INVESTIGATION ON THE SUITABILITY OF THE SPHERICAL PANORAMAS BY REALVIZ STITCHER FOR METRIC PURPOSES

Gabriele Fangi -

Università Politecnica Marche, Ancona – Italy   g.fangi@univpm.it

Commission V

Key Words: Spherical panoramas, Interpolation, panoramic images, 3D panoramic recording, panoramic images calibration, theodolite, simulation

ABSTRACT:

Commercial software of digital photography, realizing cylindrical or spherical panoramas, are becoming popular. They are delivered for tourist and documentary use. For instance they are suitable for quick documentation of field excavations in archaeology. In fact their principal application consists in the realization of active explorations known as QTVR (Quick Time Virtual Reality). It has already been proved that these panoramic images also have a metric use (Luhmann, 4, 2004), (Szelisky,Kang, 15,2001). The 3D final reconstruction of object is performed by bundle adjustment of multi-station panorama. Normally rotating cameras are used instead of mosaics (Schneider, Mass, 2204). The advantage of the stitching software consists in its economy compared to the rotating cameras. The analogy between surveying and photogrammetry is in the case of the spherical panoramas almost perfect. In fact the panoramic photos are produced for projection on a sphere of the photographs having as centre of common projection the centre of the sphere (Szelisky,12,1997). Then the sphere is mapped in the image plane by the so-called longitude-latitude projection. The image points can be regarded as analogical recording of the angular observations of a theodolite having its centre in the centre of the sphere. The spherical panorama can have a field of view up to 360°x360°. They could be the ideal "theodolite". Nevertheless the camera cannot be set correctly as a theodolite. It is necessary therefore to recover two angles to set up vertical the axis of the sphere as the bi-axial compensator in a theodolite. The estimate of the angular corrections is done by means of known directions or known coordinates of points (control directions and control points), obtained by traditional theodolite, or finally with geometric constraints as horizontality or verticality of straight lines. In order to evaluate the effects of a non perfect verticality of the principal axis of the spherical panorama, a computer programme has been written, following the steps: 1) creation of a set of points laying in the unit sphere regularly spaced along meridians and parallels; 2) projection of the points in the "cartographic" plane by the latitude-longitude projection; 3) rotation of the sphere alternatively about x and y axes of small rotation angles; and monitor the shifts of the projected points in the cartographic plane; 4) back estimation of the rotation angles; 5) angular correction. However the angular corrections are not still sufficient to guarantee a reasonable accuracy in the final 3D object compilation. The formation of the mosaic of photos doesn't happen without noises. The errors have nevertheless an evident systematic behaviour and they can be filtered out with interpolation polynomials whose parameters are estimated in correspondence of control points. For this reason the network of control points has to bee quite dense. When the terrain coordinates of the panorama centre are known, the correct image position for the control points is known, that we can compare with the actual position in the image, knowing the correction vector for any control point. Therefore the correction of the observed points in the panoramic image takes place in two steps: correction for rotation, with the estimated correction angles, then further correction computed by interpolation with the corrections estimated in the nearest control points giving a Gaussian weight to the control points. We present and comment some experiences of spherical panoramas produced with the software Stitcher 4 ®, by Realviz. The lens distortion is already corrected by the mosaicing software itself. But the main problem still consists in the noise occurring during the formation of the mosaic. There are different causes for the noise, the moving clouds in the sky, the persons and the traffic moving in the scene, the non perfect interior orientation parameters of the camera, the camera projection point off set from the rotating axis. The discussed examples are the panoramas taken 1) in Ancona the university campus, 2) Piazza del Popolo in Ascoli town, 3) Piazza del Campo in Siena. The used camera was an amatorial 35mm equivalent digital camera of 3 mb resolution. The panoramas have resolution of 10000x5000 pixel. Any pixel corresponds to 0.04 g, which is not a very high accuracy. The results are encouraging as far as control points is concerned. For example, in Piazza del Campo, a valid test area, having dimensions ranging from 100 to 150m in plan and 100 in height (the municipality tower), we took four panoramas, and with a reflectorless theodolite we surveyed 135 control points. The RMS of the residuals are 0.027 in planimetry and 0.009 m in height over 108 control points, observed at least in three panoramas whilst for the plotted points the results are not so good, the RMS of sigma naught are 0.16 m in planimetry and 0.05 m in altimetry for 358 points over a total amount of 385, and we had to discard the remaining 27. Similar results we got for the other test fields. So far the results are only partly satisfactory. There are still improvements to be performed: improve the resolution of the panorama, improve the quality of the stitching algorithms, improve the efficiency of the interpolation procedure.

