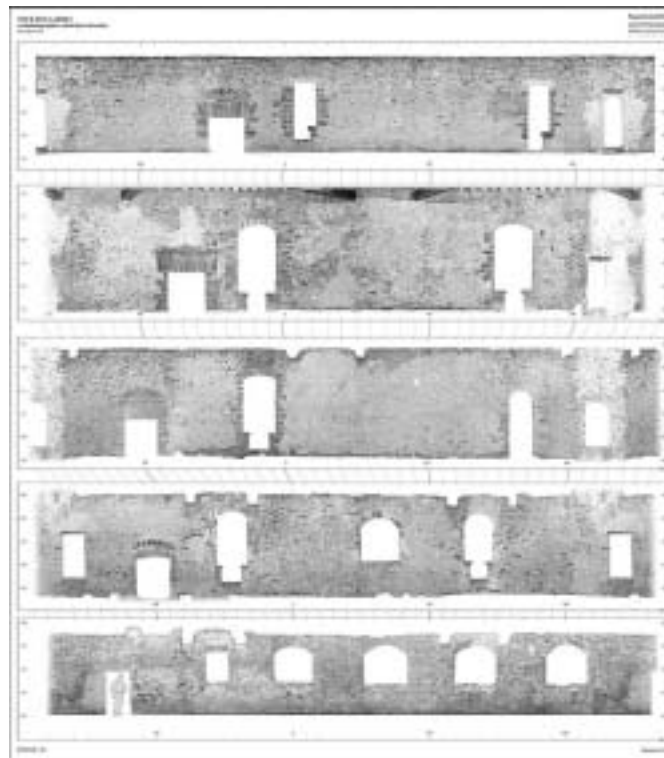


Fig. 8: The "Tour des Gardes" final document with the 5 cylindrical orthophotos.

4. CONCLUSIONS

Because of their strategic use or their architectural gracefulness, cylindrical elements of monuments are quite frequent. In France, companies specialised in Cultural Heritage surveying take up technical developments. Because they are using classical software, they are still not able to undertake appropriate surveys of this kind of surface. It's now possible to provide for this specific need.

The cylindrical orthophoto demonstrates that single-image methods and means can be efficient solutions for architectural surveys. It is hence worth considering as a serious alternative to often cumbersome photogrammetric operations.

It's possible to use similar techniques for other types of surfaces, with identical procedures, namely the definition of a reference surface (cone, sphere) and the adaptation of photogrammetric equations to the new co-ordinate system (cylindrical, polar). But we have to bear in mind the first vocation of an orthophoto, which is to provide accurate geometrical information.

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