

MULTISCALE MULTIREOLUTION SPHERICAL PHOTOGRAMMETRY WITH LONG FOCAL LENSES FOR ARCHITECTURAL SURVEYS

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Abstract

The metric documentation of architecture and cultural heritage with multi-image spherical panorama has already achieved good results, accurate and reliable (Fangi 2008, 2009). Panoramic images are generally acquired with expensive linear array rotating panoramic cameras having very high metric performances (Luhmann, Maas, 2003, 2004, and 2006). On the contrary the multi-image spherical panorama photogrammetry consists in the acquisition of partly-overlapping images taken from a unique point of view with a common digital camera and then projected on a virtual sphere with commercial stitching software; the sphere is mapped on the cartographic plane according to the equirectangular projection, producing the so-called spherical panorama. From the panorama image coordinates, the direction angles –horizontal and vertical – of an arbitrary object point are derived and can be used in a normal topographic adjustment procedure for the 3d evaluation, obviously provided more than one panorama taken from different points of view. Two angular corrections are necessary to compensate for the non perfect verticality of the sphere axes that are the two rotation angles around the horizontal axes. Differently from tachymetry where all the stations are normally linked by direct measurements along the traverse legs, in spherical photogrammetry the station points are connected together by coplanarity, observing a minimum of common points, as it is usually done in photogrammetry. Finally the block bundle adjustment estimates the coordinates of the tie points and the six orientation parameters per panorama, i.e. the three sphere center coordinates and the three direction angles. This metric documentation procedure, particularly suitable for architecture recording, is very quick and inexpensive. Low cost, easiness, completeness, light simple equipment are the main advantages. The interior orientation is skipped, consisting only in the estimation of the radius of the sphere expressed in pixel. Of the basic functions of the spherical photogrammetry, recently some new features have been added (Fangi, 2009). Geometrical constraints - like verticality, or horizontality, belonging to a plane, having equal X or equal Y - can help in the orientation and in the plotting phase to get better results. Once the object to be drawn is laying on a known surface, one can intersect this surface with the projective rays coming from one panorama only, enabling complex details to be plotted in absence of stereoscopy (monoplotting). It is possible to combine together the adjustment of spherical panos and non metric images. To try to solve the problem of the lack of stereoscopy, some procedure has been successfully applied like the photomodeling, in cad environment, using the back projection of the spherical panorama over the rough object model. Finally the algorithms of the spherical photogrammetry have been successfully experimented in the mobile mapping where the panoramas have been obtained with a six lens polycamera, Ladybug 3 (Fangi, 2009). Also the automation in the tie point detection is under experimentation (Barazzetti et al., 2010). From the photographic point of view there are still some problems remaining: the same object is imaged in the different panoramas with very large differences in the image scale, beyond the different illumination conditions, thus making the automatic procedure for tie point identification rather difficult. Normally a panorama is taken with wide-angle focal lens to reduce the amount of images, to get a more stable geometry, and for easiness. On the other end it is good to have the same image scale in the different panos of the same object region, even when they have been taken from different distances. In general the size of the panorama being the limiting factor, one wants to get the maximum resolution according to the interested FOV of the panorama: when $FOV = 360^\circ$, wide angle is the most suitable, when $FOV < 180^\circ$ normal angle, and finally when $FOV < 10^\circ$ narrow angle is preferable. The local equalization of the image scale of the interested panoramas can be obtained using different focal lenses, according to the camera-object distance. It happens that the photographic scale of a panorama is not everywhere suitable for plotting, normally too small for the farther points. To solve the problem of the remote points, one can use long focal lenses with very narrow field of view, like the one of 2.5° , used for the experiment. But long focal lenses have a weak geometry, making the orientation difficult to be achieved. For long distances, a small orientation error results in large displacement of the plotted object. To help the orientation, the described approach has been followed. From the same camera point, panoramas both with normal and narrow angle lens are taken. The first panorama is used to establish the station coordinates and some control points. The camera station coordinates can then be imposed in the orientation of the narrow FOV panorama by bundle block adjustment. The imposition of the camera station point coordinates gives a good stability to the bundle geometry and ensures a better accuracy to the plotting. The study case is the survey of the top of the bell tower of the Shrine of the Holy House, Loreto, Italy and the Saint Yves at La Sapienza, Rome. The two bell towers have been designed by the famous architects F. Borromini (half of the 17th century) and L. Vanvitelli, one century later). These richly decorated bell towers are very high, 60-70 m above ground level. It was impossible to get close to the object for practical reasons. The shape and geometry of this architecture are complex and required a good resolution for the detail plotting. Panoramas have been realized with images acquired with a normal SRL digital camera using 28, 50, 200, and

500mm focal length lenses. The application of this technique made possible the survey with good results. The flexibility and efficiency are the main advantages of spherical photogrammetry; the combined use of different length lenses, up to the very narrow FOV, enhances this characteristic feature.

KEY WORDS:

Panorama, spherical photogrammetry, architecture, model deformation

1 INTRODUCTION

The spherical photogrammetry is here intended the photogrammetric technique making use of the so-called spherical panorama. From a unique station point, images – partly overlapping - are taken around to cover totally or partially the horizon. The images are then stitched together in common commercial stitching software and projected on a virtual sphere whose radius R is arbitrary but equal to the focal length of the camera in case we don't want to reduce the original resolution. The projection centre and the focal length have to remain constant during the taking phase. The sphere is then mapped in a cartographic plane with the so-called equirectangular projection or azimuth-zenith projection. From the image coordinates x and y of an arbitrary object point P of the panorama the horizontal and vertical directions θ , φ can be derived, provided two angular corrections α_x and α_y for the non perfect verticality of the sphere axis.

$$x = \theta \cdot R \quad y = \varphi \cdot R \quad [1]$$

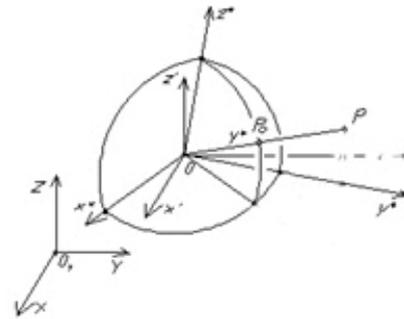
The collinearity equation [2] and coplanarity condition can be written in terms of panorama coordinates (Fangi 2, 3, 4, 10). The examples of surveys made with spherical photogrammetry are already many. The technique has proved to be fast in the taking phase, reliable, the accuracy being in the range of 1/1000 and 1/10000 of the distance photo-object. For the theory of spherical photogrammetry see (Fangi, 2007, 2008, 2009). Between the image point P' coordinates x and y and the corresponding object point P coordinates X, Y, Z the collinearity equations hold :

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

$$y = R \cdot a \cos \frac{\alpha_y (X - X_0) - \alpha_x (Y - Y_0) + (Z - Z_0)}{\sqrt{(X - X_0)^2 + (Y - Y_0)^2 + (Z - Z_0)^2}} \quad [2]$$

where R is the radius of the sphere, α_x and α_y the correction angles, θ_0 the heading, X_0, Y_0, Z_0 , the terrain coordinates of the centre of the sphere (figure 1).

Figure 1 – The sphere system, the object point P , and the terrain system



2. THE ORIENTATION PROCEDURE

The final values of the orientation parameters are supplied by a bundle adjustment, needing approximate values for unknowns; the steps of the orientation are as follows:

- Model formation (by coplanarity) of two spheres
- Absolute orientation of the model (S_transform in space)
- Concatenation of the adjacent models
- Final block bundle adjustment with a minimum of three fixed points (by collinearity).

The interior orientation is skipped consisting in the estimation of the radius R of the sphere, expressed in pixel, normally given by the stitching software itself. The requirements for control information are really very few. As example in figure 2 is shown the Sabratha roman theatre network. A set of 22 panoramas have been taken in August 2009 by the A. They have been oriented starting from a first model and then concatenated linking the next model to the previous one. Finally a block bundle adjustment has been run with least constraints (three fixed points). Only three distances have been measured. The rough wire frame, as it comes from the plotting, is shown in figure 3.

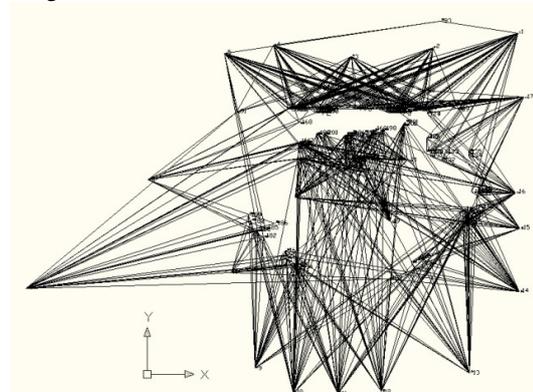


Figure 2 – The network of Sabratha Roman theatre – Libya. 22 panoramas, three measured distances, two hours of work on place.

