True digital orthophoto for architectural and archaeological applications

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Abstract
Digital orthophotos are cheap and efficient products used to represent the correct shape of any object. In the case where the surface that models the object is discontinuous, which is a frequent situation in architectural and archaeological applications, breaklines and hidden areas must be taken into account, and the orthoprojection procedure therefore needs to be more sophisticated. A complete description of the hidden areas is often obtainable using multiple images (present in the photogrammetric block), while a rigorous geometric description of the object requires the restitution of the breaklines or, as an alternative, a very small grid interval of the digital terrain model. In the case of architectural and archaeological objects, acquiring all the breaklines is almost equivalent, in terms of time and cost, to a complete photogrammetric plot. A "dense" DEM seems to be a more efficient solution: the new opportunity is offered by the laser scanning technique, which is now also available for terrestrial applications. A terrestrial laser scanner gives a very dense DEM (a few centimetres of grid interval) in seconds, with an excellent accuracy (better than ± 2 cm). The authors have conceived and developed an original software, named ACCORTHO (=ACCurate ORTHOphoto), which is here described in detail: it produces correct digital orthophotos of architectural objects, using multiple images and DTM acquired by terrestrial laser scanners. A practical example of the obtained product, based on the well known "Karlsplatz C.I.P.A. test", is shown.

1. Introduction
Orthophoto is an efficient and economic way of representing photographic information in a 2D-reference system, which is useful when the user has to measure the surveyed object without the interpretation made by an unexperienced operator. If the projection has to be made on a plane and the shape of the object is smoothed, the procedure is very simple and the reached accuracy satisfies all kinds of applications. The two previously mentioned hypotheses do not usually occur in architectural applications. There are a great deal of smoothed objects that require different reference surfaces (e.g. a dome requires a sphere or an ellipsoid). More often the shape of man-made objects is not completely smooth and a simple shaped model, based on a regular grid (DEM), is not able to describe it properly. The digital solution of orthophoto production opens up an easy and inexpensive way of solving this kind of problem. The use of reference surfaces that are not plane is now a common tool in architectural surveying: over the last years a great number of authors have described the algorithms that are used and shown very interesting applications in the restoration and documentation of the cultural heritage. Orthoprojection of rough objects is still an unsolved problem especially in architectural applications: the main difficulty is that of the complexity of the description of the analytical shape of the object, where points with the same planimetric co-ordinates show different heights. Regular grids integrated by break-lines and DSMs (Digital Surface Models) are the most popular and investigated solutions used to build-up a mathematical shape description of such an object. In both cases complex algorithms and expensive computation times must be used before and during the orthophoto production.

In this paper, the authors describe and test a solution, based on the use of DEM generated by modern terrestrial laser scanners, that preserves the practical benefits of digital orthophoto: the metrical accuracy of the product and the complete automation of the procedure. The work is a further development of the solution proposed by the authors for the production of true orthophoto in urban areas.

2. True Orthophoto of a Rough Object
Let us consider an object described by means of a correct DEM (see figure 1). If one uses the traditional approach to digital orthophoto generation, all the points hidden by the perspective effects are not represented and the visible points are duplicated on the resulting orthophoto. For example, the radiometry of point Q is

recorded twice: the first time in Q0, when point Q is orthoprojected, and the second time in P0 when one tries to orthoproject point P.

Figure 2 shows a realistic demonstration of this systematic error which originates from the uncompleted radiometry description of the object by means of a single perspective image.