1. Introduction

The spherical panorama are becoming more and more popular. They can be produced by rotating line cameras, or in a more economical way, by stitching software of multi-image digital camera stations. While for metric purposes rotating line camera are mostly used, the multi-image spherical panorama are commonly used for tourist purposes, for documentation for Quick Time exploration of virtual model. The main use of the multi-image panoramas of scene conceived in 1994 by R.Szeliski, is in the exploration of the QuickTime Virtual Reality. The question is now: can multi-

image panorama obtained with commercial software be used also for object 3d-model reconstruction and to which conditions? In our case the tested software was Realviz Stitcher ver.4. Rotating line cameras produce regular cylindrical panoramas that are adjusted in block bundle adjustment (Schneider,Maas,8,9,2004), using few control points and few tie points. The spherical panorama are possibly coupled with laser scans (Scheibe et al., 7,2004), (Haagren et al. Strackenbrock, 11,2005), or projected in a plane to get a rectified photomosaics (Haggren, et. al., 2 ,2004). Commercial software has nice features, because of their ease and attractiveness. They are continuously updated. If they are proved to have a metric value, we can have a powerful, nice tool at a very low price. Here we follow a "geodetic" approach for 3d object reconstruction.

1. The multi-image panoramas of scene

The mosaics of scene are gotten with a series of photos having the same focal, taken from the same point of view, gotten through rotation of the camera, about its projection centre. The adjacent frames have an overlap allowing them to be stitched together. The only geometric condition is the constancy of the projection centre and of the camera focal length. The principles are the followings:
- 1) if the projection centre 0 of the series of photos is always the same, then the same point P imaged in the different photos (P' in image f_1 and P'' in f_2) always lies on the same projective ray r (figure 1);
- 2) in this way all the points are projected on a sphere of arbitrary ray r having its centre in the projection centre 0 (figure 2). Every point is located by two spherical coordinates, respectively the horizontal direction θ and the zenital angle φ (figure 3).
Then every point of the sphere is mapped in a planar projection called latitude-longitude projection.

Figure 1 – *The projection on a sphere of overlapping photographs*
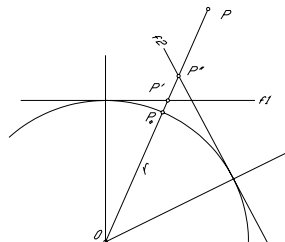
2. The principal distance estimate and the closure of a panorama

It is possible to estimate the interior camera parameters. Closing a 360° panorama will result in a closure error ξ . Then the correct principal distance f' will be

$$f'=f.(2.\pi-\xi)/\pi \qquad (1)$$

where f is an approximate value. For a full review see (Szelinsky, Shum, 13, 1997). The advantage consists in the possibility to carry out a full 360° documentation in a very simple and quick way. The stitching programme estimates the interior orientation parameters, including the radial distortion.
Notations:
X_P, Y_P, Z_P terrain coordinates of the point P
X_0, Y_0, Z_0 terrain coordinates of the projection centre 0
x', y' image coordinates of the point P in the plane projection of the sphere
x^*, y^*, z^* spherical coordinates of the point P_o , projection of P into the sphere
x, y, z corrected spherical coordinates parallel to the terrain system

Figure 2 – *Projection of an image into a sphere centred in the photographic centre*

1 . The transformations
A point P' laying in the sphere of radius r, has 3D spherical coordinates (figure 3):

$$x^* = r.\sin\varphi.\sin\theta \qquad ...$$
$$y^* = r.\sin\varphi.\cos\theta \qquad (2)$$
$$z^* = r.\cos\varphi \qquad ...$$

