DEVELOPMENT OF AN INTEGRATED SYSTEM OF TRUE ORTHO-RECTIFICATION. THE ALTAIS LRTO SYSTEM

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KEY WORDS: Most Right Method, True Orthophoto, Light Orthophoto, Nadiral Profiles Method, Multi-Visibility Analisis Method.

ABSTRACT:

At present orthophotographs are essential sources of information in all areas. The generation of these products in urban areas can be difficult and specific rectification methods are neededin order to obtain advanced orthoimages that usually have been denominated as true orthophoto. In this paper, the principal results of a research project (DATOS –Development of an Advanced True Orthoimage System for urban information source, sponsored by PROFIT Program from the Spanish Ministry of Industry, Tourism and Comerce) are presented. This system is developed thanks to the collaboration of a private company Altais S.L. and the University of Jaén, using data from the company HIFSA for the different phases of the work. In this contribution, the different phases for the development of the system and the obtained basic results are presented.

1. INTRODUCTION

Since the beginning of digital orthorectification methods in the 90s there have been important changes in cartography that have brought orthophoto to the most demanding cartographic product thanks to the simplicity on their generation methods (less time consuming methods and less production cost) and also for the countless applications as graphical base for geographical information systems. Nevertheless, the classic methodology of digital orthophoto generation presents some difficulties especially when the surface registered in the imagery to be orthorectify includes areas with high altitude changes.

These problems are specially important where relief is particularly complex due to the existence of buildings, that are areas of high interest as they concentrate most of the economic activities that imply important (and fast) changes that must be registered within cartographic information in a reasonable period of time.

In order to resolve this problem different production strategies have been developed to compensate these limitations: geometric flight desing (increase of longitudinal and transversal overlapping areas, selection of the optimal direction of flight, restriction of time windows within appropriate dates in order to avoid shadow presence, selection of cameras with less FOV, etc.) and making an effort to improve the quality of imagery using less rigorous solutions with low possibility to automate them (alterations of DTM to improve the visual aspect of the imagery, patch of imagery to avoid stretching, occluding and deformed areas, image enhancement methods to extract detailed information, etc.). All these strategies imply the increment of production costs and also the limitation on its applications, especially in urban areas. A perfect knowledge of the digital surface model (DSM) means a perfect correction of aerial photography, however, actual orthorectification methods do not resolve efficiently element rectification problems, occluding areas, mosaiking of images and shadows. This way, the commercial methods developed for digital orthophoto generation seem to resign the quality reached with these cartographic products, assuming limitations of techniques and reasoning deficiency in the geometric nature of aerial photography and the quality of altimetry data.

2. ORTHOPHOTOS TODAY

The most extended concept of orthophoto is based in correction of aerial imagery to terrain level, obviating rectification of all elements, artificial or natural, existing within it.

This is, certainly, a simplified concept of the problem to correct aerial imagery, and it resolves most of the problems raised in agro-environmental projects: Parcel and Agricultural GIS establishment, inventories (Citric, Vineyard, etc.), Identification of Registered Properties, Control of Aid Requests for Herbaceous Crop Terrain and Fodder Terrain, Land Use and Cadastral Mapping, etc. This kind of orthophoto, named as Ground Ortho (GO), is yet very useful in urban areas, however it presents some problems when dealing with urban planning projects, because in these areas many occlusions due to existence of leaning objects in the terrain force in many occasions to do additional field work to complete the work and not letting to do a direct analysis and interpretation with imagery.

Apart from the occlusions due to leaning objects, there is another phenomenon that obstructs the exploitation of imagery directly: shadows, which makes the quality of work worst and also it conditions the dates to obtain imagery, restringing the time of the year to flight when the sun leaning is higher, and reducing the daily window capture.

Finally, it is true that the quality of Ground Ortho in rural areas is good, but it also presents the described problems, which makes difficult the extraction of measurements directly from the orthophotography in elements not rectified: viaducts, bridges, etc. Also, it’s typical to see deformations and stretching areas within these imagery and zones with high slope: costs, cliffs, etc. that could be avoided considering shots with appropriate perspectives.

Nowadays, there is True-Ortho (TO) generation systems, but they present the following disadvantages:

- They require volumetric delimitation of the objects that want to be rectified using stereoscopic restitution techniques, which means a product's price increase. Therefore, a delay in orthophoto coverage generation, which is not assumable nowadays.
- They do not do an analysis of multiple incidences that considers the best perspective solution to avoid stretching and occluded areas.
- They are semi-automatic, it is necessary to decide which photographs are needed for the final completion of true ortho.
- They do not resolve the appearance of dark areas due to shadows, attenuating or eliminating them.

As a result, there is not a demand of this product, therefore, there are few new applications derived from an improvement of the study and interpretation of aerial imagery. It is essential to evolve in this sense and review the acquisition and production systems to lower prices and times of production.
Motivated by the problems from actual orthoimagery, with the interest of improving their quality, to allow getting planimetric measurements directly from any element represented, and that the most of the surface is displayed with the highest radiometric quality, the DATOS project was proposed, funded by the Ministry of Industry, Tourism and Commerce within the PROFIT program. The main objective was to develop a prototype of True Ortho-Rectification Software to reduce to the maximum the unfavourable elements that increase the price in a disproportionate way, not allowing its use within the GIS and Cartography market.
A derived objective of the True Orthophotos availability was the rapidity and simplicity of extracting information directly from the imagery in a precise way, with no need of extra field work. Therefore, this benefits the higher availability of geographic information not just for the different professional sectors but for the citizens. The orthoimage coverage is obtained rapidly, they are integrated easily in Cartographic and GIS servers, from which it would be possible to update special data with computer technology not very specialized and easy-use tools.

2.1 Preliminary Studies

Because of the complexity of the problem, it was raised the need to do a preliminary study that allowed to know in detail the actual problematic of True Orthophoto production within urban areas (Antequera, 2005) including a review of the actual methods and its procurement, to both commercial and investigation levels.
The direct analysis of the real problems derived from the actual scheme of Ortho-Rectification in urban areas has allowed a detailed study of existent problems within large scale orthoimagery in urban areas. On the other hand, this stage has also been useful to review the actual solutions implemented in commercial software.
One of the conclusions of this study was that the requirements of a GO should be normalized from a geometric point of view, not just because of the precision parameters established for an equivalent cartography, but also for the critical distance in which unaccepted occluded areas appear, such as the disappearance of very stretch streets due to leaning buildings.
The preliminary study allows us to do an optimal planning of projects (depending on the buildings height and urban structure orientation, the flight axis is planned and the focal distance and overlapping percentages more adequate are chosen) minimizing the effects of occlusions appearing in GO, and also confirming the production problems from actual solutions invaliding this procedure.
Once the principal problems was established, the actual methods of True Orthophoto generation have been revised. This task have allowed to put on scene the most advanced methods actually in research, to begin from the actual developments and try to improve the procedures and algorithms already experimented, and to consider the best solution to develop the LRTO application.

2.2 State of the Art

The actual methodology requires the volume definition of the objects (in vector format) that appears leaning in the aerial photography. This is a not automatic process, which needs specific human, software and hardware resources increasing the cost of the product and make complicate its introduction within the GIS and Mapping market. Moreover, its geometric quality is not enough precise as it is required according to the scale tolerances. Any error in the imagery orientation, like the error from the capture, makes the existence of a disorder between the vector and the image that does not allow the direct application in the calculation of the true ortho. This problem has been occurring historically in the production of linear maps, according with technology and needs of the moment, that have served for a determined application, but that have been replaced by newer coverts that require higher precision and a new structure of information adapted to new tools of exploitation.
Actual technology allows precise and economic DSM production. A perfect knowledge of the digital elevation model allows a perfect correction of aerial photographs. LIDAR systems offer in an automatic way a great density of data in its first return where the real surface of terrain is shown. The knowledge of building contours and the definition of objects methodologies have been registered very important improvement related with the automatic (and semi-automatic) data extraction processes. Its implementation within orthorectification processes is immediate, nevertheless a review of the rectification algorithms is needed, that bear in mind this information. The differential methods developed and calculation strategies to simplify the orthorectification process, that allowed the procurement of digital orthoimages very efficiently, must be improved to rectify pixel by pixel methods, looking at all the information within the photograph and is corresponding elevation in the terrain.
Most of existent techniques of true ortho generation are based in algorithms of Z-Buffer visibility (Catmull, 1974; Amhar et al., 1998; Rau et al., 2000; Rau et al., 2002; Sheng et al., 2003; Zhou, 2005), imposing to methods of occluding areas detection from digital models of buildings combined with digital models of terrain (Amhar et al., 1996; Kuzmin et al., 2004), that require the availability of high acquisition cost data.
Methods based in Z-Buffer algorithms resolve the ambiguity of each orthophoto pixel considering the distance of the perspective centre to the point in question, considering visible the closest ones. Nevertheless, this technique presents certain problems that make these algorithms not to be implemented in market solutions:

- Sensibility to digital terrain model resolution in relation to image resolution, which effect implies an imprecise detection of not visible zones.
- The need to introduce additional points in building fronts that implies to come back to the use of digital models of buildings.

In 2007, two new methods have been presented (Habib et al., 2007) to safe limitations and requisites of high cost of methodologies based in Z-Buffer existent algorithms, based in the analysis of angles along radial directions from nadiral point to detect occlusions:

- Radial circular sweep method. Determines a map with occlusions doing a radial sweep of the DSM increasing the angular value of visibility α for each azimuth angle θ (Figure 1).

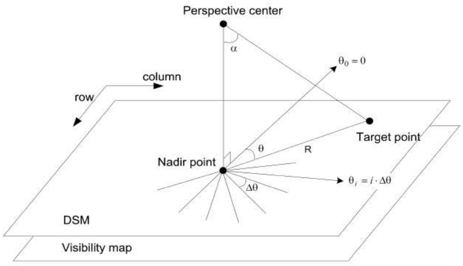

Figure 1. Radial circular sweep method (Habib et al., 2007)

- Spiral sweep method. Introduces the variant of the spiral sweep of DSM starting in the nadiral point checking directly angles of visibility in radial direction.

These experimentally tested methods, present some problems for the generation of individual orthophoto that require the fusion of common areas to complete zones detected as invisibles, and with no mosaiking, for which no continuous coverts of true orthophotos are generated, having to introduce seamlines needed to mosaic orthophotos from the neighbourhood in a posterior stage.

3. DEVELOPMENT OF THE ALTAIS-LRTO SYSTEM

The Altais LRTO system was raised by modules, starting with the development of a basic orthorectification method, which could integrate progressively algorithms that resolve the problems that actual orthophotographs have, until the most rigorous solution was reached of True Orthophoto.

3.1 Ground Ortho Module: GO+.

Orthorectification Module to ground level based in a simple mathematic model of collinearity equations and additional parameters, which uses calibration data from the camera, and inner and exterior orientation data from imagery.
The raised solution is rigorous through an orthorectification method pixel to pixel from the most nadiral image, different from the differential methods used in most of the existent programs that were simplified solutions adapted to computer technology of that moment.

3.2 Right Ground Ortho Module: RGO+.

It is an orthorectification module to ground level, which includes an algorithm that searches imagery depending on the incidence angle of the perspective ray. This module supposes the introduction of a new method of Orthorectification and Mosaiking based in an algorithm that searches optimal photographs, not just the minimal distance with respect to the nadiral point considered (known as MOST NADIRAL), but also the optimal incidence angle to avoid presence of "stretching areas" within the final digital orthoimage, method that is called MOST RIGHT.

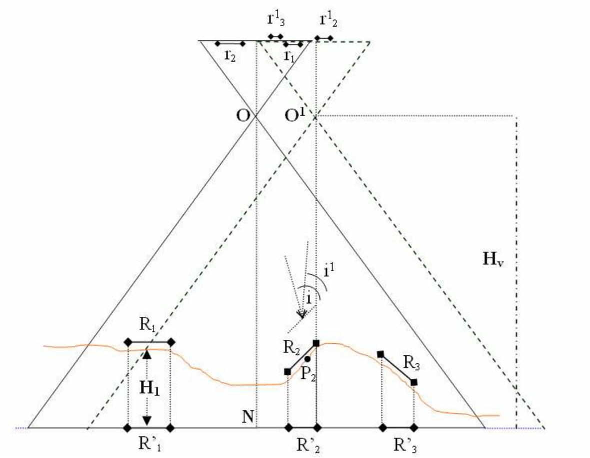

Figure 2. Most Right Method

Usually flights are planned to a scale or resolution that differences of local scale of photography are absorbed. For this height differences within the terrain are taken into account, so that the final scale allows uniform GSD greater than the input GSD, within an admissibility percentage.
However, the slope of the terrain is not taken into account in these calculations, which influences directly in the scale and therefore in the resolution of the imagery.
In figure 2, it can be seen how the solution Most Nadiral offers less resolution for segment R_2 from the image with centre of projection in O^1 that from the image with centre of projection in O.
As the incidence angle i over segment R_2 is greater than angle i^1, we have $r^1{}_2 < r_2$ and therefore:

$$E_{vr_2} = \frac{r_2}{R'_2} > \frac{r^1{}_2}{R'_2} = E_{vr^1{}_2}$$

where $E_{vr^i{}_j}$ is the flight local scale to which the segment R_j is represented in photograph i.
If the sensor resolution is "s", and "g" and "g^1" are the ground resolutions respectively obtained from the imagery with centres in O and O^1, we have:

$$g = \frac{s}{E_{vr_2}} < \frac{s}{E_{vr^1{}_2}} = g^1$$

This is why a priori the improvement of resolution is clear.
If g^0 is the nominal output resolution, it will exist a limited incidence angle i^0, which is a function of the aperture angle of perspective ray and the slope of terrain, just as $g^1 > g^0$, from which there will be a stretch in the imagery for view angles smaller, i.e. where the next relation is not true:
$GSD_{input} / GSD_{output} < 1$.
The optimal incidence angle is obviously the one that is closest to 90º, however it will have to be valuated the advantages and disadvantages of using this algorithm without restrictions.

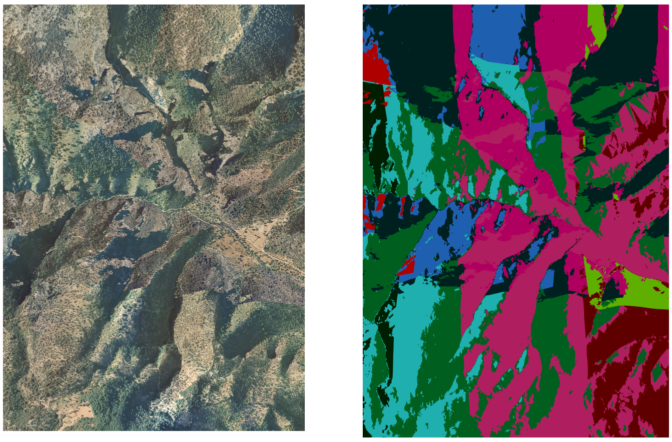

Figure 3. Example of the use of various photographs depending on the best incidence angle, (solution Most Right).

3.3 Right True Orthophoto Module: RTO+.

RTO+ is a true orthorectification module that uses an algorithm of intersection of the perspective ray with the DSM to search imagery with occluded areas due to leaning objects. In this module, an own algorithm was developed to generate true orthophotos using a combined analysis of the optimal incidence angle and the intersections of the ray with defined obstacles within the digital surface model in the nadiral direction. The analysis of visibility is done for each pixel of the orthophoto and for all the photographs in which it will be represented, in increasing order of distance to the corresponding nadiral points, starting by the solution MOST RIGHT. In this way the orthorectification and mosaiking is resolved in one step, just like in the latter module. A height profile is considered from the digital surface model with its origin in the corresponding terrain point, and the longitude that is determined by the maximum possible leaning (Figure 5).

3.4 Light RTO+ Module: LRTO+.

It is a module developed to determine shadow areas within the orthoimage and to enhance them, using the DSM and the information of the true position of the sun. This last module pretends to deal with one of the principal problems of working with orthophotos in urban areas, the presence of shadows that make difficult to interpret final imagery and that arise important problems of radiometry adjustment of orthorectify imagery. Therefore, within this line it was introduced an algorithm of shadow attenuation, based on the precise calculation of the position of the sun for each photograph, from the exposure data from GPS systems, and the digital surface model, combined with the radiometry analysis of digital imagery (intersecting the geometrical model of shadows and the empirical model of shadows represented in the image).
The process was planned in two stages: Detection and Enhancement (lighting).

- In the first place the determination of shadows, based on the same Profiles Method for detection of occluded areas in the sun direction. The position of the sun is estimated in ecliptic coordinates through this formula (data obtained from the Yearbook of the Observatorio Astronómico de Madrid of 2005 (IGN España):

$$\lambda_{\Theta} \cong 279^{o}.77 + 0^{o}.98563 \times d + 1^{o}.915 \times sen(0^{o}.986 \times d - 3^{o}.2) + 0^{o}.02 \times sen(2^{o} \times d - 12^{o})$$
$$\beta_{\Theta} = 0^{o}$$
$$\varepsilon \cong 23^{o}.438641 - 0^{o}.00000036 \times d$$

Where d is the day and the fraction of the year's day.
$(\lambda_{\Theta}, \beta_{\Theta})$ are the ecliptic coordinates of the sun.
ε is the obliquity of the ecliptic.

These are transformed to the horizontal coordinate system (A,h) through the Time Equation and easy spherical trigonometry formulation.
This way, in the same orthorectification process, it is possible to identify those pixels that stay under the influence of a shadow, which can be contrasted with the digital level assigned to that pixel.

- In second place, the local enhancement of digital levels from the image in those zones, using all the radiometric advantages from digital photogrammetric cameras that do the capture in 12bits.

This opens the possibility to increase the possible window of flight for this kind of tasks, which is nowadays very limited to the time of the year (and central hours of the day) when the solar inclination is appropriate.

4. PROPOSAL METHODS FOR TRUE ORTHOPHOTO

The method adopted in the DATOS project, consists in an analysis of the radial angular visibility from the terrain point, in the nadiral direction of each image in which this point appears (Figure 4).
This development, named "Multi-Visibility Analysis of from the object" presents the advantages of angular methods that resolve problems from methods based on Z-Buffer algorithms of DSM´s cell size and the availability of additional information from buildings, and simplifies the true ortho production process, eliminating the need to do mosaiking afterwards and the analysis of occluded areas within images, as both stages are included within the algorithm.

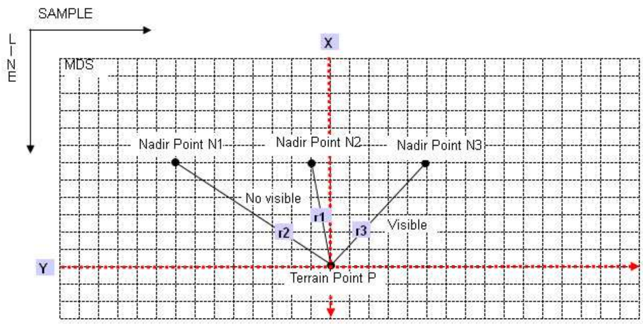

Figure 4.- Multi-Visibility Analysis from the object Method

The main characteristics of the Multi-Visibility Analysis from the object Method used in True Ortho to detect shadows and occlusions are:

- It is a radial method that analyses the visibility of each terrain point in the principal nadiral direction, considering it as the one that defines the closest Nadiral point, and secondly, in increasing order of nadiral distances of photographs where the point can be represented.
- It is an angular method that compares visibility angles of each point from the DSM from the terrain point with respect to the visibility angle of the Perspective Centre. The identification of occlusions method is named "Nadiral Profiles Method" (Figure 5).

- For each terrain point the height profile is determined in the principal radial direction and this is followed from the terrain point throughout the nadiral determining the visibility angles.

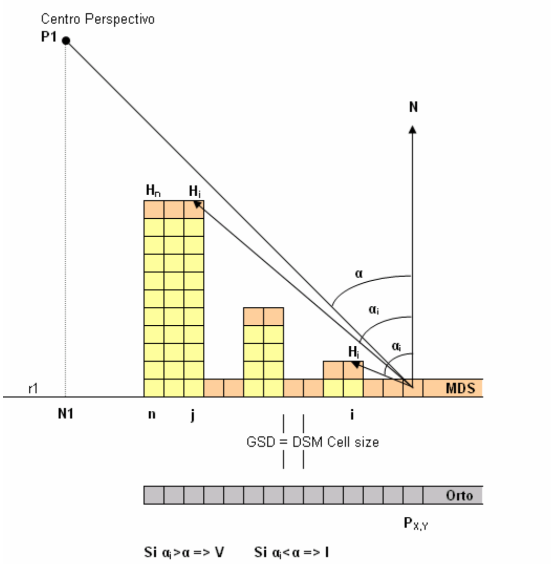

Figure 5.- Nadiral Profiles Method

In this method there are two factors that acquire special importance that will influence in the efficiency and the quality of the rectification.

- The profile longitude, which can be determined by the maximum height of buildings and the maximum terrain slope, assuming a maximum occlusion at the end of the used area of the photograph (eliminating overlapping areas).
- The profile resolution, which can be considerer as one-dimensional, with equal or higher resolution that the one from the DSM.

The problem of orthoimage generation in urban areas is no doubt very complex to resolve, because of the great amount of information that take part in the process (digital images, digital surface models, …), format varieties and storage structures and, obviously, because of the specific cases that exist in resolving real problems.
This is especially interesting if it is considered that within the process very expensive equipment are involved, which limit the number of tests done, for economic reasons.
Modules of orthorectification are based at the moment in compatible data with the software used for the projects, throughout the use of their support files that contain: exterior orientation parameters, sensor auto-calibration parameters, digital surface models; and they generate images in standard format: TIFF with associated files of georreferenciation TFW; all these directly exploitable by any Cartography/GIS user.
The systems has been developed within a C++ environment (Borland Builder C++ 2006, Microsoft Visual Studio 2006) using specific graphic libraries for image handling (Leadtools Medical Imaging Suite v.15). In figure 6 an example of the program's interface is shown.

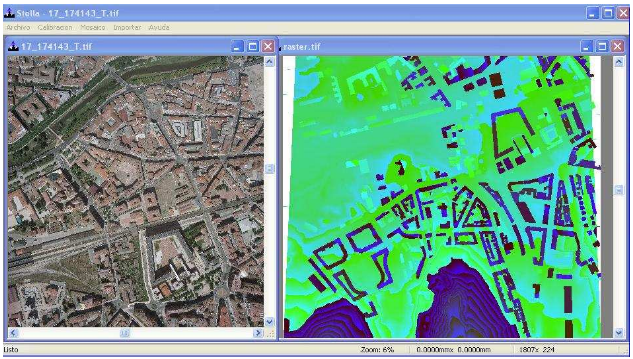

Figure 6. General interface of the Altais-LRTO application.

5. RESULTS

For the development of this program it was essential the information obtained from different tests done throughout the project. The framework of this project used, in one way, synthetic models in which different algorithms were tested over an environment of synthetic images, and on the other way, in a posterior stage, using real imagery obtained with the DMC digital photogrammetric camera.
The use of the model allowed to have a perfectly controlled environment in which different configuration of "flights" could be tested, referring to different scales, overlaps, building typology, … with a terrain information that can be obtained easily, very fast and with no cost. Figure 7 shows a detail of the model used and on the other way, its definitive location to take the images in the Laboratory of Industrial Topography and Calibration of Jaén University. Figure 8 shows examples of results obtained with the ALTAIS-LRTO program from the model's imagery, which procedure of capture, orientation, etc can be consulted in Pérez et al. (2008).

Figure 7.- Model used for development of the software in initial stages getting ready algorithms.

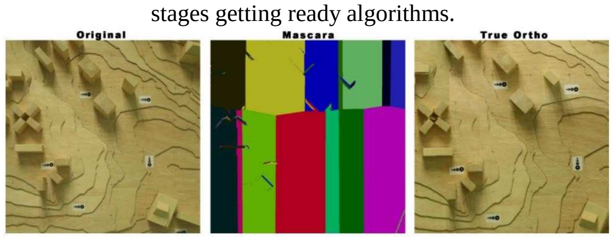

Figure 8.- Example of tests done using the model. RTO+ algorithm preliminary results

Obviously, the objective of having a system to generate orthoimages is not reached unless it is applicable to real imagery that usually is used to generate urban orthoimages. Thus, to complete the tests, a real test was planned and executed additionally, providing maximum quality information required to posterior verification of results derived from it. Real data for this definitive program tests have been captured by the company HIFSA using the digital photogrammetric camera Z/I DMC equipped also with a LIDAR Leica ALS50. This selection has been done after a detailed analysis of the actual problematic of process for orthoimage generation in urban areas in which the company Altais, S.L. has participated. Figure 9 shows in one way an example of one orthoimage obtained using classical methods of orthorectification (Ground Ortho), and on the other way, the orthorectification resulting from using the program ALTAIS-LRTO, in an area in Burgos with a flight from year 2007.

Figure 9.- Example of True Orthorectification using the solution Altais-LRTO.

6. CONCLUSIONS

A new method of orthorectification was developed giving notable improvements compared with commercial systems as it integrate analysis of multiple incidence algorithms:

- