

PROBLEMS RELATED TO THE GENERATION OF TRUE-ORTHOPHOTOS WITH LIDAR DDSMs

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ABSTRACT:

Nowadays orthophotos from satellite and aerial imagery are very requested products, considering their low cost motivated by the highly automated production chain. The generation of orthophotos requires a block of oriented images and a digital model of the ground (DTM or DSM). In case a DTM is adopted, the lackness of information about buildings results in distortions. The availability of a LiDAR DDSM allows to overcome this problem, even though if the spatial resolution is not very high, some problems in correspondence of building contour might arise. To solve for this drawback, a method based on thickening a LiDAR DDSM from an initial grid of 2x2 m² to a 0.2x0.2 m² one is proposed here. This method has been implemented by exploiting the availability of a spatial DB of the same area, which allows to classify all points of the thickened DDSM in two categories: those belonging to a building and those not. A test of the method has been carried out on a photogrammetric block taken over the town of Lecco (Northern Italy) by a RC30 Wild camera at 1:17,000 mean scale, and afterward digitized by scanning. The LiDAR DDSM adopted has been provided by Lombardia Region at a spatial resolution of 2x2 m². The thickening of the DSM has been performed using a building mask extracted from the new spatial DB of Lecco. Orthophotos created in this manner take advantage of the whole cartographic and spatial material already available at the Public Administration Department, and presents an improved accuracy than a classic orthophoto with a computation time approximately equal.

1. INTRODUCTION

In recent years, increasing demand for digital orthophotos has been pushing researchers to improve data quality and reduce production costs. Indeed, if in the past orthophotos were considered a cheap alternative to vector maps, or a by-product of the photogrammetric mapping process, today they have come to play an autonomous role. This is mainly motivated by two factors: the growing worldwide diffusion of *web location services* (see e.g. Heipke, 2005; Walter, 2005; Leberl, 2007) requiring geographical support, which might help on-line users to access information; the need of organizations to produce detailed and up-to-date geographical data describing land changes, a particularly important task when dealing with urban areas, where data of high resolution and accuracy are required. Furthermore, the availability at an operational level of new technologies, such as IMU sensors, airborne digital cameras and aerial laser scanners, has significantly contributed to the development of orthophoto production.

Not long ago, before the development of LiDAR technology, dense DTMs/DSMs could be generated at low cost only by means of aerial photogrammetry. However, especially in highly urbanized areas, due to perspective occlusions, a photogrammetric DTM/DSM may produce a higher error rate than LiDAR (Brovelli & Cannata, 2004).

Therefore, we would like to investigate how urban area orthophotos could be improved through the use of LiDAR DDSMs.

Currently, Italian government agencies and departments tend to buy gridded DTMs/DSMs with a resolution of 2x2 m or 1x1 m.

Therefore, we have looked into problems related to using such DSMs, and we have tried to understand somehow these

problems may be solved using other mapping products generally available at government agencies and departments. The results obtained should be considered as practical guidelines for institutions which would allow them to improve orthophoto quality by exploiting already available material (Dequal & Lingua, 2004).

The resulting orthophotos will not have perspective deformations and can therefore be directly superimposed onto spatial databases or vector maps, which are not affected by such deformations. The generation of accurate orthophotos based on the use of DSM to model ground geometry was first proposed by Amhar *et al.* (1998) under the term "True-Orthophoto[®]". It was then implemented in different photogrammetric packages. From a theoretical point of view, the generation of a true-orthophoto[®] does not significantly differ from that of classical orthophotos; however, it does introduce further problems, requiring suitable solutions (Schickler, 1998; Brown, 2003). For example, when a building is correctly represented, no information is obtained about the ground level area due to the occlusion produced by the building itself. If the generation of orthophotos is based on single images, there is no way to correctly fill in these empty areas. Consequently, the portions of orthophoto relative to these areas are usually generated by means of the DTM alone without the DSM, and this results in duplication of the image content ("ghost image"). The solution to this problem is to combine several images from different points of view (Rau *et al.*, 2002, Biasion *et al.*, 2004), so if there is an occlusion area on an image, information about this area can be extracted from another images.

A more complex issue to cope with is that of roof modeling. If the goal is the realization of a high resolution true-

orthophoto[®] and the DSM has a lower planimetric resolution, information about where the roof border of a building is located might be lacking, and here the algorithm does not know if a pixel of the image represents a piece of terrain or roof. The result is a rough roof border, without a straight line (Figures 7 and 9).