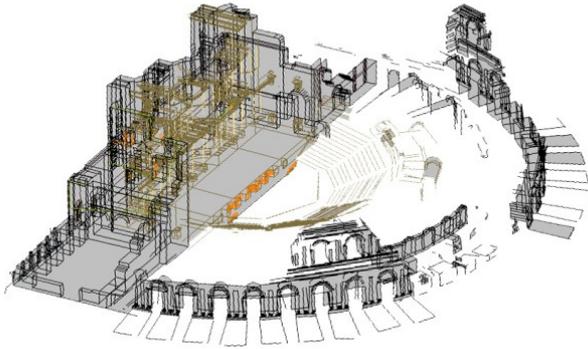


Figure 3 – The wire-frame of Sabratha theatre – Libya, plotting by Cecilia Pisa -

3. NEW FEATURES

Of the basic functions of the spherical photogrammetry, recently some new features have been added (Fangi, 2009).

3.1 Geometrical constraints

To improve the quality of the orientation and therefore the one of the plotting it is possible to add to the block adjustment some geometrical constraints, such as the belonging to the same plane, the horizontality, the verticality, to have the same X or the same Y, for an arbitrary couple of points.

3.2 Combination with DLT

It is possible to combine the adjustment and the plotting with images oriented with DLT. This is useful when we want to use archive images or in general non-metric images.

3.3 Monoplotting

When the object surface is known, it is possible to intersect it with the projective rays coming from one panorama only, enabling complex details to be plotted in absence of stereoscopy.

3.4 From pano to stereo

From the panorama orientation it is possible to get control points to orient stereoscopic non metric images.

3.5 Interactive Photomodeling by backprojection of the oriented panoramas

In CAD environment it is possible to project the oriented panorama over the rough model enabling the capability to edit it and to improve it, up to the coincidence with the projected panoramas.

4. THE EFFECTS OF THE ORIENTATION ERRORS

To study the effects of the incorrect estimation of the orientation parameters, the following experiment has been realized. The aim is to show the qualitative behavior of the errors only and not to quantify numerically their amount. An artificial set of 100 points, arranged in a regular grid on a vertical plane, has been computed. From two station points S1 and S2 symmetrical placed in front of the grid, the horizontal and vertical directions has been computed, error-free, (figure 4). With these directions the points have been projected on the spheres with center in the station

points. The sphere points are projected on the equirectangular panorama, giving the perfect panorama point coordinates. The normal orientation procedure, as it was a real case, has been executed, obtaining model points perfectly coincident with the original grid points.

After then, the orientation parameters of the second panorama have been modified one by one by a certain amount, and the point coordinates computed again. The differences with the original points are the deformation of the model or the errors in the object due to the orientation errors.

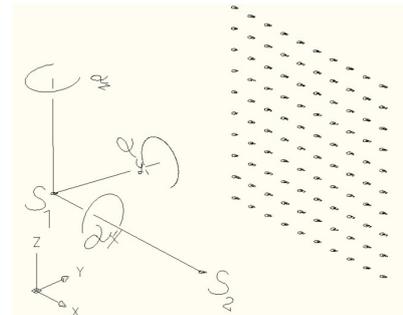


Figure 4 – The layout of the artificial control grid

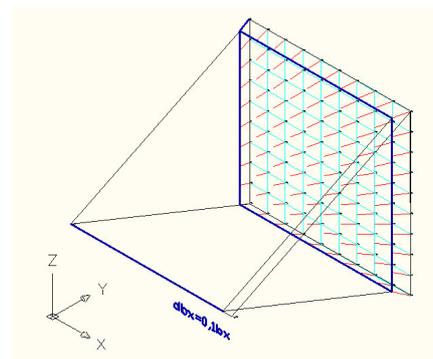


Figure 5 – Model deformation due to variation of the base dbx

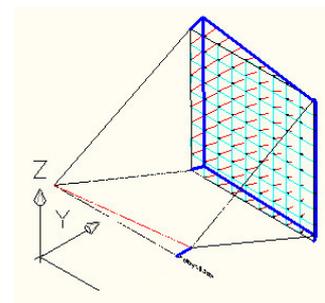


Figure 6 – Model deformation due to variation of the base dby

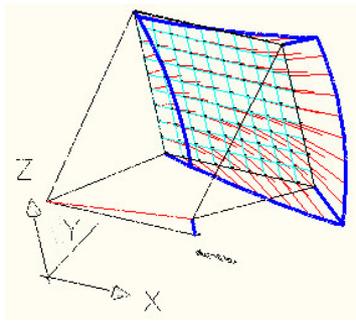


Figure 7 - Model deformation due to variation of the base db_z

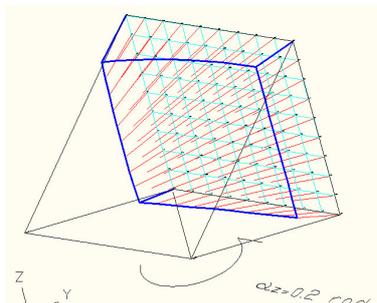


Figure 8 - Model deformation due to variation of the rotation $d\alpha_z$

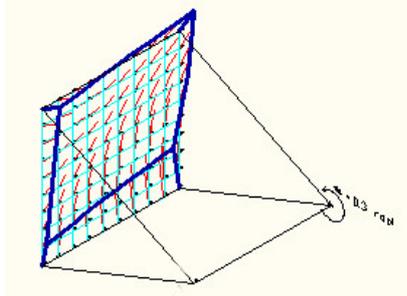


Figure 9 - Variation of the rotation $d\alpha_x$

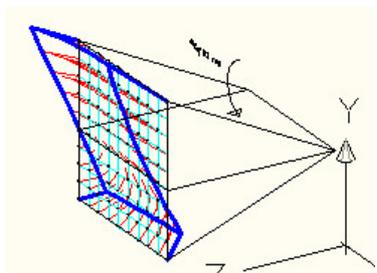


Figure 10 - Variation of the rotation $d\alpha_y$

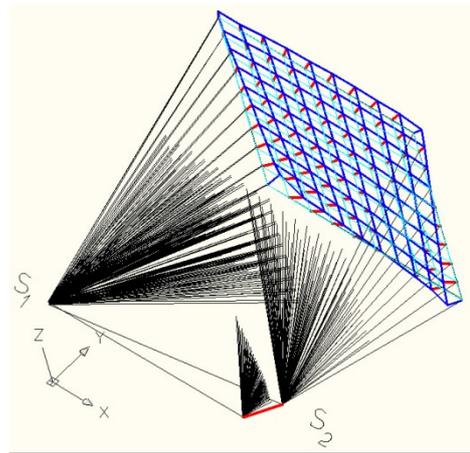


Figure 11 - Variation of the sphere radius dR_2

Being b the length of the model base the given errors have been

$$db_x = db_y = db_z = 0.1b$$

and

$$d\alpha_x = d\alpha_y = d\alpha_z = 0.2 \text{ rad.}$$

$$dR_2 = 0.1R_2$$

It is evident that the base variation only produces a linear variation of the model in the scale. All the others orientation errors generate non-linear deformation. The wrong value of the sphere radius R_2 shifts the position of the panorama center S_2 in the object space (figure 11). In this respect the introduction in the bundle adjustment of some geometrical constraints and the selfcalibration (see par. 3 and 5) can help to form correctly the model and to improve the quality of the plotting.

5. CALIBRATION BY MULTIREOLUTION PANORAMAS OF DIFFERENT FOCAL LENGTH.

The radius R of the sphere is taken equal to the focal length f of the camera, when the original resolution is wanted to be kept. When a panorama is closed at 360° , an angular error ξ results and the adjusted focal length R' is $R' = R(1 - \xi)/360^\circ$ (Zelisky, 1997). In case of Narrow Angle (NA) focal length it is practically impossible to close at 360° , due to the amount of needed images. In this case it is better to estimate the correct focal length R by the self-calibration. But the geometry of the NA bundle is weak. To make it stronger one can operate as follows. From the same station point two (or more) different focal length panoramas are taken, one with WA and another one with NA. The self-calibration is performed in the block bundle adjustment adding the geometrical constraints of the coincidence of the two station points. In this manner the easiness and accuracy of orientation of WA panorama is coupled with the angular resolution of the NA lenses (see table 1). As example, with the camera used in our experiments, Canon EOS 450D, having the image width $a=4272$ pixel (figure 13) and a lens of focal length of 500 mm, one pixel corresponds to $2''$, thus obtaining a very good resolution, equivalent to a first class theodolite (figure 18).