3. The latitude-longitude projection

An arbitrary point P in the plane projection, has coordinates

$$x' = r.\theta \qquad y'=r.\varphi \qquad (3)$$

being the angles expressed in radiant.
1. Computation of the radius r of the sphere: we are given the plan image of the multi-image spherical panorama, produced by the software.
The width a of the image is equal to the diameter of the sphere, from which one can compute the value of the radius

$$r = a /2\pi \qquad (4)$$

2. Transformation of the plane coordinates (3) in angular values

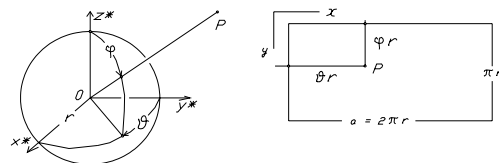$$\theta = x'/r \qquad \varphi = y'/r \qquad (5)$$

**Figure 3** – *The latitude-longitude projection.*

4. The correction of the angular attitude of the spherical panorama

The panoramic photos can be regarded as analogical recording of the angular observations of a theodolite having its centre in the centre of the sphere. Nevertheless the camera cannot be set correctly as a theodolite. It is necessary therefore to recover two angles to set up vertical the axis of the sphere. The estimate of the angular corrections it is done by means of known directions or known coordinates of points (control directions and points), obtained by traditional tachymetry, or finally with geometric constraints as horizontality or verticality of straight lines.

4.1. Control directions

Placed a theodolite in the centre of the spherical panorama (in practice the centre of the theodolite is put in the projection centre of the camera), the angular directions φ and θ are measured to the same points where the coordinates image x and y through eqns. (4) and (5) the corresponding angular directions are derived φ' and θ'. The uncorrected coordinates x^*, y^*, z^* on the sphere of the panorama are obtained by eqns. (2). With (2) one can also compute the correct spherical coordinates x, y, z with theodolite directions φ and θ

Figure 4 – *The three angular corrections*
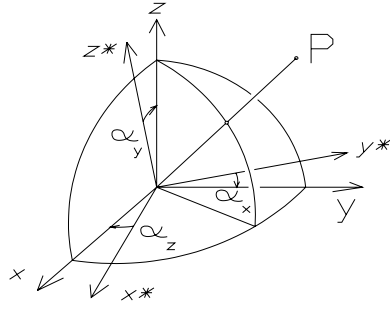
To pass from coordinates x^*, y^*, z^* to the correct ones x, y, z, a rotation $R(\alpha_x, \alpha_y, \alpha_z)$ has to be applied. When the rotations are small:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} 1 & \delta\alpha_z & -\delta\alpha_y \\ -\delta\alpha_z & 1 & \delta\alpha_x \\ \delta\alpha_y & -\delta\alpha_x & 1 \end{bmatrix} \cdot \begin{bmatrix} x^* \\ y^* \\ z^* \end{bmatrix} \quad (6)$$

Re-ordering:

$$\begin{bmatrix} 0 & -z^* & y^* \\ z^* & 0 & -x^* \\ -y^* & x^* & 0 \end{bmatrix} \begin{bmatrix} \delta\alpha_x \\ \delta\alpha_y \\ \delta\alpha_z \end{bmatrix} = \begin{bmatrix} x-x^* \\ y-y^* \\ z-z^* \end{bmatrix} \quad (7)$$

For any observed points three equations can be written in three unknowns. An example is given in 7.1.

4.2 Control Points

The angular corrections can be estimated knowing the correct position x_P, y_P of the control points in the images. These "true" image coordinates can be obtained since the terrestrial coordinates are known
- of the panorama centres X_0, Y_0, Z_0
- of the control points X_P, Y_P, Z_P

The scale coefficient λ is known: $\lambda(P_i)=d/r$ (8)
as ratio between the radius of the sphere r and the known distance d to the point P

$$d=((X-X_0)^2+(Y-Y_0)^2+(Z-Z_0)^2)^{0.5} \quad (9)$$

Keeping in mind the similar triangles (in practice collineary equations, figure 5), we have:
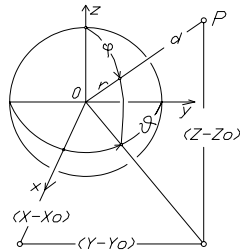
$$x=r(X-X_0)/d; \quad x=r(Y-Y_0)/d; \quad x=r(Z-Z_0)/d \quad (10)$$

Eqns (7) then become:

$$\begin{bmatrix} 0 & -z^* & y^* \\ z^* & 0 & -x^* \\ -y^* & x^* & 0 \end{bmatrix} \begin{bmatrix} \delta\alpha_X \\ \delta\alpha_Y \\ \delta\alpha_Z \end{bmatrix} = \begin{bmatrix} \frac{r}{d}(X-X_0)-x^* \\ \frac{r}{d}(Y-Y_0)-y^* \\ \frac{r}{d}(Z-Z_0)-z^* \end{bmatrix} \quad (11)$$

The $\delta\alpha_z$ can be omitted because it is included in the zero orientation bearing θ_0 of the camera.

Figure 5 – *The colinearity of the object point with the centre of the sphere, and the point on the sphere*

4.3 Geometrical constraints
To get the corrections of rotations it is possible to make use of geometrical constraints.

4.3.1 Verticality condition

When two points P_1 and P_2 lay in the same vertical line for them $X_1=X_2$ e $Y_1=Y_2$: subtracting the first two eqns relative to the two points, eqns (11), omitting $\delta\alpha_z$:

$$\delta\alpha_x=(y_2^*-y_1^*)/(z_1^*-z_2^*)$$
$$\delta\alpha_y=(x_2^*-x_1^*)/(z_2^*-z_1^*) \quad (12)$$

the terrain coordinates X, Y, Z disappear, and therefore it is not necessary to known any terrain point, included the camera station.

4.3.2 Horizontality condition
If two points P_1 and P_2 have the same elevation $Z_1=Z_2$: by subtracting the third equation, another condition equation is supplied where again X, Y, Z disappear and therefore it is not necessary again to know any terrain coordinate

$$\begin{bmatrix} -(y^*_1-y^*_2) & (x^*_1-x^*_2) \end{bmatrix} \cdot \begin{bmatrix} \delta\alpha_x \\ \delta\alpha_y \end{bmatrix} = \begin{bmatrix} -(z^*_1-z^*_2) \end{bmatrix} \quad (13)$$

The coordinates x^*, y^*, z^* are then transformed by rotation (6) with the estimated angles into the corrected coordinates x, y, z. Finally the correct directions are obtained then by:

$$\varphi = acos(z/r) \qquad \theta = atan(x/y)\pm n\pi \quad (14)$$

5. Simulation of the procedure

To check the correctness of the procedure, a simulation program has been written, performing the following steps:
a. create a net of regular points laying on a sphere, along meridians and parallels:
b. create the plan map projection latitude-longitude of the points;
c. give a small rotation about x (y) axis, and create the corresponding longitude-latitude map and observe the shifts of the points (figures 6, 7);
d. estimate back the angular corrections according to point 4.1 or 4.2;
e. apply the corrections;
f. create the longitude-latitude map of the corrected points and compare it with the one b.

Figure 6 – *The ideal sphere after small rotations about x and y axes*
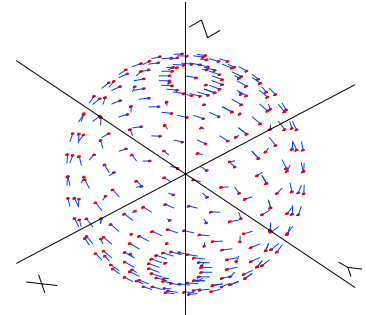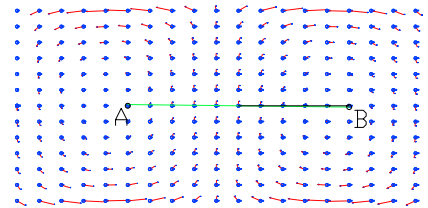

Figure 7– *The typical pattern of (exaggerated) shifts of points of the ideal sphere due to small rotation about y axis.*

The two centres of rotations A and B are the representation of the diameter about which the rotation takes place. The length AB is half of the total width of the plan image (figure 7). (figure 8). This typical pattern of shifts for the control points has been observed in almost any real spherical panorama produced by Stitcher Realviz.
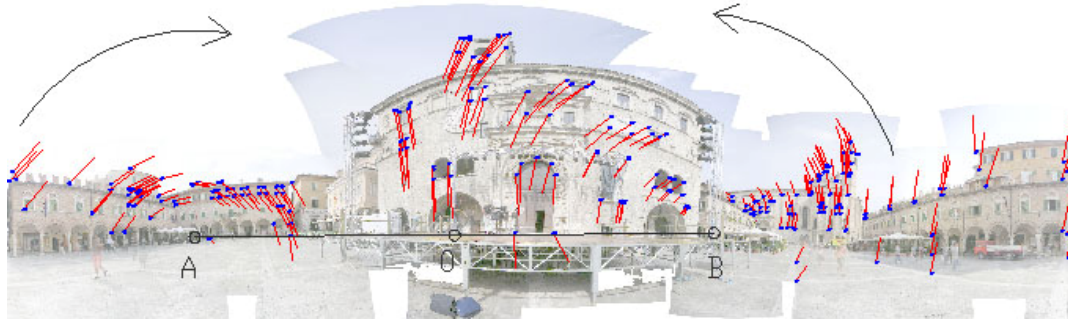
Figure 8: *Ascoli Piceno, Piazza del Popolo. Resolution 15000x7500 pixels. The typical pattern of the errors on the control points due to rotations $\delta\alpha_x$ and $\delta\alpha_y$ about the horizontal axes x and y. In red the amplified original errors on the control points, in blue the remaining errors after the correction of rotations. After the polynomial correction the image points in practice coincide with their correct position*

6. Polynomial corrections to the image observations

After the corrections of rotation, it is necessary to apply further corrections to the image coordinates of the panorama points. The formation of the mosaic of photos doesn't happen without noises (figure 9).

Figure 9 – *The ghosting effects, normally they are particularly evident in the border regions.*

In our experiences some unmistakable errors remain whose entity makes the spherical images to be difficult to use. Luckily the errors have an evident systematic behaviour. The control points are projected on the sphere of the panorama and then mapped in the projection plan of the latitude-longitude through the (3), getting the correct position x_P, y_P. The corrections of an arbitrary point are estimated by polynomial interpolation.

The image corrections *dx* and *dy* of an arbitrary point are estimated by simple interpolating polynomials functions on the nearest control points as follows:

$$dx = x_p - x' = a_0 + a_1.x' + a_2.y'$$
$$dy = y_p - y' = b_0 + b_1.x' + b_2.y' \qquad (15)$$

The weight of the observations is inverse with the squared distance to the control points.

$$w_i = w_0 / e^{d*d} \qquad (16)$$

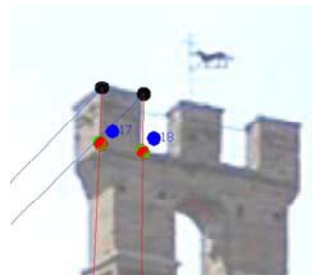The point is forced to move towards its correct position.

Figure 10 – *In black the original image points, in green their correct position, in blue after the correction for rotation, in red after the polynomial correction*

7. The Experiments

We present the results of the following experiments:
- The university campus
- Piazza del Popolo in Ascoli Piceno
- Piazza del Campo in Siena

The camera was a Konika-Minolta XG 3mb resolution.