The aim of this paper is to present a solution which corrects this unwanted effect by exploiting a Dense Digital Surface Model (DDSM) using LiDAR data integrated into a spatial database which provides information about the building ground coverage. This solution may seem contradictory, given that the generation of an orthophoto is based on the availability of a higher quality product, such a Spatial DB.

However, given the occlusion issues discussed here, this practical solution results in improvements to the quality of spatial data which can be used by government institutions, especially if the following considerations are taken into account:

1. digital orthophotos can be generated and upgraded with a higher frequency and a lower cost with respect to existing vector maps;
2. upgraded orthophotos are a very useful tool for checking landscape content and detecting changes, especially in urban areas.

In addition to the presentation of the method implemented for deriving geometrically corrected orthophotos, and to the results of its application, in the following an analysis of cases in which corrections may or may not be truly necessary will be reported.

2. THE PROPOSED METHOD

As shown in Section 1, the problem focused in this paper has aimed to correct the border effects (see Fig. 7) due to the absence, which is very common, of break-lines in the DDSMs used to derive digital orthophotos. In urban areas this outcome is evident for buildings, specifically when they show large difference in height with respect to their surrounding terrain.

Break-lines can be obtained by three different strategies. The first one is based on the automatic extraction of the building contours from the DDSM itself (i). However, DDSMs have often resolution of about 1 m or less, which makes approximate the derived contours, especially when buildings do not have simple shapes, such as regular figures with sides much longer than the DSM resolution (Forlani *et al.*, 2005). The automatic detection of a detailed roof perimeter needs a resolution of a few tens of centimetres, which is rarely available.

Indeed, even though LiDAR data are usually acquired with a higher point density, they are usually delivered, after filtering, at a resolution of 1-2 m. The other possible strategies rely on the building contour availability from external data source (ii), e.g. vector maps, or on their manual digitization from imagery (iii); the last solution is generally of low practical interest because of its high cost. Both the two solutions (ii) and (iii) require also the knowledge of the height of each building, whose availability is not commonplace in all countries. However, also when building heights can be derived from maps, these are limited to mean values, which do not enable to correctly model the roof geometry.

The proposed method tries to exploit the high accuracy in describing the building height, which is typical to DDSM, coupled by the detailed description of building contours, which can be extracted from existing Spatial DB or digital vector maps, data that are generally available for the most urban areas.

Starting from the original LiDAR DDSM, a denser one at a few centimetres resolution is generated, according whether the new grid node lies on the roof or on the terrain. Considering the planimetric layout of all building contours (and possibly accounting for other objects which need to be corrected due to their relative height with respect to the surrounding terrain), two binary masks are generated (see Fig. 1):

1. the *building mask* (BM): the building raster map;
2. the *terrain mask* (TM): the raster map which is complementary to the BM.

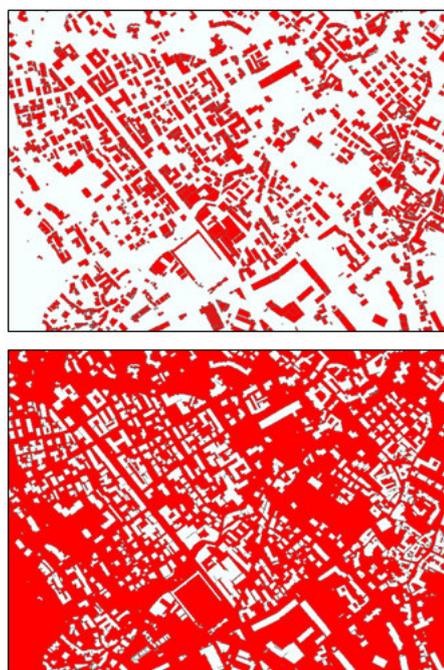


Figure 1. The *building mask* (on top) and the *terrain mask* (on bottom).

Obviously the sum of both masks gives the entire zone. From an original vector format the two masks are rasterized with a planimetric resolution higher than that of the DDSM (few centimetres). Then the original DDSM is resampled according to new denser regular grid. Every new node will have the height of the nearest cell of the original DDSM, considering if the point lies on the BM or on the TM (Fig. 2). The approach allows the roof to be determined with a precision equal to the raster masks.

The densification of the original DDSM is carried out at first on the zone covered by the BM, in such a way that the new node outside this mask is classified as a null value. The same operation is later performed with the TM. The sum of the two resulting DDSMs gives the whole DDSM useful for the generation of the geometrically corrected orthophoto.