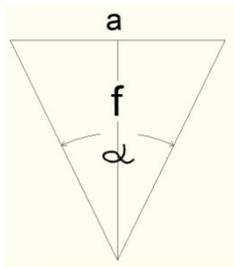


Figure 13 -

| | | | | |
|----------------|---------|---------|--------|--------|
| f (mm) | 28 | 50 | 200 | 500 |
| f (pixel) | 5500 | 10000 | 38000 | 93000 |
| α (gon) | 42° 44' | 24° 10' | 6° 35' | 2° 40' |
| Ifov | 36" | 20" | 6" | 2" |

Table 1 – Angular resolution of one pixel



Figure 14. Saint Yves at La Sapienza – Rome – 28mm image of the weathercock

5.1 The survey of the Saint Yves in Rome and Holy House Shrine in Loreto.

They are two noticeable examples of baroque style; the first church was designed by F.Borromini in the half of 17th century and the other one by L.Vanvitelli less than one century later. For the survey of the of Saint Yves church in Rome 16 panoramas have been taken outside an 8 inside; in three station points, three different focal lenses have been used, 28, 50 and 200 mm to survey the top of the bell tower. The top of the bell towers are rather distant from the station points, from 70 m to 100 m about. The resolution of the WA panorama is not suitable for the accurate plotting, so also NA lenses have been used, 200mm, and 500mm. For the orientation of long focal the selfcalibration with the constraints have been used in a block bundle adjustment. A similar procedure has been followed for the survey of the top of the bell tower of Holy House Shrine in Loreto, Italy, where 50, 200, 500mm have been chosen. In table 2 the comparison between the adjustment without selfcalibration and geometrical constraints a) and with b) for three panorama, in Saint Yves and in Loreto. The standard deviations in all the three directions reduce by one order of magnitude in the first case, in the second one they reduce but not so much.



Figure 15.
 Saint Yves at
 La Sapienza
 – Rome –
 50mm image
 of the
 weathercock



Figure 16. Saint Yves at
 La Sapienza – Rome –
 200 mm image of the
 weathercock. The three
 image in figures are
 taken from the same
 point using three
 different lenses 28mm,
 50mm, 200 mm

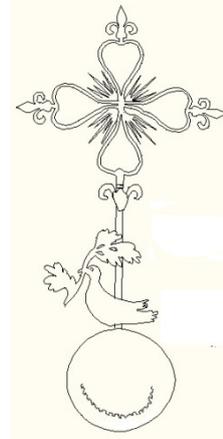


Figure 17 (right) – The plotting
 of the weathercock of Saint Yves
 at La Sapienza , Rome (detail)

Saint Yves s.d. (m) no calibration Vs selfcalibration + constraints
(200mm)

| N. Pano | σ_x (m) | σ_y (m) | σ_z (m) |
|-------------|----------------|----------------|----------------|
| 7 | ± .301 | ± .342 | ± .236 |
| 8 NO SELF | ± .229 | ± .298 | ± .190 |
| 9 NO CONSTR | ± .286 | ± .389 | ± .182 |
| 7 | ± .046 | ± .038 | ± .022 |
| 8 SELFCAL | ± .052 | ± .037 | ± .024 |
| 9 + CONSTR | ± .067 | ± .046 | ± .029 |

LORETO s.d. (m) no calibration Vs selfcalibration + constraints
(500mm)

| N. Pano | σ_x (m) | σ_y (m) | σ_z (m) |
|-------------|----------------|----------------|----------------|
| 7 | ± .589 | ± .541 | ± .327 |
| 8 NO SELF | ± .699 | ± .708 | ± .415 |
| 9 NO CONSTR | ± .352 | ± .336 | ± .092 |
| 7 | ± .331 | ± .331 | ± .149 |

| | | | | |
|---|----------|--------|--------|--------|
| 8 | SELF CAL | ± .294 | ± .294 | ± .095 |
| 9 | + CONSTR | ± .021 | ± .312 | ± .020 |

A detail of the plotting is shown in figure 17. In figure 18 the 500 mm panorama of the Loreto Church, taken from a slop distance of about 100m. Note the richness of detail.



Figure 18 - Loreto – Holy House Church – The top of the bell tower – 500 mm focal length.

CONCLUSIONS

One of most desired feature for a close-range architectural photogrammetry is the flexibility and efficiency. Spherical photogrammetry proved to be fast, reliable, enough accurate. To improve the efficiency and the accuracy, the photoscale has to be adequate to the object distance. For the fairest points Narrow Angle lenses are the most suitable lenses, limiting the FOV of the panorama to a few degrees. The geometry of the NA panorama is unfortunately weak in comparison with the WA one. The bad estimation of the focal lens and of the station point can spoil the accuracy of the plotting, as it is shown in the orientation errors section. Two types of panorama have to be taken from the same point, one WA and another one with NA. The described procedure of self-calibration with the imposition of the coincidence of the station points brings to a better orientation, taking full advantage of the NA resolution.

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