7.1 The University campus

In the university campus we made three panoramas with resolution 10000x5000 pixels.. With a theodolite we measured 40 control directions and we compared them with the ones derived from the spherical images. In table 1 the results of the comparison. The differences are mean absolute value and expressed in grades. In fig. 11 one of the three panoramas. The largest errors occur in vertical directions, the correction for rotation is valid but sufficient

Table 1 – *Angular Differences Image VS theodolite (g)*

Stat.	Horizontal directions			Vertical Angles		
	a)	b)	c)	a)	b)	c)
S1	0.158	0.057	0.004	0.368	0.064	0.022
S2	0.143	0.078	0.002	0.206	0.159	0.010
S3	0.216	0.047	0.003	0.833	0.072	0.050
mean	**0.172**	**0.078**	**0.003**	**0.469**	**0.098**	**0.027**

a) Original differences
b) After correction for Rotations
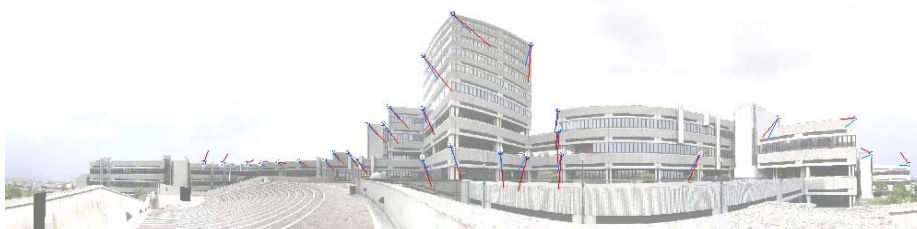c) After Polynomial Correction

Figure 11 – *Ancona Faculty Campus. In red the original errors, in blue the errors after the correction for rotations. Resolution 10000x5000*

7. 2 Piazza del Popolo in Ascoli Piceno

We made four panorama and we surveyed 205 control points. The results of the orientations of the images are on tables 2 and 3 (figure 8). With :
a) mean distance (correct position – actual position) pixel
b) "   "   after the correction of rotation
c) "   "   after polynomial correction
d) number of control points

Table 2 – *Errors on the Control Points (in pixels)*

panorama	a).	b)	c)	d)
1	23	14	0.9	120
2	46	7	2.6	100
3	37	4	1.5	75
4	38	18	4.0	93
5	13	6	1.5	116
6	58	10	0.7	107
Average	**36**	**10**	**1.9**	

(cm)	0-1	1-2	2-3	3-4	4-5	5-7	7-9	9-13	13-20	20-50
dr	49%	10%	5%	3%	2%	4%	3%	5%	2%	5%
dz	82%	4%	2%	1%	2%	1%	1%	2%	2%	4%

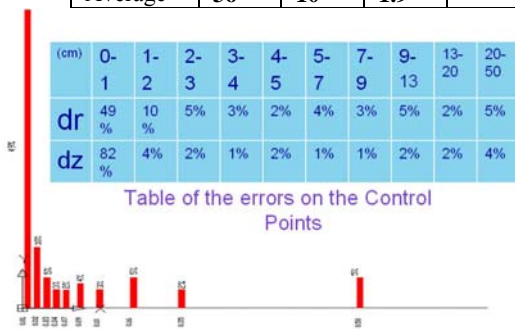Table of the errors on the Control Points

Table 3 – *Ascoli , Piazza del Popolo. The frequency of errors on the Control Points*

After the two described image corrections, 3d object coordinates of the control points by intersection of projective rays, have been computed and compared with the known "true" coordinates, regarded as error free. Over 202 control points 49% have a planimetric error *dr* of less than 1 cm and 82% less than 1 cm in altimetry. Only 12% have an error bigger than 10 cm in planimetry and 8% in altimetry (Table 3).

7. 3 Piazza del Campo in Siena

Piazza del Campo a Siena is a very wide square with size of about 300x250 m and it has a shell shape form, it has a tower 87 m of height, so we tough that it could have been a good field test (figures 9,10,12). We formed four spherical panoramas from different positions: we surveyed by traditional theodolite techniques 135 control point and the four cameras station points. The results of the orientation and correction of the four panoramas are synthesized in Table 4. With:
a) mean distance (correct position – actual position) pixel
b) "   "   after the correction of rotation
c) "   "   after polynomial correction
d) number of control points
e) number of discharged observations

Table 4 – *Errors on the Control Points (in pixels)*

panorama	a).	b)	c)	d)	e)
1	17	14	0.5	94	11
2	7	16	0.4	106	21
3	31	21	0.2	97	15
4	22	16	0.6	75	50
average	**19**	**17**	**0.4**		

The mean distance from the actual image point to its correct position is 19 pixels. Differently from the case of Piazza del Popolo, after the correction of the rotations the mean error is reduced only to 17 pixels. Not only the improvement is very little, but also the second panorama worsens. This can be easily explained since the stitching software itself has a tool for the vertical alignment. Finally the polynomial correction makes the error to be less than 1 pixel for all the panoramas.
The RMS of the differences are 0.027 in planimetry and 0.009 m in height for the 108 control points observed at least in three panoramas whilst for the plotted points the RMS of sigma naught are 0.16 m in planimetry and 0.05 m in altimetry for 358 points over a total amount of 385, and we had to discard the remaining 27. For the 3d-object evaluation we use normal geodetic software for adjustment for networks. The network was adjusted with least constraints (Fangi, 1, 2004). Of the four panoramas we had to discard some observations affect by gross errors. The different quality of the four panoramas is evident: while in the first panorama the discharged observations are only 11, in the fourth 50 observations had to be cancelled. The a-posteriori σ_0 is 17.7×10^{-4} rad = 0.11 g, while the initial resolution is 1pixel = 0.03 g = 4×10^{-4} rad, that can be regarded as a-priori σ_0. It is very important to be able to consider separately every observation one-by-one to check its correctness, which is not a-priori guaranteed due to the effects of the possible deformations of the panorama, to separate the good observations from the wrong ones. Therefore any point must be visible in at least three panoramas. As last test we used 14 CP as check points taking them out from the image orientation, and comparing their computed coordinates with the "true" ones. The average of the absolute value of the differences are dx = 0.10m, dy = 0.09 m and dz = 0.34m.

8. The ArcGis correction

We tried to use the gereferencing functions of ArcGis to correct the map image from its actual position to a new correct one employing the control points. But we did not find any meaningful quality improvement and moreover we got a problem in the tails of the image. The two tails were deformed by the software and they were not more coinciding as they should have been (figure 13). The RMS of the errors on the control points are identical in planimetry to the ones of 7.3 (unmodified images), whist in altimetry the results worsen from 0.009 m to 0,023m.

Figure 12: *Piazza del Campo, Siena. Resolution 15000x7500 pixels. The pattern of the amplified errors on the Control Points, in red the original ones, in blue after the correction of the rotations. With the further polynomial correction the image points in practice coincide with their correct position*

9. The ROTA routine

We wrote a routine to correct the original images with the estimated rotations. We did not find any real quality improvement. The only practical result was that the corners in the image became vertical (see the corners of the tower, figure 14).

Figure 13 - *The correction with georeferencing function of ArcGis. The two tails of the image are deformed and they are no more coinciding as they should be*
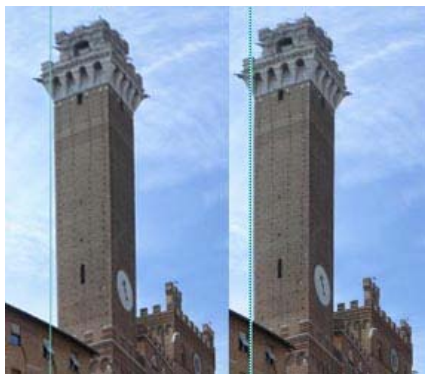
Figure 14 – *On the left the original image (detail). The corners of the tower are not vertical. After the correction for rotation the corners are now vertical*

Conclusions

The correction of the image coordinates in a two steps procedure (rotation-polynomial) is proved to be a valid approach to allow 3d object reconstruction, provided a sufficient quantity of control information. The multi-image spherical panoramas can be utilised for measurements, although there are still some improvements to be done to reach a better accuracy: increase the image resolution from the actual limit of 15000x7500, improve the stitching algorithms, (with the complete removal of the doubling effects) and improve the interpolation algorithm. The spherical panorama have a field of view up to 360°x360°, including any visible point: for this reason they could be the ideal image. Multi-image panoramic images are excellent synthetic view, are easy to perform, have low cost, have the same coverage of many traditional photogrammetric models. An interactive evaluation procedure, enabling the check of the results during the observations, would be very effective.