The flow chart of the developed method is shown in Figure 3.

In the following sections some applications of the proposed method based on different data set covering the same area will be shown.

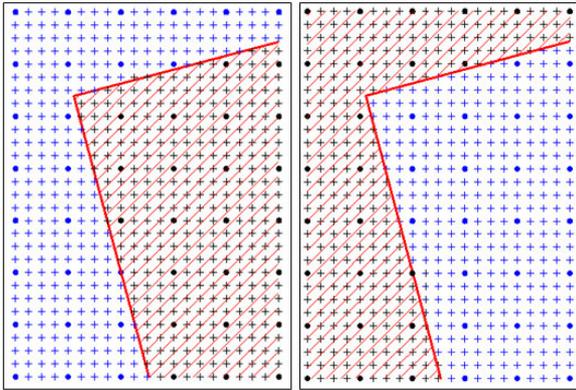


Figure 2. The creation of the Building and Terrain DDSMs
 Legend: ● node of the original DDSM
 + node of the new DDSM
 // mask

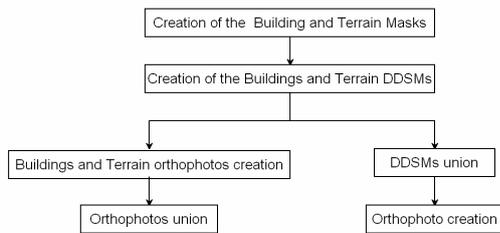


Figure 3. Flow chart of the proposed method

3. ORTHOPHOTO USING A GRID DTM

3.1 Data set description

The proposed method for the generation of orthophoto has been tested on a small aerial block (8 images) captured over the city of Lecco (Lombardia, Italy) by an analogue camera Wild RC30, equipped with a standard lens (150 mm). Images have been taken during 2003 and feature a mean scale of about 1:17000, covering an area of about 10,000 m². The transformation from analogue to digital has been accomplished by using a photogrammetric scanner at a geometric resolution of 14 μm pixel size, corresponding to a footprint on the terrain of about 20 cm.

The aerial triangulation and the ortho-rectification have been performed by Geomatica V10 Orthoengine, i.e. by using a standard commercial processing package. The advantage of the proposed technique relies in the fact that no special algorithms have to be implemented for the orthophoto generation, but only a pre-processing of the DSM is needed. This consists in the creation of both masks adopted to classify points on the terrain and on buildings, that are derived from a *spatial DB* of the study area. This has been created by a digital photogrammetric process on the basis of the same image block adopted for the generation of the orthophotos themselves. Indeed, either the *spatial DB* and the images represent the landscape exactly at the same time, and therefore they should not show differences. On the other

hand, discrepancies might arise concerning the DSMs and the DTM adopted for testing the procedure, which have been captured at different epochs.

In the next sub-sections, results using DTM and DSM with different resolution will be shown.

3.2 Results using a 20 m DTM

Initially orthophotos at two different image resolution (50 cm and 20 cm, respectively) have been created based on a DTM covering the whole Lombardia region, featuring a grid of 20 m resolution.

In figure 4 a patch of the resulting orthophoto at the resolution 20 cm is reported. The layer corresponding to buildings on the *spatial DB* has been super-imposed to orthophoto, in order to check the quality of the geometry correction. In reality, these tests have been performed on a wider area than that shown in figure 4. For the sake of picture clarity and readability, here we only show a detail of orthophotos generated by different data sets and methods over the area where a large commercial centre designed by Renzo Piano arises. This choice is motivated by the complex geometry of the roof and the height of this building (50 m), representing a very critical case study to check the effectiveness of the proposed approach.

In figure 5 a zoom on the central area of figure 4 is reported, showing that low buildings are correctly represented because the use of a DTM does not result in significant errors. On the contrary, the piece of orthophoto corresponding to the central building has not an adequate correspondence with the vector map, because a DTM in this area is not able to provide information to correct geometric distortions. The mean magnitude of this misalignment error results in the order of some meters. Very similar results have been obtained with both 20 cm and 50 cm resolution orthophotos.

