FURTHER DEVELOPMENTS OF THE SPHERICAL PHOTOGRAMMETRY FOR CULTURAL HERITAGE

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KEY WORDS: Spherical Photogrammetry, Mosaics, Bundle adjustment, DLT, Multi-image spherical panoramas, 3d photomodeling

ABSTRACT:

The spherical photogrammetry with multi-image panoramas, proved to be very useful for metric documentation and recording of Cultural Heritage. Low cost, easiness, rapidity, completeness are the main advantages of this new technique. As examples of survey Plaza de Armas in Cuzco, Peru, and some Italian churches are shown. The panoramic photogrammetry has been chosen in a public tender to document and survey five villas designed by A.Palladio in Northern Italy. Panoramic imaging is now used to produce interactive exploration and realistic models of some of the most noticeable monuments of Libya in a joint Italian-Libyan project. Recently, to improve the quality of the plotting and capabilities of the technique, some new features have been added: 1) the so-called monoplotting, 2) the imposition of some geometrical constraints such as verticality, horizontality of lines, the belonging to the same plane in the space, 3) the orientation of non-metric plane images by DLT, being the panorama the provider of the control information, and finally 4) the back projection of the panorama for the model rendering and editing, (photomodelling). 1)The monoplotting is the possibility (limited to objects lying on a plane) to plot from one panorama only. The missing stereoscopy doesn't enable complex details to be plotted, but in case that this detail, lays on a plane, its 3d coordinates are computed by intersection with the plane of the projective lines coming from one panorama. 2) The imposition of some geometrical constraints can help in the orientation phase, providing information useful to improve the accuracy of the plotting. 3) DLT There is the possibility to orient non metric images, as touristic images, or archive images, taking the control points from the panorama bundle block, making use of DLT approach. In particular this is useful where the visibility given by the panorama is difficult, like in the zenithal areas. 4) Photomodelling. The back-projection of the spherical panorama consists in the possibility, given by the knowledge of the orientation parameters, to back project the panorama over the surfaces of the plotted 3d model of the object. This procedure speeds up the rendering phase, making it easier, and partly overcome the difficulty caused by the lack of stereoscopy, to plot rough, uneven surfaces, enabling the interactive photo-modeling. The model can be edited and modified until it coincides with the projections of the panoramas.

1. THE SPHERICAL PHOTOGRAMMETRY

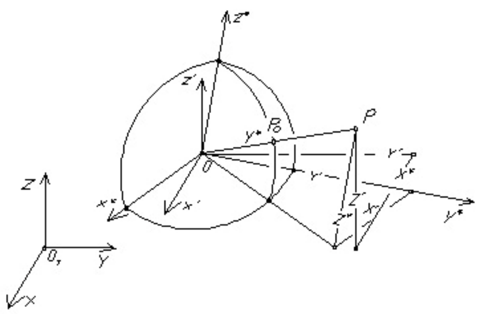
The photographic documentation with spherical photography is already a very common practice (Google Street, etc). In addition we proved that it can have good quality metric contents, giving raise of what we called Spherical Photogrammetry). For the theory of spherical photogrammetry see (Fangi, 2007, 2008). From a unique point of view a series of photographs, partially overlapping, are taken covering 360°. Then, the rendered panorama is mapped on a plane with the so-called equirectangular projection. From the image point *P'* and the corresponding object point *P*, the collinearity equations hold :

$$x = R \cdot \left(-\theta_0 + atg \frac{(X - X_0) - d\alpha_y (Y - Y_0)}{(Y - Y_0) + d\alpha_x \cdot (Z - Z_0)} \right) \qquad [1]$$

$$y = R \cdot a\cos \frac{d\alpha_y (X - X_0) - d\alpha_x (Y - Y_0) + (X - X_0)}{\sqrt{(X - X_0)^2 + (X - X_0)^2 + (X - X_0)^2}}$$

where x and y are the panorama coordinates, X, Y, Z are the terrain 3d coordinates, R the radius of the sphere, $d\alpha_x$ and $d\alpha_y$ the correction angles (roll and pitch), θ_0 the heading, X_0, Y_0, Z_0, the terrain coordinates of the sphere centre (figure 1).

Figure 1 – Relationship between the pano-sphere and the object point P



1.1 Orientation with control points and bundle adjustment

The orientation, i.e. the determination of the six orientation parameters per panorama, can be performed in a bundle adjustment provided some control points, using the collinearity eqns [1].

1.2 Orientation with model formation by co planarity

In case that no control points is available, one panorama can be oriented with respect to any other one using the coplanarity condition [2], figure 2, followed by bundle adjustment.

$$[X' \quad Y' \quad Z']M'^T \begin{bmatrix} 0 & -bz & by \\ bz & 0 & -bx \\ -by & bx & 0 \end{bmatrix} M'' \begin{bmatrix} X'' \\ Y'' \\ Z'' \end{bmatrix} = 0 \qquad [2]$$

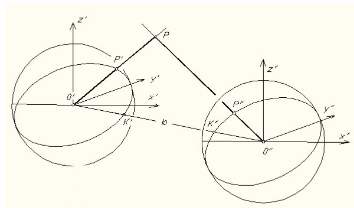


Figure 2 – The coplanarity of the spherical panoramas

where M are the rotation matrices, *bx, by, bz* are the components of the base *b* (Fangi 2007, 2008). The model coordinates are then used as input in a bundle adjustment. Some control information is needed for the size and levelling of the model.

2 SOME EXAMPLE PROJECTS

The examples of survey by spherical panorama are already many. Here some of them are shown and briefly described.

2.1 The church of Santa Maria Goretti, Corinaldo, Italy. The church in neo-classical style has been surveyed taking 8 panorama inside and 3 outside, 20 control points inside, 10 for the façade (figure 3).

2.2 Plaza de armas, Cuzco, Perù – in november 2007 C.A.Bozzi took 13 panoramas. No control point being available, the orientation and the dimensions have been derived from Google-Earth high resolution, after the model formation and bundle adjustment. The square, in the Unesco list, is one of the richest place of architectural and historical interest of the world. Two main churches, in colonial spanish baroque style, are facing the square, toghether with four minor churches, and the monumental intrance of Sant'Antony Abad university (figure 4).

2.3 Villa Poiana, Poiana Maggiore, Italy. The villa designed by A. Palladio, has been successfully used as test of the spherical photogrammetry procedure for documenting, archiving and surveying. In the figure 5 the rendered model build after the wire-frame.

2.4 Needle of desert, Wadi Nadif, Libya – The major emergencies of Libya (Sabrata, Leptis Magna, Cyrene) have been documented and surveyed using spherical photogrammetry, limited to the most meaningful items. The so-called needles of desert, are funerial monuments, the one in fig. 6, is of 15^{th} century.

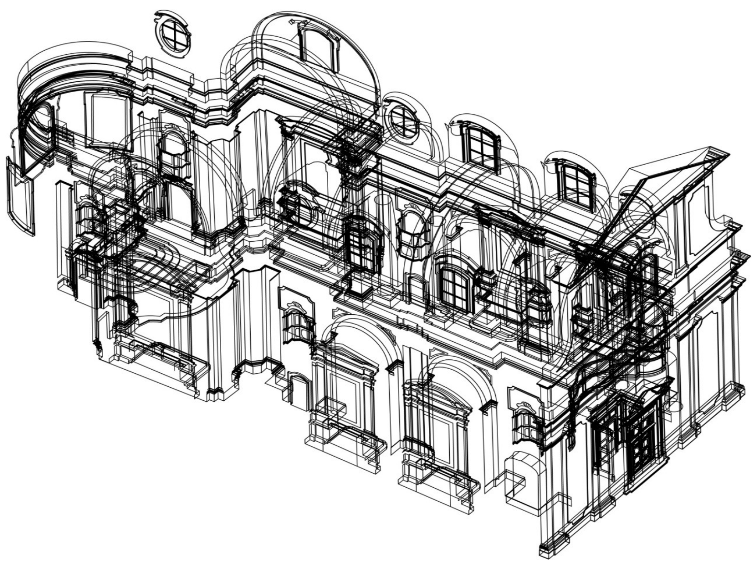


Figure 3 – The church of Santa Maria Goretti, Corinaldo, Italy (by M.Belluccini), wire-frame

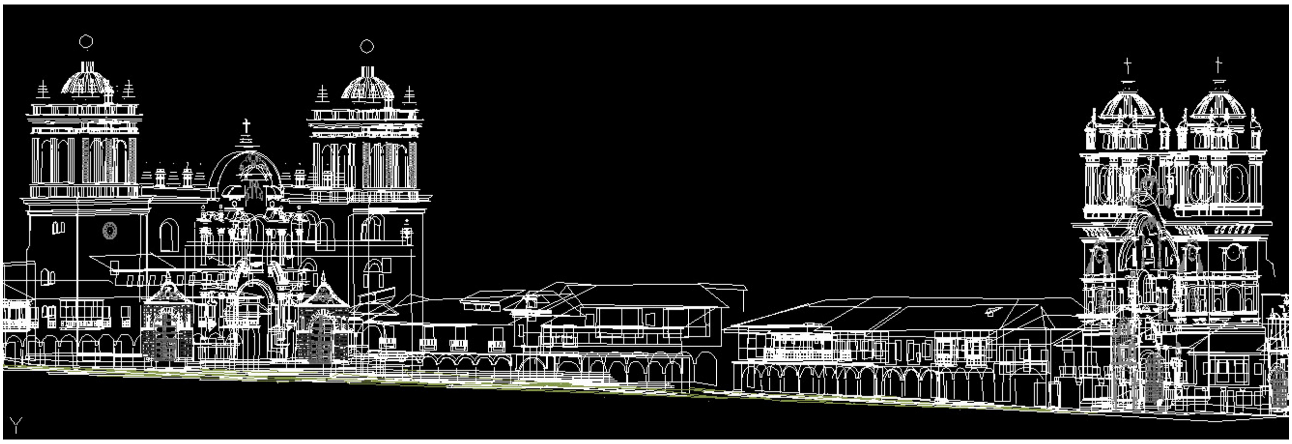


Figure 4 - Plaza de Armas, Cuzco, Peru

Figure 5 – Villa Poiana, (A. Palladio), Vicenza, Italy

Figure 6 – Wadi Nadif, Libya, needle of desert (E.d'Annibale)

3 IMPROVEMENTS OF THE SYSTEM

To strengthen the geometry of the block, enhancing the quality and increasing the capabilities of the plotting, some improvements have been added to the system such as geometrical constraints, the orientation of non-metric images, the monoplotting. Let's briefly examine them.

3. 1 Geometrical Constraints

Very often, especially in architecture, one can take advantage of some geometrical information:

3.1.1 Verticality of lines. When two points P_1 and P_2 lye on the same vertical line, the 2 condition equation can be added to the block adjustment system $X_1=X_2$ and $Y_1=Y_2$ [3] that linearized are

$$dX_1-dX_2= X_2-X_1 \quad \text{and} \quad dY_1-dY_2= Y_2-Y_1 \qquad [4]$$

3.1.2 Horizontality of lines. When two points P_1 and P_2 lye on the same horizontal line, one condition equation can be added to the block adjustment system $Z_1=Z_2$ [5] that linearized is

$$dZ_1-dZ_2= Z_2-Z_1 \qquad [6]$$

3.1.3 Equal X (Y). This condition holds when two points lye on a plane parallel to the coordinate plane and one condition equation can be added of the [4].

3.1.4 Condition of belongings to a geometric plane. When more than three points belong to the same plane $aX+bY+cZ+1=0$, arbitrary oriented in the space, one can find by least squares the parameters a, *b, c* of the plane and then write the linearized condition eqn for any point of the plane.

$$a.dX+b.dY+c.dZ=-(1+aX+bY+cZ) \qquad [7]$$

3.2 DLT – Orientation of non-metric images

The **DLT** (Direct Linear Transformation) approach is well known. It is applied when a non metric image has to be used in photogrammetry to estimate its 11 orientation parameters + one for the distortion. A good amount of control points, well distributed in the image are needed. These points can be supplied by the block adjustment of the panoramas. This is especially useful for the zenithal areas where the visibility provided by the panorama is poor and hardly understandable. Here the inner dome of San Lorenzo church in Turin, is shown, where the cupola is particularly complicated and high. The vision provided by the planar images is much more comfortable than the one given by spherical pano, allowing the ribs of the vault to be easily plotted (figure 7).