Acknowledgements

References

(1).G. Fangi (2004) - *Block Bundle Adjustment for Theodolite Stations in Control Networks - The case of the Guggenheim musuem in Bilbao*, - ISPRS Archives vol. XXXV part B5, pg 372-376 17(3):1–11, July 1983.

(2) H.Haggrén, H. Hyyppä, O. Jokinen, A. Kukko, M. Nuikka, T. Pitkänen, P.Pöntinen, R. Rönnholm (2004) – *Photogrammetric Application of Spherical Imaging* - Panoramic Photogrammetry Workshop, Dresden 19-22 February 2004 – ISPRS Archives Vol. XXXIV, part 5/W16

(3) T. Luhmann (2004) – *A Historical Review on Panorama Photogrammetry* - Panoramic Photogrammetry Workshop, Dresden 19-22 February 2004 – ISPRS Archives Vol. XXXIV, part 5/W16

(4) T.Luhmann, W. Tecklenburg (2004) – *3-D Object Reconstruction from Multiple-Station Panorama Imagery* - Panoramic Photogrammetry Workshop, Dresden 19-22 February 2004 – ISPRS Archives Vol. XXXIV, part 5/W16

(5) T.Luhmann, W. Tecklenburg (2005) – *High-Resolution Image Rectification and Mosaicing – A comparison between Panorama Camera and Digital Camera* - , Berlin, Panoramic Photogrammetry Workshop, 24-25 February 2005 – ISPRS Archives Vol XXXVI-5/W8

(6) J.A.Parian, A.Gruen (2004) – *An Advanced Sensor Model for Panoramic Cameras* – ISPRS Archives Vol XXXV (B5) pp 24-29

(7) K.Scheibe, M.Scheele, R. Klette (2004) – *Data Fusion and Visualization of Panoramic Images and Laser Scans* - Panoramic Photogrammetry Workshop, Dresden 19-22 February 2004 – ISPRS Archives Vol. XXXIV, part 5/W16

(8) D.Schneider, H.-G. Maas (2004) – *Application and Accuracy Potential of a Strict Geometric Model for rotating Lines Cameras* – Panoramic Photogrammetry Workshop, Dresden 19-22 February 2004 – ISPRS Archives Vol. XXXIV, part 5/W16

(9) D.Schneider, H.-G. Maas (2005) – *Combined Bundle Adjustment of Panoramic and Central Perspective Images* – , Berlin, Panoramic Photogrammetry Workshop, 24-25 February 2005 – ISPRS Archives Vol XXXVI-5/W8

(10) H. Shum and R. Szeliski . *Construction of Panoramic Image Mosaics with Global and Local Alignment*. In ICCV Vol. 36(2), pages 101-130, 2000.

(11) B.Strackenbrock, B.Tsuchiya, K. Scheibe (2005) - *3D-Modelling and Visualisation fram 3D-Laser Scans and Panoramic Images* - , Berlin, Panoramic Photogrammetry Workshop, 24-25 February 2005 – ISPRS Archives Vol XXXVI-5/W8

(12).R. Szeliski.(1996) *Video Mosaics for Virtual Environments*. In IEEE Computer Graphics, Volume 16(2), pages 22-30.

(13) R. Szeliski and H. Shum. (1977) *Creating full view panoramic image mosaics and environment maps*. In Proc. of SIGGRAPH, pages 251-258.

(14) H.Shum, R.Szeliski (2001) – *Construction of Panoramic Image Mosaics with Global and Local Alignment* in Panoramic Vision, Springer, N.York 2001

(15) S.B.Kang,R.Szeliski, (2001) – *3D environment Modeling from Multiple Cylindrical Panoramic Images*, in Panoramic Vision, Springer, N.York 2001

(17) Realvitz Stitcher Manual, http://www.realviz.com