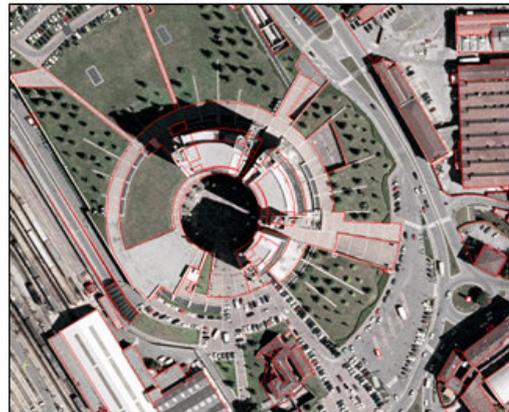


Figure 4. Orthophotos with resolution 20 cm generated by using a 20 m resolution DTM; the building layer (in red) has been super-imposed.

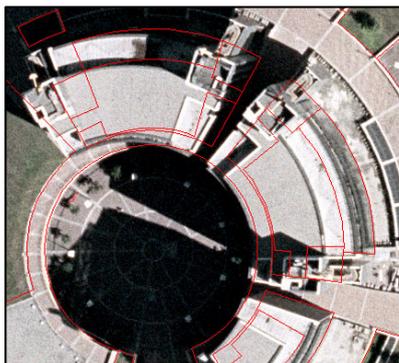


Figure 5. Detail on errors concerning the Renzo Piano building by using the DTM at 20 m resolution.

3.3 Results using a 2 m LiDAR DTM

LiDAR (*Light Detection and Ranging*) technology is able to provide a complete 3-D model (DSM) of the investigated surface. By filtering vegetation, buildings and other objects, a DTM can be derived with an accuracy in the order of decimetres.

In this test, a DTM at a resolution of 2 m has been provided by the Land Administration Dept. of Lombardia Region.

A detail of the orthophoto generated using a LiDAR DTM at 20 cm image resolutions is shown in Figure 6. Also in this case, like in Fig. 4, there is not a good correspondence to vector maps in case of tall buildings.

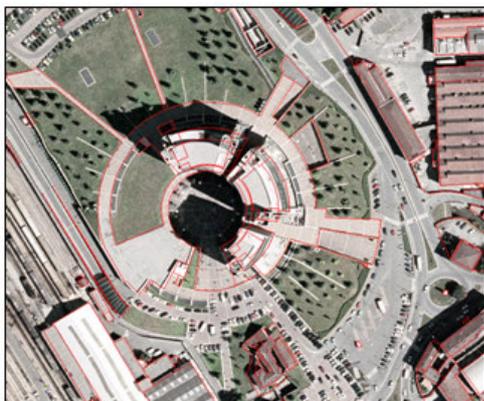


Figure 6. Orthophotos at an image resolution 20 cm according to a LiDAR DTM of 2 m resolution.

4. ORTHOPHOTO USING A GRID DSM

LiDAR allows also to derive a DSM of the interested area, that can be used to straighten up the position of each buildings, especially when the height is relevant. The adopted DSM was also provided by Lombardia Region at a 2 m spatial resolution.

Some tests have been performed at the original resolution of the DSM (2 m), and with other two reduced resolutions (4 m and 10 m). These last DSMs have been created with a thin out operation on the original DSM, up to 4 m (deletion of the 50% of the nodes), and 10 m (deletion of the 96% of the nodes). In Fig. 7 the orthophoto at image resolution of 20 cm according to a DSM of 2 m is shown.

Likewise the previous case when a DTM has been adopted, here the correspondence between orthophoto and vector data is satisfying not only for low buildings, but also for the tall constructions. Moreover, results achieved by using DSMs at different resolutions (2, 4 and 10 m) are quite similar, even though the results correspond to the use of the DSM at the higher resolution (2 m). After a more accurate analysis, it is possible to pick out a jagged gutter line on each orthophoto, generated by a lack of data along the roof edges (see Fig. 7). Indeed, here an interpolation of the grid DSM is needed, because the resolution of the orthophoto is higher than the resolution of the DSM, but the algorithm has not information about where the roof edge is really located. The interpolation is based on the height values of the points in a surrounding area, independently if a point is located on a terrain or on the roof building.

