THE SOLID IMAGE: a new concept and its applications

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ABSTRACT:

A photo image can be considered a central perspective of the acquired object with good approximation. If the internal and external orientation of the camera are known, in case of a digital image it is possible to establish the direction in the space of each object point represented by a pixel in the image. If only one image is available, it is impossible to determine the spatial X,Y,Z position of such object points, because the simple direction is insufficient: all the points along that direction would give the same image point.
By means of a dense digital elevation model (DDEM) of the acquired object, every pixel (and therefore every direction in the space) can be associated to the value of distance between the centre of perspective and the object point represented by the pixel itself. In this way each pixel can be referred to the 3D position of the corresponding object point in an absolute reference system.
The DDEM can be derived from an existing map or by the use of surveying instruments and procedures. Recently, a series of new instruments, based on the laser technology, have been introduced on the market, giving the possibility to obtain a DDEM in a quick and cheap way.
The integration of the DDEM geometric data with the image radiometric data suggests a new concept: the “solid image”.

1. INTRODUCTION

An image can be considered a central perspective of the photographed object. If internal and external orientation are known it is possible, for every pixel of the image, to determine the direction of its projecting ray in the space. If only one image is available, that direction is insufficient to reconstruct the 3D position of the object point (i.e. its X, Y and Z coordinates). In fact, all the points positioned along that direction in the space would give the same pixel on the image.
The recent introduction in the market of laser scanner sensors in the field of survey instruments allows dense digital elevation models (DDEM) of the object to be obtained.
The integration of the laser scanner data with the digital image data can give the possibility of associating a value of distance to every direction in the space, defined by each pixel. This distance is calculated as the distance from the perspective central point (the “taking point”) and the object point represented by the pixel. If two angles defining a direction in the space and the above mentioned distance are known (these 3 figures are called “spherical” or “3D polar” co-ordinates), it is easy to reconstruct the spatial position (i.e. the X,Y,Z co-ordinates) of every point repre-sented in the image.
The traditional RGB radiometric data of the image together with a 3D model acquired by the laser scanner lead to a new concept: the “solid image”.
Advantage and potentials of this innovative product are due to the possibility of:

- getting the spatial position of points in the object reference system;
- direct and easy carrying out of correct 3D measurements on the image;
- obtaining a great deal of information in a simple and rapid way, using the high quality original images and any traditional photo viewer software available on the market.

Based on the solid image, it is possible to foresee several new applications: a second image of a stereoscopic pair can be created, a RGB coloured virtual 3D model can be carried out, etc.

2. THE SOLID IMAGE

2.1 Definition

A “true colour” digital image is made up of 3 matrixes, named R, G and B, each one containing one of the 3 fundamental colours (Red, Green or Blue).
The solid image, in addition to a classical digital image, records the distance values of the represented points from the taking centre. Assuming that the digital image is a central perspective of the photographed object and the internal and external orientations of the image have been determined, the spatial position is completely given, for each pixel, if the distance between the perspective centre and the photographed object point is known. This information is stored in an additional matrix that has the same size as the RGB ones (in terms of rows and columns). Therefore a “solid image” consists of a 4 level matrix: **RGB** and distances **d** (see Fig. 1).
The information on the spatial position of the photographed object points is obtained using a dense 3D model (DDEM), easily acquired by a laser scanner. To obtain a correct solid image, the laser scanning and the photo should be taken from two points not too far each other, in order to avoid hidden areas in the image, where the laser scanner is unable to determine the distance from the perspective centre and the object points.

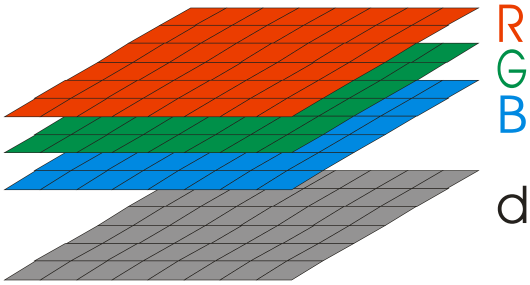


Figure 1. Structure of the solid image

For the purpose of building solid images, a specific software has been developed in Visual Basic 6.0.

2.2 Image calibration

In order to fill the matrix "d" with a correct value of the distance to every pixel, it is necessary to calibrate the image. The calibration process consists of the estimation of the internal orientation parameters of the camera. In architectural surveys, often cameras are not metric. In this case, the lens distortion parameters have to be determined.
This can be achieved by measuring the image coordinates for a sufficient number of points, the object coordinates of which are known (control points). The procedure can be completely automatic if a laser scanner is used for this purpose.
Some reflecting targets are placed on the object. The laser scanner is able to measure, in addition to the 3D point positions, the reflectivity of the object. Special reflecting targets (*markers*) have the property to almost totally reflect the laser pulse, while natural points do not do the same. If the marker size and their mean reflectivity are known, it is easy to determine the marker's position in the laser DDEM and in the image, in a completely automatic way. Once the marker's position is defined, one can estimate the calibration parameters of the camera and its external orientation by using a bundle solution.

2.3 Projection of the cloud of points

If the internal and external image orientation parameters are known in the object reference system, it is possible to project the DDEM ("cloud of points") onto the digital image. The mathematical model used for this operation is the central perspective model. The components $\Delta\xi$ and $\Delta\eta$ that represent the radial distortion are added to the collinearity equations:

$$\xi=\xi_0+\Delta\xi-c\frac{r_{11}(X-X_0)+r_{21}(Y-Y_0)+r_{31}(Z-Z_0)}{r_{13}(X-X_0)+r_{23}(Y-Y_0)+r_{33}(Z-Z_0)}$$
$$\eta=\eta_0+\Delta\eta-c\frac{r_{12}(X-X_0)+r_{22}(Y-Y_0)+r_{32}(Z-Z_0)}{r_{13}(X-X_0)+r_{23}(Y-Y_0)+r_{33}(Z-Z_0)} \qquad (1)$$

The distortion components are modelled by:

$$\Delta\xi=(\xi-\xi_0)\cdot\left(k_1\cdot\rho^2+k_2\cdot\rho^4+k_3\cdot\rho^6\right)$$
$$\Delta\eta=(\eta-\eta_0)\cdot\left(k_1\cdot\rho^2+k_2\cdot\rho^4+k_3\cdot\rho^6\right) \qquad (2)$$

where ρ is the distance from the centre of the image (radius) and k_1, k_2, k_3 are the radial distortion parameters. Other types of distortion have not been considered.

2.4 Interpolation of the distance matrix

The density of the pixels in the digital image is usually greater than the density of the cloud of points obtained by the laser scanner device. For this reason, when the laser points are projected onto the digital image, the distance matrix it is not completely filled in every pixel position: the values of distance are associated only to some pixels.
In order to obtain a complete distance matrix it is necessary to integrate the missing values with an interpolation procedure.

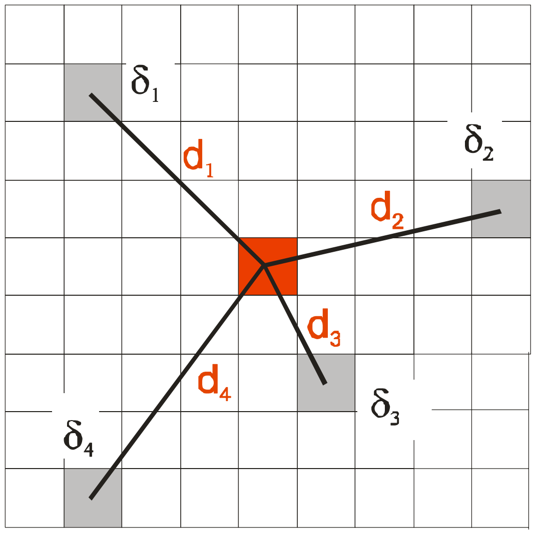


Figure 2. Interpolation of the distance matrix

The "average weighed method" has been used. The four nearest pixels, which the value of distance is known, are considered.
The computation of the interpolated value of distance is carried our by the formula:

$$\delta_{i,j}=\frac{d_1\cdot\delta_1+d_2\cdot\delta_2+d_3\cdot\delta_3+d_4\cdot\delta_4}{d_1+d_2+d_3+d_4} \qquad (3)$$

where **i,j** are the indexes of the current pixel, **δ** are the distance values to the object points and **d** are the distances, on the image, between the pixel i,j and the pixels used for the interpolation (see Fig. 2).

2.5 A field test: the Tetrarchi statue

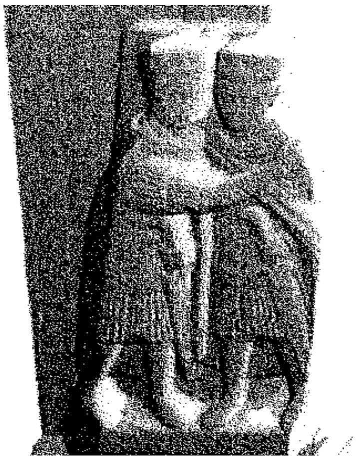
The complete procedure for the construction of a solid image has been tested, using as a test area the Tetrarchi statue, a famous sculpture placed in the San Marco's Square in Venice (see Fig. 3 a).
The Tetrarchi group, also known as the "Four Moros", is a marble sculpture on the outside of San Marco's basilica in

Venice, next to the "Porta della Carta" of "Palazzo Ducale". The statue represents, according to tradition, the four governors of the Roman empire (4th AC century – to want of Diocletian emperor).

2.6 Survey operations and instruments

A complete survey of the statue has been performed in order to obtain the solid image of the sculpture. Some reflecting targets (markers) has been placed on the object for the automatic calibration process.
A Riegl LMS-Z420 laser scanner has been used for the DDEM acquisition (see Fig. 4-b). This instrument has a accuracy of ± 5 mm in the distance measurements. The minimum angular step is 10 mgon.
The laser scanner acquisition of the statue has been carried out from a mean distance of about 4 m and with angular steps of 20 mgon. The time required for the scanning was about 20 minutes. The acquired point cloud has been filtered with a specific software developed by the research group of the Department of Geo-resources and Land - Politecnico of Turin.

a)



b)

Figure 3. Surveying of the Tetrarchi Statue. a) The Riegl LMS-Z420 Laser Scanner
b) The obtained cloud of points (DDEM).

This software is able to eliminate outliers and gross errors that are present in the laser acquisition. Figure 3 b) shows the filtered 3D model.
Photos have been taken using a Nikon D1X digital camera equipped with a 28 mm fixed focus objective (Fig. 4).

Figure 4. The digital camera Nikon D1X

A classical survey of the statue has also been carried out, in order to check the new procedures, comparing the results.

2.6 Image calibration

As the first step, the digital image calibration was carried out. The image size is 1312 pixels in height and 2000 pixels in width, its resolution is 300 dpi. Therefore the pixel size is about 12 µm.
Some high reflecting targets have been placed on the statue, allowing the automatic calibration of the image. The estimation has been performed using a bundle approach, by means of a software package made by our research group.
The obtained results are shown in Tab. 1.

Table 1
camera orientation parameters and lens distortion

Image orientation parameters			
external			
X_0	99.982 m		
Y_0	100.699 m		
Z_0	103.220 m		
ω	1.018592 gon		
φ	3.437747 gon		
κ	-0.19099 gon		
internal		radial distortions	
ξ_0	-3.776 mm	K_1	0.000175488
η_0	-3.677 mm	K_2	0.00000076
c	28.890 mm	K_3	-0.00000003

Tab 1. Camera orientation parameters and lens distorsion

In addition, the radial distortion parameters of the objective have been estimated.
From the radial distortion parameters it is possible to obtain the lens radial distortion curve.

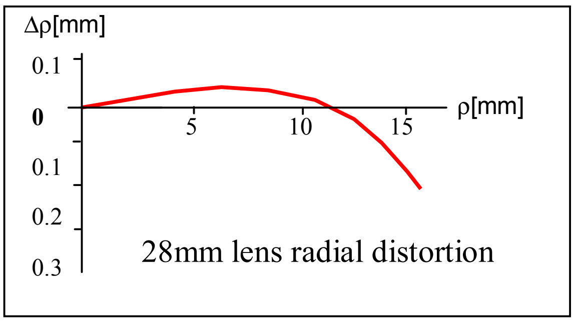


Figure 5. The lens radial distortion curve

2.7 Projection and interpolation

Once the internal and external image orientations are known, the projection of the point cloud onto the image and the interpolation of the distance matrix can be carried out.
The distance matrix can be seen as a grey scale image, where the grey levels are proportional to the distances (black = shortest distance, white = longest distance). (Fig. 6).
In order to verify if the projection and interpo-lation processes have been carried out in a correct way, it is possible to display the RGB original image and the above mentioned "distance image" in a same window. It is also possible to link and overlap the two images.

Figure 6. Distance matrix image.

These functions are offered by the ENVI software (ENvironment for Visualizing Images, by Research Systems Inc). (Fig. 7).

Figure 7. Overlap between the original colour image and the grey distance matrix

Once the solid image has been built, some first important results are achieved.
The solid image can be visualized by using many of the software packages for digital image analysis, available on the market. Some of these packages allow the operator to see in real time the radiometric values RGB just moving the cursor onto the image.
The solid image gives more information: for each pixel, the distance between the centre of the perspective and the photographed object point is known, and therefore it is easy to compute in real time the XYZ position of the point itself in an absolute reference system and to show the 3 co-ordinates on the screen.

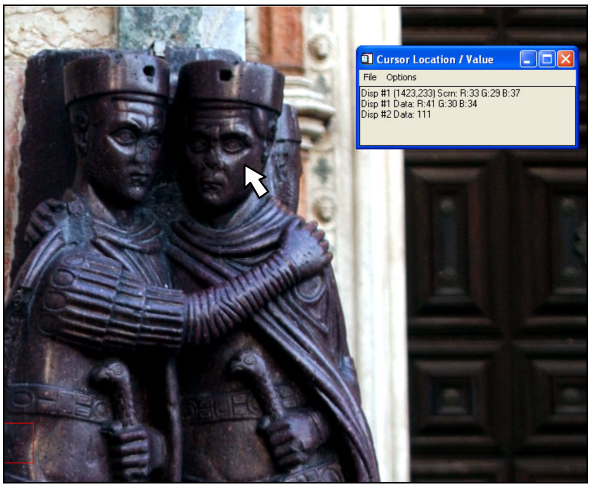


Figure 8. The solid image and the cursor location window

The same software also allows a three-dimensional visualization to be obtained that derives from the integration of the two images.
The thus obtained three-dimensional visualization is not the correct 3D model of the object but rather a model in which the taking geometry is not considered (central perspective).The 3D visualization however allows one to intuitively understand whether the solid image creation has been correctly performed or whether some errors have occurred during the creation phase.

Figure 9. 3D visualization of the statue (ENVI software)

3. CONCLUSIONS

Solid images open the road to a series of new products in the field of architectural and land surveying applications. A solid image makes possible:

- to determine in real time the position of any point in a 3D reference system, using a common PC;
- to carry out three-dimensional correct measures (lines, areas, volumes, angles, …), just selecting some points on the image;
- to integrate the information given by a high quality original colour image with the 3D geometry of every point represented in the photo.

A wide series of further practical applications can be foreseen.

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