THE MULTI-IMAGE SPHERICAL PANORAMAS AS A TOOL FOR ARCHITECTURAL SURVEY

Gabriele FANGI

Polytechnical university of Marche, Ancona, Italy, g.fangi@univpm.it

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ABSTRACT

The surveys of the interior of two churches in Italy, the Magdalene's church in Pesaro, and San Dominic church in Arezzo, are shown and described as examples of a new photogrammetric technique. The first church is one of the most noticeable baroque architecture in the Marche region and it has been designed by the famous architect Luigi Vanvitelli in 18th century, the second one is a large and simple church in Arezzo. The proposed technique is based on the multi-image spherical panoramas. For the formation of the plane image of the spherical panoramas the commercial software has been used. The spherical panorama can be regarded as the analogical recording of the angular observations of a theodolite having its center in the center of panorama. But to be set in operational conditions as a theodolite, the spherical panorama has to recover two rotation angles to set the verticality of its principal axis. The estimation of such rotation angles can be performed both in a preliminary phase prior to the plotting or in a unique phase in a block adjustment. Control points, control directions, geometric constraints such as verticality and horizontality of space lines, can be used. In these study-cases almost no one of such control information was necessary, but the only block adjustment was sufficient. The block adjustment finally furnishes the estimation of the unknown points coordinates together with the six orientation parameters per panorama, three translations and three rotations, by means of the known geodetic equations of the horizontal direction and the zenith angle, (modified to take into account the two horizontal correction angles), that are nothing else than the collinearity equations of the spherical panoramas. The technique of the spherical panoramas has previously been experimented and used for the survey of two of the most noticeable Italian squares, Piazza del Popolo in Ascoli Piceno and Piazza del Campo in Siena. By that time, to be able to use the panoramas, besides the angular corrections, further polynomial corrections were necessary, gotten from a dense network of control points (100-200), (Fangi, 2006). In the case under examination not only such corrections were not needed but also no control point was used. The procedure improvement can be explained with the shorter distances, with the good improvement of the Stitching software, (that thanks also to the ceiling texture, produced better panoramas), and finally with the improvement of the adjustment algorithms, via the block adjustment. The image distortion is automatically corrected by the software itself in the rendering phase, by merging the overlapping image frames. The interior orientation is skipped. For the time being, the final plotting accuracy is limited by the quality of the panoramas and by the resolution of the spherical images. In the shown examples the width was 10000 and 15000 pixels for all the panoramas, corresponding to an angular accuracy of 0.04-0.03 g, therefore very scarce. The 3d plotting was performed with monoscopic multi-image observations. In the first example the block adjustment supplied, besides the orientation parameters, the coordinates of about 600 points, observed in at least three panoramas. The achieved accuracy is in the order of few the centimetres say $\sigma_x = \sigma_y = \pm0.02$ m and $\sigma_z = \pm 0.03$m. The advantage of the spherical panorama in comparison to classical photogrammetry consists in the greater completeness of the information due to its 360° amplitude, giving a synoptic view of the whole environment. A single panorama can replace many image frames; a couple of panoramas can substitute many photogrammetric models. The spherical panoramas are very simple, fast and easy to realize, they are very economic, and they are a very useful and powerful tool for the documentation and survey of the cultural heritage.

1. INTRODUCTION

Till now the only metric applications of images panning to 360°, were mainly those gotten with high resolution rotating cameras (5, Luhmann, Tecklenburg, 2004, 6, 7, Schneider, Maas, 2004). The technique here proposed uses on the contrary panoramas realized with images taken with normal digital cameras and then mosaicate with common commercial software. The projection sphere of the images is mapped in the cartographic plane with the so-called longitude-latitude representation from which the angular directions can be drawn that one would measure with a theodolite whose center coincides with the center of the sphere. The greatest difference consists in the fact that while the theodolite is set with its principal axis vertical, in the case of the sphere it is not possible to sufficiently make vertical the principal axis. One must estimate and apply two correction angles around the two horizontal axes (as it is done by a biaxial

compensator in the theodolite). After the correction, the restitution of the object takes place with the normal topographical methods as intersection and resection. The parameters of orientation of a panorama are six, the three coordinates of the center and three angles, of which one, around the z axis, is the zero bearing, common to all the angular theodolite stations. Among the center of projection, the image point and the object point the collinearity equations are written, which are nothing but the traditional equations to the horizontal direction and the zenith angle, corrected to take into account of the missed verticality of the principal axis. One can also write the coplanarity equations between two panoramas and estimate the five parameters of the relative orientation of one panorama to the other one and to proceed therefore to the computation of the model coordinates. In this approach the phase of interior orientation is completely omitted. The pattern of the errors has practically been observed in all the real panoramas as a consequence of the missing axis verticality. The survey with the spherical

panoramas has been in fact experimented for the first time for two noticeable Italian squares, Plaza of the People to Ascoli Piceno and Piazza del Campo in Siena (3, Fangi, 2006). In the tests here proposed, realized for the survey of the interior of some churches, almost no control point was needed. The improvement of the technique can be explained with the particular geometry of the objects but above all with the block adjustment of the observations.

2. THE MULTI-IMAGE SPHERICAL PANORAMAS

The theory of the multi-image spherical panorama has been developed by Szelisky in 1994 for the Apple Computers (8, Szelisky, Shum, 1997). The whole extension to 360° around the taking point is covered by photos, all of them having the same center of taking, and partially overlapping. The ray connecting this center with the object point intersects the two adjacent photos in the corresponding image point. Such ray projects the image points on a sphere of arbitrary radius. The sphere is then mapped on the cartographic plane with the so-called latitude - longitude representation (figure 1).

$$x = r.\theta \quad e \quad y = r.\varphi \qquad [1]$$

with the angles expressed in radiant. Such representation is not conform, nor equivalent. The poles of the sphere are represented by two segments of equal length to the circumference of the sphere, and therefore equator and poles have the same length. The height of the map is equal to the development of a meridian. From such representation the angles of direction of the projective line can be drawn. In fact, knowing the extension, the radius of the generating sphere is derived.

$$r = a / 2\pi \qquad [2]$$
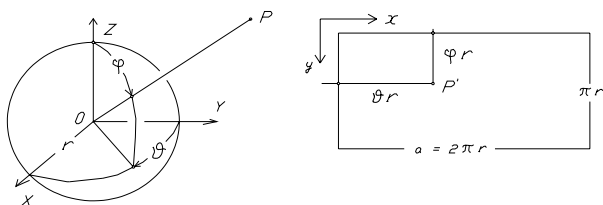$$\theta = x/r \quad \varphi = y/r \qquad [3]$$

Figure 1 - The latitude-longitude projection. Relationship between spherical coordinates and the image coordinate of a spherical image

They are the same that would be measured with a theodolite. Two are the differences: the first one is the achievable precision, in fact maximum width is around the 20.000 pixels, and every pixel corresponds to 0.02 gon, therefore very inferior to the one of a theodolite. The second difference is that in the sphere, contrarily to what happens in the theodolite, the axis cannot be set vertical with sufficient accuracy. It is necessary therefore before derive the angular directions, to estimate and correct two angles of rotation around the horizontal axes. Such operation is equivalent to a biaxial compensator of a theodolite. The estimation of such angles can be done with different methods (6, Fangi 2006) such as control directions, control points, geometric constraints such as horizontality and verticality and finally block adjustment.

3. THE COLLINEARITY EQUATIONS OR THE CORRECTED EQUATIONS OF THE HORIZONTAL DIRECTION AND OF THE VERTICAL ANGLE

3.1. The point coordinates.
Given the spherical coordinates of an object point P(X,Y,Z) in a reference system linked to the sphere:

$$X' = X - X_0$$
$$Y' = Y - Y_0 \qquad [4]$$
$$Z' = Z - Z_0$$

The spherical coordinates of the same point P in a system centred in the sphere and parallel to the terrestrial system, are (figure 2):

$$X^* = d.\sin\varphi.\sin\theta$$
$$Y^* = d.\sin\varphi.\cos\theta \qquad [5]$$
$$Z^* = d.\cos\varphi$$

3.2 The "levelled" or corrected spherical coordinates can be drawn by those X', Y', Z' of the system sphere:

$$\begin{bmatrix} X^* \\ Y^* \\ Z^* \end{bmatrix} = \begin{bmatrix} 1 & d\alpha_z & -d\alpha_y \\ -d\alpha_z & 1 & d\alpha_x \\ d\alpha_y & -d\alpha_x & 1 \end{bmatrix} \cdot \begin{bmatrix} X - X_0 \\ Y - Y_0 \\ Z - Z_0 \end{bmatrix} = \begin{bmatrix} d\sin\theta\sin\varphi \\ d\cos\theta\sin\varphi \\ d\cos\varphi \end{bmatrix} \qquad [6]$$

By dividing the first by the second one we get:

$$\theta = atg\frac{X^*}{Y^*} = atg\frac{r_1(X-X_0)+r_4(Y-Y_0)+r_7(Z-Z_0)}{r_2(X-X_0)+r_5(Y-Y_0)+r_8(Z-Z_0)} = \qquad [7]$$

$$= atg\frac{X'-d\alpha_z \cdot Y'-d\alpha_y Z'}{d\alpha_z \cdot X'+Y'+d\alpha_x \cdot Z'}$$

From the third:

$$\varphi = a\cos\frac{Z'}{d} = a\cos\frac{r_3(X-X_0)+r_6(Y-Y_0)+r_9(Z-Z_0)}{d} \qquad [8]$$

$$= a\cos\frac{-d\alpha_y X'+d\alpha_x Y'+Z'}{d}$$

where $d = \sqrt{X'^2+Y'^2+Z'^2} = \sqrt{X^{*2}+Y^{*2}+Z^{*2}}$

is the distance of the sphere center O from point P, invariant in the two reference systems. The preceding equations are the equations of collinearity for the spherical panoramas or the correct equations of the horizontal direction and the vertical angle corrected to take into account the missed verticality of the sphere. They must be linearized near approximate values of the parameters and coordinates and then adjusted in block, according to a surveying technique already set-up (2, Fangi, 2004). The restitution takes places by means of the eqns. [7]and [8]. The approximated values are supplied by a classical procedure where the initial values of the correction angles are set to zero, or by means of the relative orientation described in 4.
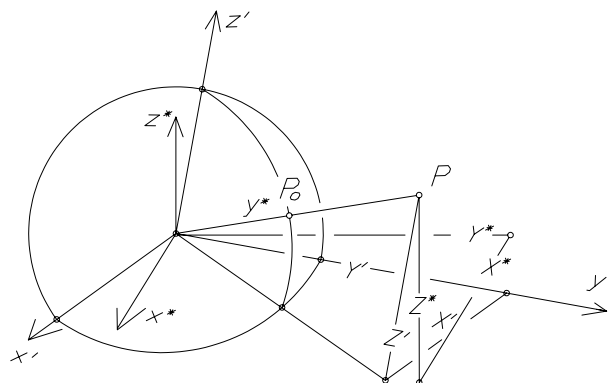

Figure 2 - Relationship between object coordinates, spherical coordinates, before and after the correction of verticality.

4. THE COPLANARITY CONDITION

The two corresponding image points P'(x',y',z') and P"(x'',y'',z'') on the two spheres lay on the same epipolar plane O'PO" and their coordinates satisfy the coplanarity condition:

$$g = x'^{T} V x'' = 0 \qquad [9]$$

$$[x' \quad y' \quad z'] R'^{T} \begin{bmatrix} 0 & -bz & by \\ bz & 0 & -bx \\ -by & bx & 0 \end{bmatrix} R'' \begin{bmatrix} x'' \\ y'' \\ z'' \end{bmatrix} = 0 \qquad [10]$$

where R' and R" are the rotation matrix of the two bundles, bx, by, bz, the components of the base b. Eqn. [10] is linearized and divided by the value of the two radii:

$$[(\sin \varphi'.\sin \vartheta') \quad (\sin \varphi'.\cos \vartheta') \quad \cos \varphi'] \begin{bmatrix} 1 & -\delta\alpha'_z & \delta\alpha'_y \\ \delta\alpha'_z & 1 & -\delta\alpha'_x \\ -\delta\alpha'_y & \delta\alpha'_x & 1 \end{bmatrix}$$

$$\begin{bmatrix} 0 & -bz & by \\ bz & 0 & -bx \\ -by & bx & 0 \end{bmatrix} \begin{bmatrix} 1 & \delta\alpha''_z & -\delta\alpha''_y \\ -\delta\alpha''_z & 1 & \delta\alpha''_x \\ \delta\alpha''_y & -\delta\alpha''_x & 1 \end{bmatrix} \begin{bmatrix} (\sin \varphi''.\sin \vartheta'') \\ (\sin \varphi''.\cos \vartheta'') \\ \cos \varphi'' \end{bmatrix} = 0$$

$$[11]$$

The procedure is similar to the one set up for the theodolite stations that was called "blind traverse" (Fangi, 1,1998), with the sole difference that the unknown parameters increase from four to six and that the relative orientation is performed with five independent parameters among the 8 possible, as in traditional photogrammetry. The solution of [11] brings to the relative orientation of one bundle with respect to the other one. The relative orientation is useful to link stations not having reciprocal observations and therefore to supply the approximated values of the unknown coordinates to input in [7] for the block adjustment. Note that no control information neither interior orientation is needed.
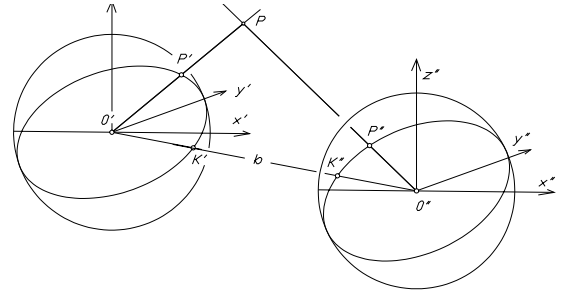

Figure 3 – The coplanarity of two spherical panoramas

5. THE CHURCH OF THE MAGDALENE IN PESARO

Our first tests on the metric use of the spherical panoramas date from 2005. The experiments have been done in the campus of the faculty of Engineering in Ancona, in Piazza del Popolo in Ascoli Piceno, in Piazza del Campo in Siena. The results have not been satisfactory entirely (3, Fangi, 2006). The church of the Magdalene is in Pesaro has been designed by the architect Luigi Vanvitelli and built between 1740 and 1745. It is a Baroque church of medium size (figures 4, 7 and 8). Five panoramas have been taken one in the center and four according to the principal directions of the plan (figure 4). Every panorama is composed by 25 frames taken with Panasonic Lumix TZ10 camera 35mm equivalent focal length, 5Mb. The software used for the formation of the panorama is Stitcher 5 Realviz, the width of every panorama is 10.000 pixels. With a theodolite the position of the five centers of the panoramas has been established. A block adjustment of the observations has been done, fixing the coordinates of three station points only, and the results are the following:

Figure 4 - The central panorama of the Church of the Magdalene in Pesaro, with the errors amplified 10 times
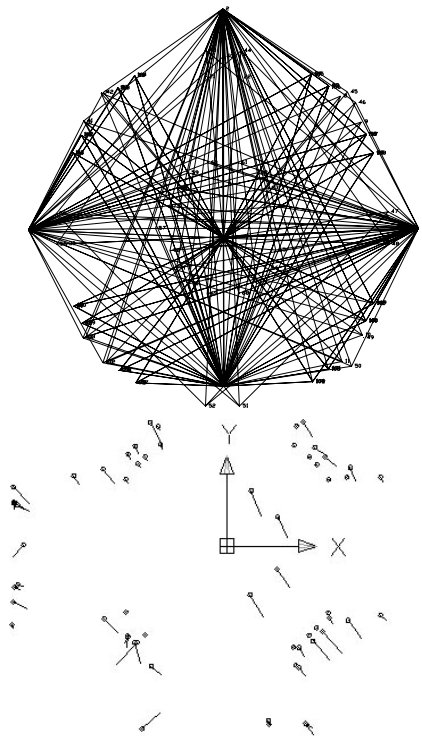
Magdalene Project, Pesaro September 2006
Number of observations=   4640
Number of unknowns =   1764
   Redundancy=   2876
Number of unknown points   583

sigma zero =   .0018754 rad = 0.1194g = 3 pixel.
Average of sd of the adjusted points
  sqmx=   .029m sqmy=   .032m sqmz=   .043m

Figure 5 - Church of the Magdalene, Pesaro - The observation network done from the five panoramas

Figure 6 - Distribution of the error vectors amplified 10 times. It is evident a systematic effect

After the restitution, 64 check points, taken with the reflectorless total station, have been compared with those taken with the photogrammetry, table 2.

Figure 7 - Church of the Magdalene, Pesaro. The wire-frame of the model, axonometry.
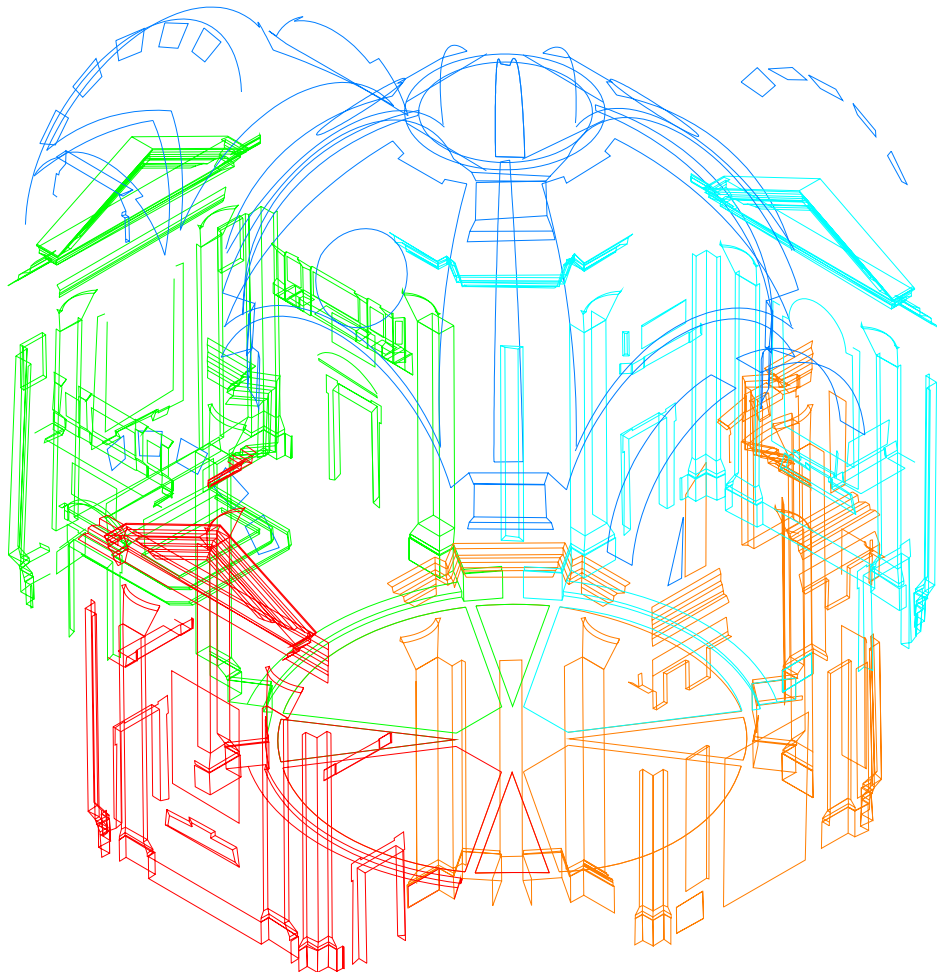
In figures 4 and 6 the effects of a systematism are evident; therefore even if the average value of the module for the errors is 6 cms, when the systematic error is eliminated, a consistent reduction of such value will result. In the table 2 are shown the values of the correction angles. Note that their standard deviations are of one order inferior.

Stations Points (64 check points)	Points (58 check points)	(51 check points)
sx = 0.0234 sy = -0.0333 sz = 0.0044 mean module = 0.0639	sx = 0.0190 sy =-0.0197 sz =0.0081 mean module = 0.0470	sx = 0.0203 sy = -0.0246 sz=0.0065 mean module = 0.0537

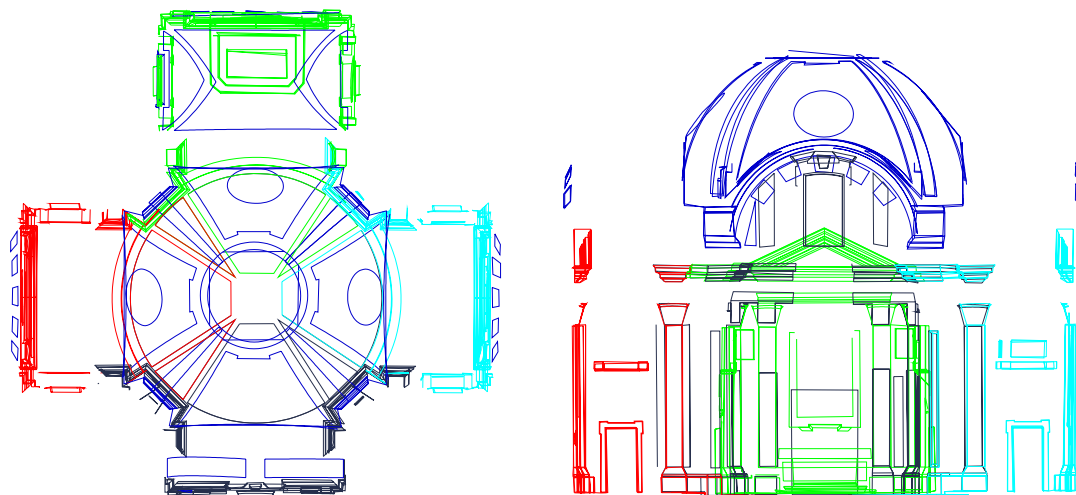| Table 1 – Average of RMS errors on check points (in m)		
Only 3 fixed	3 SP+ 3 Control	Test 3 SP+ 10 CP

Figure 8 – Church of the Magdalene – Plan and lateral view of the wire-frame

Table 2 – Values of the correction angles and their standard deviations (gon)					
panorama	1	2	3	4	5
Alfax	-0.5323 ±0.0148	-0.2807 ±0.0104	0.1954±0.0096	-0.24620 ±0.0111	0.0560 ±0.0097
alfay	-0.3198±0.0148	-0.3877±0.0104	0.0332±0.0096	-0.42673±0.0111	-0.4414 ±0.0097

6. THE CHURCH OF ST. DOMINIC IN AREZZO

Church of rectangular plan with narrow high gothic windows was built at the end of the 1200; it guards in the altar the famous painted Crucifix of Cimabue (XIII sec.). The inside, with one nave only with beamed ceiling, is decorated with frescos of the 13th and 14th centuries (figure 9). On the right wall the Gothic chapel Dragondelli stands. Two panoramas with Lumix Panasonic FZ50 camera, 35 mm equivalent focal length, 10Mb, were taken by the A. only for tourist purposes.

The panorama formation is by Autopano Pro, the width of every panorama is 15.000 pixels. Since no one measure nor control point were available, the plotting was carried out with the procedure of the relative orientation, described in 4, where an arbitrary value of 100 was given to the base. As can be seen, the building frame is oriented according to the relative symmetric system and it is not levelled. It was not possible to plot the abse, for the bad quality of the intersection and for the lack of photographic coverage. Obviously it is not possible to give some qualitative parameter of the restitution. The geometric congruence can serve as sole verification.
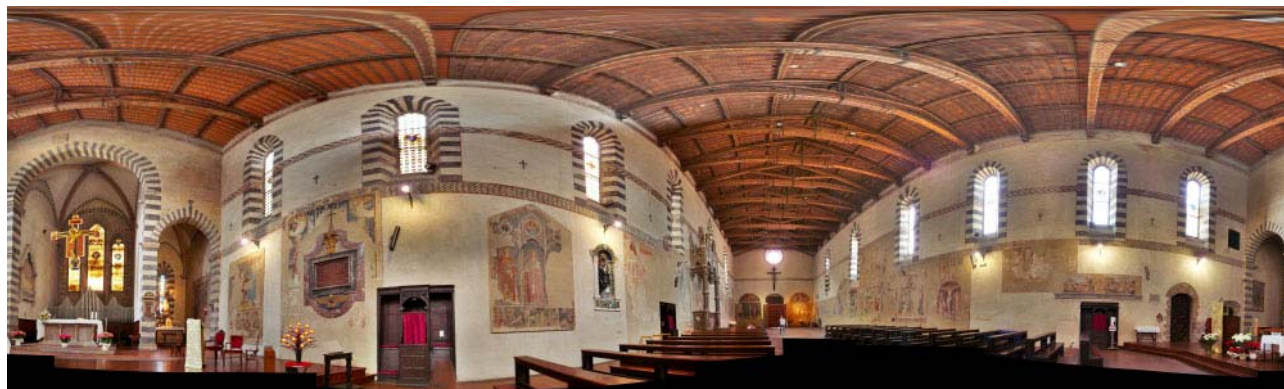

Figure 9 - Church of St. Dominic, Arezzo, one of the two spherical panoramas utilized for the plotting

CONCLUSIONS

The accuracy of the here proposed photogrammetric procedure is the one typical of the monoscopic systems.

The advantages are many: the great speed of execution, every couple of panorama includes or replaces many photogrammetric models, the completeness of documentation, every panorama constitutes the ideal image extending 360°. The possibility to skip the interior orientation, due to the spherical form of the equivalent sensor or pseudo-sensor, permits the direct plotting from relative orientation. Finally the great inexpensiveness of the system, being the equipment very economic and light. On the other side the limit is in the low spatial resolution and in the prevailing use for indoor environments, where the construction of the panorama is facilitated by the presence of the ceiling. All these advantages with the possibility to perform a plotting with very simple measurements only, like tape distances, make the procedure to be a very useful tool for recording and classification of cultural heritage, even for non expert people.
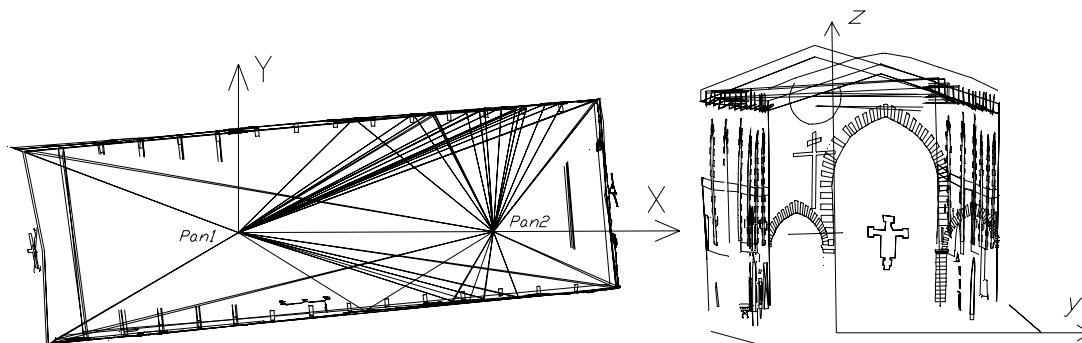

Figure 10 - The network of observations of St. Dominic for the relative orientation, with the two panoramas Pan1s and Pan2 and the relative system
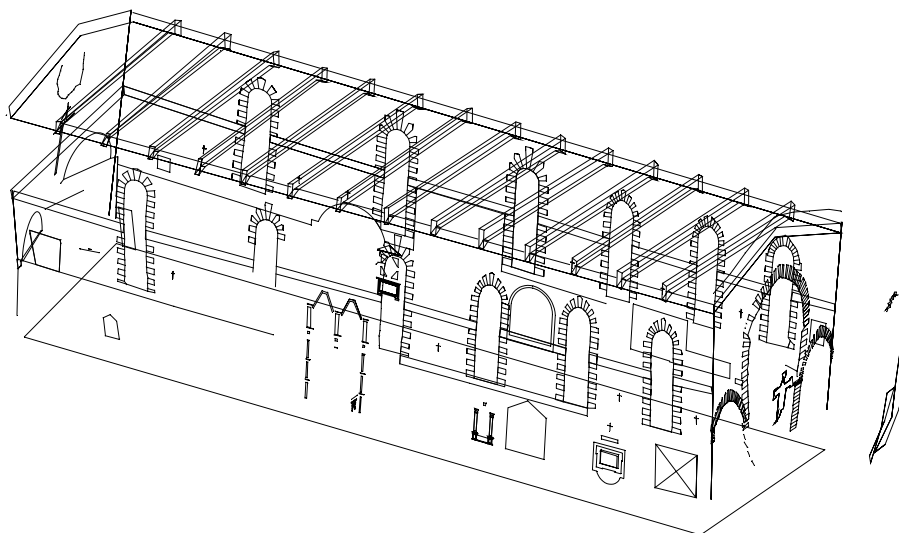

Figure 11 - Church of St. Dominic, Arezzo, axonometry of the plotting (wire-frame).Due to the bad configuration of the intersection, the front and back walls are characterized by a scarce precision

Besides the possibility not to employ expensive instrumentation as the theodolite and the capability to perform the plotting in relative orientation, the sizing and the levelling can be done afterwards by simple means, make the procedure a precious tool for the survey and the cataloguing cultural heritage in the developing countries.

Thanks

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REFERENCES

1. Fangi G. (1998) *The Coplanarity Condition For The Orientation In Surveying - ISPRS Arch.* WG VI/3
2. G. Fangi (2004) - *Block bundle adjustment for theodolite stations in control networks - The case of the Guggenheim museum in Bilbao,* - ISPRS Archives vol. XXXV part B5, pg 372-376 – ISSN 1682 - 1750
3. G.Fangi (2006) - *Investigation On The Suitability Of The Spherical Panoramas By Realviz Stitcher For Metric Purposes*, ISPRS Archive vol.XXXVI Part 5
4. H.Haggrén, H. Hyyppä, O. Jokinen, A. Kukko, M. Nuikka, T. Pitkänen, P.Pöntinen, R. Rönnholm (2004) – *Photogrammetric Application of Spherical Imaging* - ISPRS Archives Vol. XXXIV, part 5/W16
5. T.Luhmann, W. Tecklenburg (2004) – *3-D Object Reconstruction from Multiple-Station Panorama Imagery* - ISPRS Archives Vol. XXXIV, part 5/W16
6. D.Schneider, H.-G. Maas (2004) – *Application and Accuracy Potential of a Strict Geometric Model for rotating Lines Cameras* –ISPRS Archives Vol. XXXIV, part 5/W16
7. D.Schneider, H.-G. Maas (2005) – *Combined Bundle Adjustment of Panoramic and Central Perspective Images* – , – ISPRS Archives Vol XXXVI-5/W8
8. R. Szeliski and H. Shum. (1997) *Creating full view panoramic image mosaics and environment maps.* In Proc. of SIGGRAPH, pages 251-258.