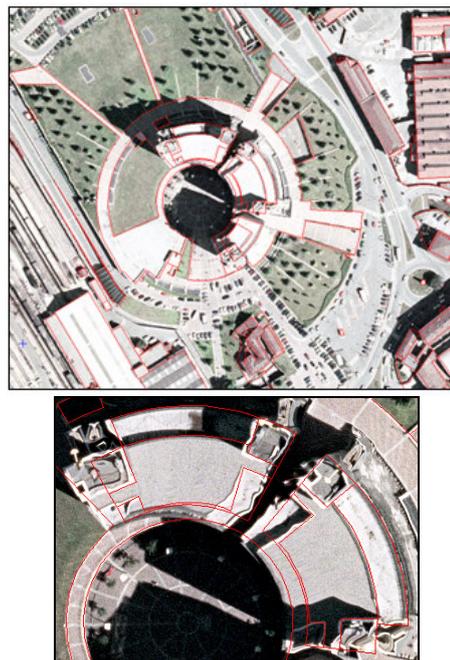


Figure 7. Orthophoto at image resolution of 20 cm, according to a DSM at resolution 2 m (on top); on the bottom a detail showing the jagged gutter line effect is reported.

5. ORTHOPHOTO USING THE PROPOSED METHOD

5.1 Generation of orthophotos

The method to generate orthoimages proposed in this paper has been developed to avoid the jagged gutter line effect due to the use of a coarse DSM.

As described in Section 2, the first step is to create the *buildings* and *terrain masks* of the considered area in raster format. Using a *spatial database* provided by the administration of the city of Lecco, we could extract only the zone relating to the surface covered by buildings, while the remaining part have been classified as terrain. From an original vector format, both masks have been rasterized with 40 cm and 20 cm pixel size resolution (see Figure 1). These resolutions allow to derive information about where a

building border line is really located with a largest error of 40 and 20 cm, respectively.

The following step is the thickening of the original 2 m LiDAR DSM to the same resolution of the masks. Initially, the portion covered by the BM has been thickened, by assigning the height value of the first nearest node (*nearest neighbour* method) to each new grid node of the derived DDSM, considering only the point inside the mask. To each point outside the mask a “nodata” value has been assigned. The same operation has been performed with the TM. These tasks have been implemented to be carried out in GRASS and ArcGIS GIS environments.

By using these two DDSMs it is now possible to generate of the corresponding orthophotos (Figure 8).

The last step is the fusion of both orthophotos, being one the complementary of the other. The same result could be achieved by the preliminary mosaicking of two DDSMs and the generation of the complete orthophoto in only one step.

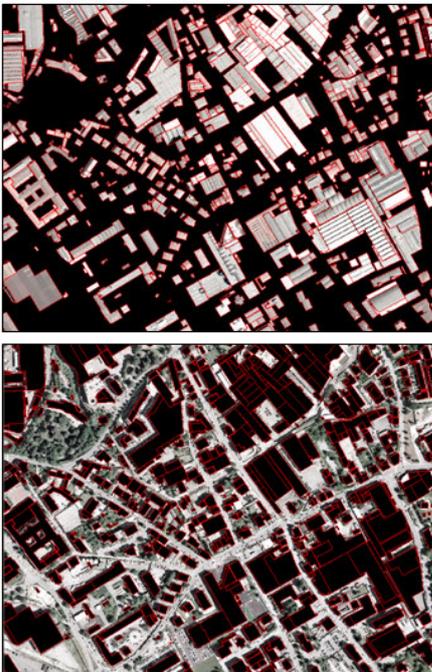


Figure 8. Orthophotos generated in correspondence of *buildings* and *terrain DDSMs*.

5.2 Results with the proposed method

In order to show the improvement in the orthophoto quality obtained by adopting the proposed method, we focus on the results achieved in correspondence of the building of Renzo Piano already used in the previous cases. In Fig. 9 the orthophotos generated on the basis of the *building DDSM* and the full orthophoto are reported. In this case the *building DDSM* has a resolution of 20 cm, exactly the same of the orthophoto. Results are very good, being the jagged gutter line effect fully removed. Figure 10 illustrates the results using the complete DDSM with the union of both *buildings* and *terrain DDSMs* to generate an orthophoto at the resolution of 20 cm. Here both DDSMs at resolutions of 20 and 40 cm have used.

In these cases the correspondence between the vector map and the corrected orthophoto is verified in zones with both low and tall buildings, therefore in every area of the picture.

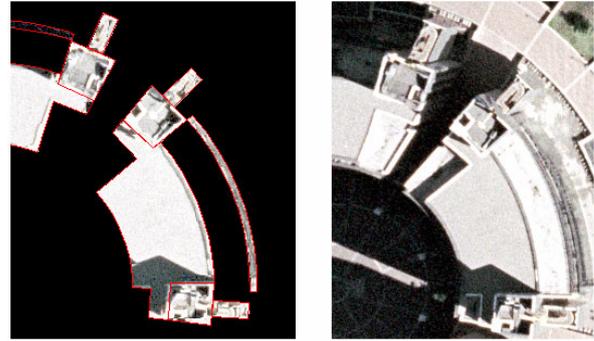


Figure 9. The orthophoto generated on the basis of the *buildings DDSM* and the complete orthophoto.