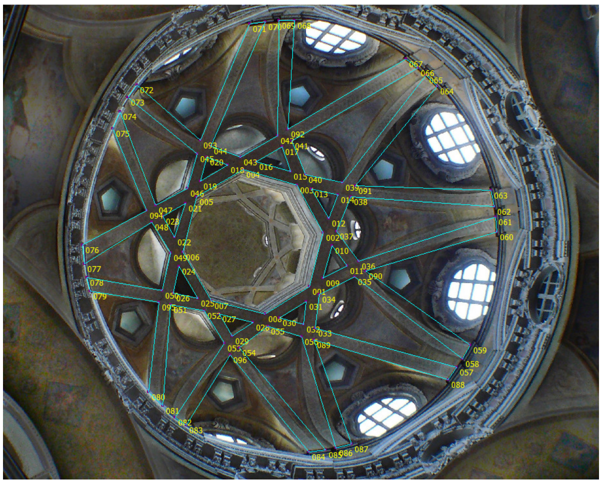
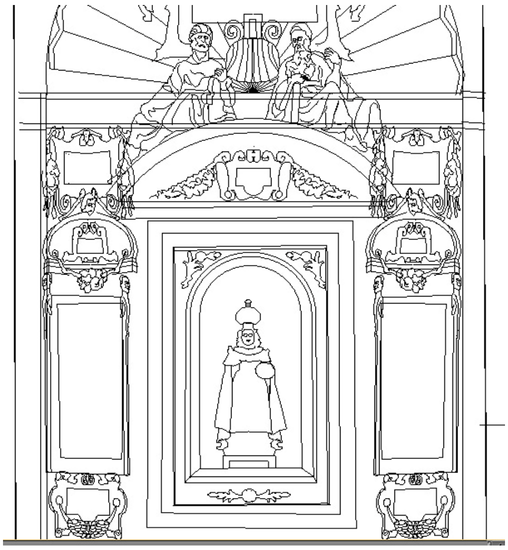


Figure 7 – The ribs of the inner vault of the cupola of San Lorenzo church in Turin, Italy

3.3 Monoplotting

The limit of the system is the lack of stereoscopy thus preventing the plotting of natural surfaces, and curved lines. But in case that the line to be plotted is laying on a plane, it is possible first to find the equation of the plane and then to intersect the plane with the projective lines [1] coming from one panorama only. In the figures 8, 9 the decorations of the baroque church S.Maria della Carità in Ascoli Piceno (Italy).



Figures 8 – Church of S.Maria della Carità, Ascoli P.,Italy The baroque decoration has been plotted in monoplotting mode flattering the lines in the average plane.

4. THE TECHNIQUE OF THE BACK PROJECTION: Al-DEIR IN PETRA, JORDAN

The Monastery (Al Deir), Petra, is a Unesco World Heritage Site, Jordan, Middle East (figure 10). The Monastery is the largest monument in Petra. The Deir received this name from the cave that is known as the Hermit's Cell.

4.1 The Survey

During a tourist tour in May 2008, the A. took three panoramas, from left side, right side and from a central position (figures 10, 12). The orientation was performed with relative orientation procedure. Taking the two exterior panos as base, the left and the right ones, a model was formed, using eqns. [2] and [1]. Than the model has been rotated to make *x* axis parallel to the facade. Only one distance was possible to measure with a Disto® distantiometer, the high of the entrance door (8.20 m) thus allowing the scaling of the model. With the model points got in such a manner, also the central panorama has been oriented by resection. The final values of the orientation parameters have been obtained by block bundle adjustment with eqns. [1]. Obviously this project cannot be regarded as a real survey, due to its limitation and incompleteness, but only as a small test about the suitability of the panoramic photogrammetry for metric documentation of such monuments.

Figure 10. Portion of the left panorama of the Deir temple.

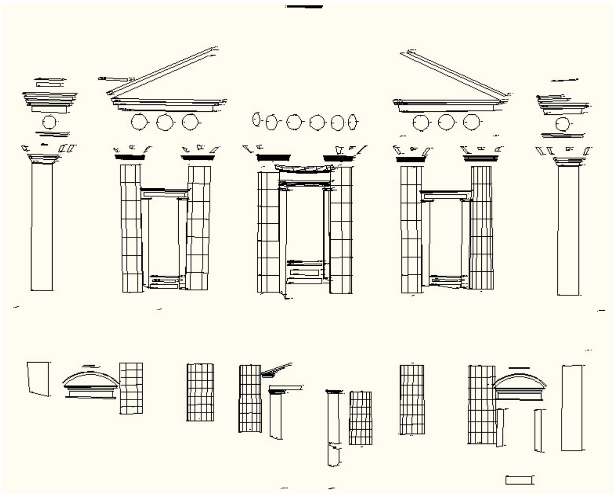


Figure 11 – The wire-frame of the temple (by E.Ministri)

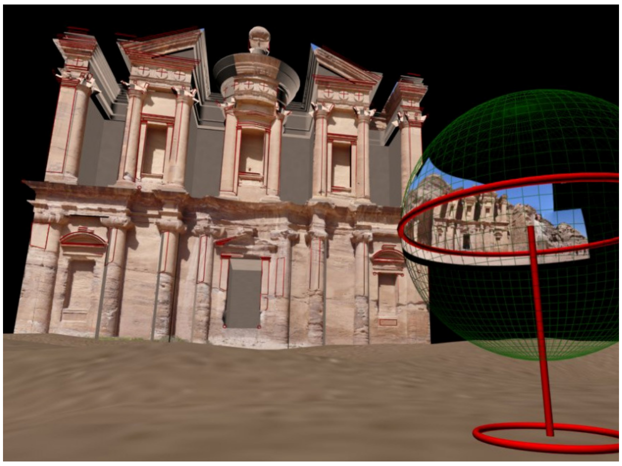


Figure 12. – The back-projection of the panorama into the model (E.d'Annibale)

4.2 The Interactive Modelling

The surface is very irregular eroded and rough due to the weather action on a very tender rock, (sandstone). The plotted wire-frame (figure 11) is limited therefore to the only identifiable points that are few in comparison to the whole of the monument, because of the lack of stereoscopy. The whole lower part and the deepest parts are completely missing. Then to complete the evaluation, the following procedure has been applied. The wire frame has been imported in 3D Studio Max® 9 environment. The next step has been to pass from the lines of the wire-frame model to the surfaces of the model, although approximate in the beginning. The three panos have been applied to the three spheres, centred in the three stations points, in their correct position, derived from the orientation parameters. Due to the capabilities of the software, the panos are projected from the projection centres over the model surfaces, allowing editing and modifying them up to the satisfactory fitting of the projected panoramas from all the directions. The object is modelled in small simple surfaces, like planes, cylinders, etc. There are tools in the software able to edit points and surfaces. For instance, it is possible to modify in real time the diameter of a column at the base and at the top, until the column fits in its projection.

This performance could be defined as interactive photomodelling by projection of the oriented multi-image spherical panorama

5 CONCLUSIONS

Very many are the advantages of the spherical panoramas:

- The high speed of the execution of the survey
- The completeness of the documentation, the pano having 360° fov
- The simplification of the photogrammetric problem, the inner orientation is skipped
- The low-cost of the hardware, limited to a digital camera, and a tripod.

The main limit of the system is that only the identifiable points can be plotted, because of the lack of stereoscopy. The monoplotting and the back-projection are tools to try to solve the limit.

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11. 3D Studio Max 9 . Owner Manual

Acknowledgements

The plotting and editing of projects have been performed by:

- Santa Maria Goretti church by M. Belluccini
- ad Deir by E. Ministri and E.d'Annibale.
- the needle of desert by E.d'Annibale
- villa Poiana by E.d'Annibale, F.Fiori
- Plaza de armas Cuzco by C.M.Agostoni
- Decorations of S. Maria della Carità by L. Baldassarri

The panoramic survey in Cuzco has been done by C.A.Bozzi. The A. thanks all of them.