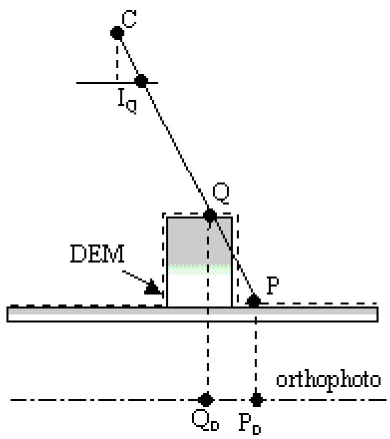

Figure 1. Orthoprojection with hidden areas

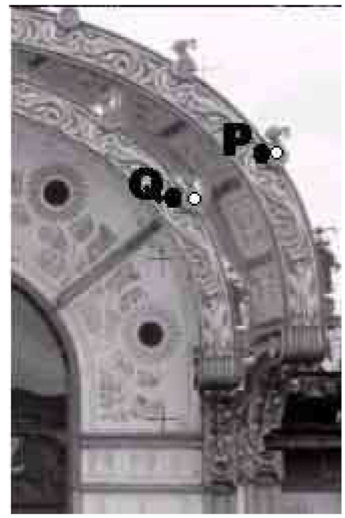

Figure 2. Practical example

Considering the previously mentioned effect, it can be stated that, in order to generate a true orthophoto of an unsmooth object, a correct shape description and a complete radiometry recording of all points of the object must be used. This last requirement can be accomplished only by using different perspective images of the object itself and by avoiding the possibility of using the grey (or colour) value of a point Q for the orthoprojection of a point P lying on the same perspective ray.

As far as 3D modelling techniques are concerned, deeper consideration is required on the present day evolution of the research activities.

2.1. 3D model generation

The build up of a correct 3D-shape description of an unsmooth object can be obtained using different approaches.

The first class of solutions tries to minimise the number of points and geometric information required to give a complete 3D description.

The first approach is that of the use of a regular grid integrated by means of all the breaklines needed to describe the height discontinuities of the object. Simply considering the façade of a building, it is clear that the survey of all the breaklines would mean plotting almost the entire object: the survey of the break-lines is not automatic and therefore not economic for an orthophoto generation. The second solution is the definition of a DSM using geometric primitives to describe the boundaries of the object. This last approach has been studied in detail and set up to model buildings in urban areas: plane triangles and quadrangles are defined as geometric primitives and a relational database is used to manage this sophisticated instrument. When applying this solution to architectural objects more types of geometric primitives must be considered (e.g. cylinders, spheres, etc) to correctly describe the structural and decorative elements currently present in this particular kind of object. The generation of a DSM cannot be automated; the setting up and the management of such an instrument require complicated software and a large amount of computation time.

Dense irregular grids represent the second class of tools that are useful to describe the shape of an object, where the distance between two points ranges from 50 cm to few centimetres. In these models the density of the points replaces the intelligence of the previous solutions. It is possible to conceive three different ways of generating a dense grid. The first is the manual survey of the points. Let us consider a small 10 m x 5 m façade, an acquisition of one point each 2 cm in the X and Y directions and a speed of acquisition of 2 s per point: an experienced operator, working 6 hours a day could record this dense grid in 3 days! The second possibility is the use of automatic DEM generation using matching algorithms. It is well known that this solution gives almost 70% of the required points or less for critical situations: the remaining points must be corrected or integrated manually by an operator. It is obvious that these two possibilities are not able to construct a dense grid in an economic way. The third way of generating a dense grid is the use of modern terrestrial laser scanners. These surveying devices are able to acquire thousands of points in a few seconds, with high accuracy. The laser scanner technology, based on optical-electronic devices, uses a high intensity pulse directed towards the object to survey, in order to have a distance from the device itself. A digital image is derived from thousands of different pulses where all the measurements on single points are pure 3D locations. Over recent years a great deal of tests have been set up on the use of laser scanners mounted onboard aeroplanes in order to derive high precision DEM, with the precision being independent of the sensor and target distances.

As far as terrestrial applications are concerned, laser scanner devices guarantee different acquisition accuracies ranging from ±5 mm (e.g. CYRAX 2500 manufactured by CYRA Technologies Inc.) to ±25 mm (e.g. LMS-Z210 manufactured by RIEGL). These instruments are fully portable sensors, specifically designed for the acquisition of 3D images; a rotating mirror directs the internal laser range-finder transmitter beam over a precise angular pattern and the resulting range measurements comprise a very accurate 3D dimensional representation of the acquired scene. The grids generated by terrestrial laser scanners are irregular, the X and Y spacing depending on range and direction between the instruments and the measured point: this means that it is possible to manage the density of the points by simply changing the acquisition distance. The acquisition process is completely automated and the DEM generation of any object (acquisition and processing of the data) is an easy and quick procedure. For these reasons the dense DEM generated by a laser scanner device can be considered the optimal solution for a correct and complete 3D description of the shape of a complex object, both from the technical and economical points of view.

3. True Orthophoto Generation

Amhar and Ecker proposed an original solution for the generation of true orthophoto in 1996. The procedure, devoted to the production of orthophotos in urban areas, uses a DSM managed by means of a relational database. All images are classified in terrain and building surfaces and the orthopoto is generated in separate phases: first the terrain then the roofs. The results of these treatments are then merged in a single digital orthophoto. Hidden areas are eliminated through superimposition of the orthophoto generated from other images.