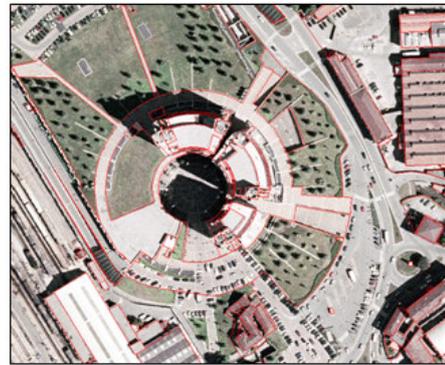


Figure 10. Orthophoto generated from a 20 cm DDSM.

5.3 Quantitative check of the results

A quantitative control of the results using a 20 m resolution DTM and a 2 m LiDAR DSM has been performed with the evaluation of the displacements between the spatial DB and the generated orthophotos. In particular, a sample of 100 buildings around the tall Renzo Piano building adopted a case study has been chosen for this control. The histograms in Figure 11 represent the measured displacements.

As it can be seen by analyzing the histograms, with a 20 m DTM the errors vary from a few centimetres up to 5-6 meters, the latter corresponding to the tallest buildings. Using a 2 m DSM, the error is always less than the DSM resolution but the jagged gutter line effect is present.

Finally the check with the proposed method has given errors in the range of few centimetres, because the orthoprojection of buildings has been corrected to coincide to the contours coming from the vector map.

Moreover, it was verified that the 40 cm DDSM resolution orthophotos have also a high quality, even though the best results can be obtained by fixing the resolution of the DDSM exactly equal to the resolution of the orthophoto, (in our case 20 cm).

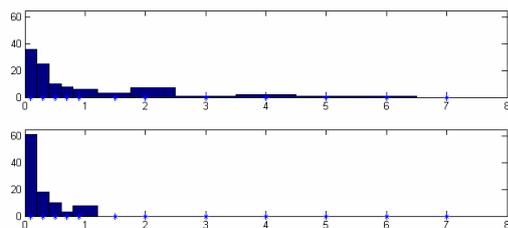


Figure 11. Displacement histograms (in m) measured using a 20 m DTM (on top) and 2 m LiDAR DDSM (on bottom)

5.4 Computational cost

It was verified that the computational cost depends mainly on the values of the output parameters, and specifically on the final orthophoto image resolution. In the test executed with the different DTMs, DSMs and DDSMs, the time necessary for the orthophoto production was about the same if the orthophoto resolution was kept constant. This is quite obvious, because with a low resolution DTMs or DSMs the software must execute a grid interpolation to get the height values needed for the rectification of each pixel of the original image. Instead, with a DDSM the interpolation is not necessary and this can increase the computation speed. In any case the file dimension is considerable (for example passing from 2 m up to 20 cm resolution, the dimension of the file has increased by about 96%) and therefore, considering the need to manage a so large file, the computational time remains about the same.

6. FINAL CONSIDERATIONS AND FURTHER IMPROVEMENTS

This paper proposes a method, which has been tested on real data, for generating orthophotos geometrically corrected to account for modelling of buildings. The implemented technique exploits a Dense Digital Surface Model (DDSM) acquired through LiDAR technology, coupled with a vector map describing the shape of the buildings. The method is useful when the goal is to create a high accuracy orthophoto in which every building is correctly rectified.

For this reason, it is particularly suitable for areas where there is a high density of tall buildings. When generating such orthophotos (also described in the literature as “True-orthophoto[®]”), the main problem to consider is the rectification of the gutter line of every building with a precision of the same order of the orthophoto’s geometric resolution. Tests carried out during this research have shown that this problem cannot be solved for by using DTM or DSM only.

In the paper, the orthophoto corresponding to the building roof is generated by deriving heights from the DSM through a simple interpolation method (nearest neighbour). This technique could be improved by better 3-D modelling of the roof structure (e.g. by using a parameterized model), or by a more refined interpolation technique. The decision about which portion of the ground is covered by buildings is currently taken by using existing vector maps of the same area. However, the vectorization of raster maps (Brovelli & Zamboni, 2006) would make available this kind of data as well.

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