The solution proposed in this paper tries to simplify this approach. The input data for the generation of the true orthophoto of a rough object are: a dense DEM, generated by a laser scanner device, and a series of oriented images containing the radiometric description of all the points to be orthoprojected.

The aims of the procedure are: to maintain complete automation so as to guarantee the same performances of traditional orthoprojection software and to avoid the previously highlighted problems (see par. 2).

Let us consider the object in figure 3. In perspective images, higher points hide a lower point, therefore the procedure must run from the highest to the lowest point.

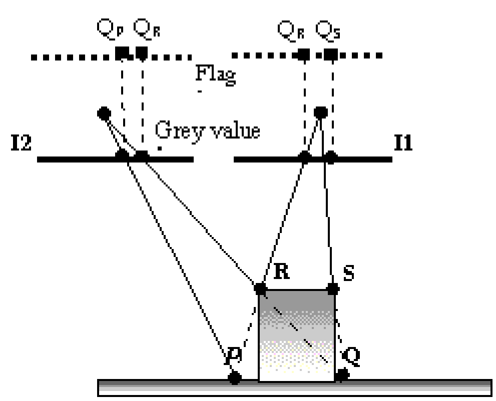

Figure 3. True orthoprojection

The procedure starts from point R. The best recording of the grey value of this point can be found in the image which has the projection centre nearest to the point itself (image I1). In order to avoid the duplication of the images (see fig. 2), this pixel should be inhibited: for this reason a "flag image" is created where each pixel records the height used for the orthoprojection of the correspondent pixel on the original image. Point R has also been recorded in I2 and, for the same reason, the pixel representing point R on I2 should also be inhibited.

The procedure orthoprojects point S with the same criteria (point S will only be recorded in I1). When the procedure orthoprojects point P, it finds the pixel on I1 that was used before for point R. The flag image inhibits the second use of this pixel, because the height recorded on it is higher than the height of point P. Then the procedure looks for the grey (or colour) value in I2. The pixel is not inhibited and the orthoprojetion of point P is possible. After this, the procedure orthoprojects point Q. The first attempt is to use the corresponding pixel on I1, but this pixel has been used for point S and the "flag image" then inhibits the radiometric value reading. The second attempt is to use the corresponding pixel on I2, but this pixel has been inhibited because it contains the grey (or colour) value of point R. In this case no more images are available and the orthoprojection of point Q cannot be defined. This simple example describes all the possible cases of the true orthoprojection.

4. The Accortho Software

The procedure described in the previous paragraph has been implemented in a specific software called ACCORTHO (ACCurate ORTHOprojection).

The input data are a regular dense grid generated from the irregular DEM acquired using a laser scanner device and a set of oriented images. The software runs in two separate steps. In the first step, the software:

- computes the heights of each pixel of the output image (the true orthophoto) and orders the pixels from the highest to the lowest;
- extracts the portions of the images involved in the procedures;
- constructs the index of the images for each pixel where it is possible to find the radiometric value of the pixel. The images are ordered considering the distance between the projection centre and the pixel;
- generates one empty "flag image" for each input image.

The second step of the procedure performs the process described in the previous section. Figure 4 shows the flow-chart of the software.

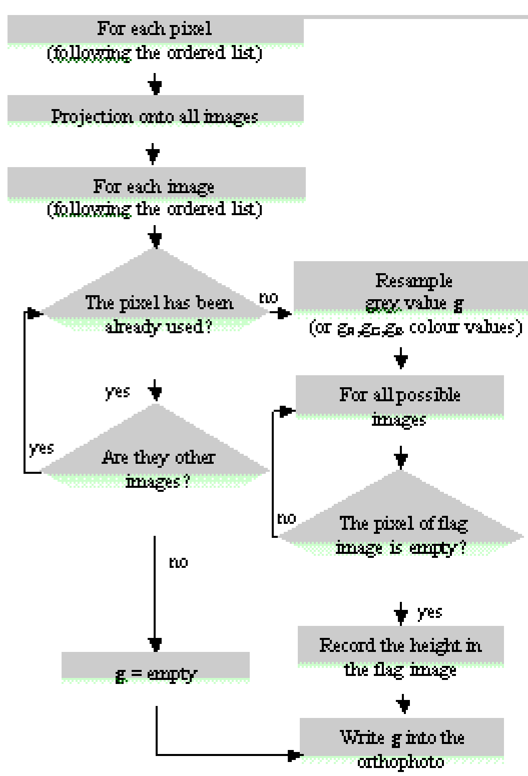

Figure 4. Flow-chart of Accortho

5. Test of the Procedure

The software was tested on a set of data acquired by TUV and Politecnico di Torino for the "KARLSPLATZ C.I.P.A. test". The DEM was acquired (summer 1999) using an LMS-Z210 laser scanner, manufactured by RIEGL-Laser Measurement System, located in Horn - Austria.

The LMS-Z210 laser-scanner is a fully portable sensor, specifically designed for the acquisition of 3D images. The LMS-Z210 device operates with any standard PC or notebook, has a measuring range up to 350 m and a field of view of up to 80° x 340°. The scanning time is approx. 30 to 240 s, with a nominal metric accuracy of ± 2.5 cm.

Four different scenes have been acquired to build the 3D model of the principal façade. The acquisition time varied from a few seconds to a couple of minutes; less then one hour was necessary for the acquisitions, even when taking the displacement of the instruments into account. The post-processing phase includes the 3D reconstruction using tie points, materialised onto the monument through reflective stickers.

The software is able to locate through an autocorrelation procedure the 3D position of the reflective stickers (characterised by a high reflectivity in the near-infrared wavelength), and imposes the correspondence of the co-ordinates (in a given reference system) of them in the different images (tie points).

The 3D reconstruction generates 3D files (in a 3DD file format) that can be easily viewed using free-of-charge Internet downloadable software such as COSMOS.

The 3D-model reconstruction can be easily performed thanks to the capability of the LMS-Z210 laser-scanner and the good potentialities of the post-processing software. No problems arose during the surveys nor in the image-processing phase. The capability of the acquiring system to pass through glass surfaces (with high transmittance coefficients and refraction index) could cause some problems for architectural surveying, particularly due to object distance misplacement (all the features behind glass surfaces) and shift, caused by the refraction coefficient. Approx. 100.000 points that form the resulting original DEM have been processed. A regular DEM (5 cm point spaced in the X and Y directions) has been generated with a new procedure based on a statistical approach that allows the detection of the outliers and gross errors. All the images acquired by means of a ROLLEIFLEX 6006 semimetric camera have been digitised using a calibrated UMAX DTP scanner at 1400 dpi resolution.

Figure 5 shows the orthophoto generated using ACCORTHO. Observing the image in figure 5, it can be seen that the lamp in front of the station hides a significant portion of the façade. This phenomenon is very common in terrestrial images: parked cars, people, lamps and so on are frequent obstacles. This noising effect can be avoided if, between all the used images, at least one shows the area that is hidden in the other images. The crosses of the semimetric images cause the same problem. In order to avoid this effect, and to generate a "clean" orthophoto, the pixel of each image that contains noising information have been blocked directly into the "flag images", recording an height that is greater than the maximum height of the used DEM. Following the implemented procedure, these pixels will not be used during the orthophoto generation process.

Figure 5. Rough orthophoto of KARSPLATZ

Figure 6 shows the final results of the entire process. Using a standard PC (PENTIUM III - 880 MHz - RAM 512 Mb), the computation time (including the generation of the regular DEM and the generation of the final orthophoto) is of about 5 minutes. Figure 7 shows the superimposition of a traditional plotting of the façade. This result is almost perfect: the mean discrepancies are less than one pixel (which size on the object is 5 mm x 5 mm).

Figure 6. Final true orthophoto

Figure 7. Raster-vector superimposition

6. Conclusions

ACCORTHO is an easy software that is able to produce true orthophotos of architectural objects thanks to a completely automated procedure.

Using a correct dense regular DEM, it is possible to generate orthophotos with an accuracy that is sufficient for most architectural survey applications.

The proposed procedure can be applied to any kind of discontinuous objects (urban areas, monumental and archaeological sites, museum documentation, etc.) and allows a great diffusion of orthophoto benefits in unexplored fields.

The simplicity of the proposed solution is due to the correct mixture of different techniques: photogrammetry, laser scanner, digital image processing.

Acknowledgement

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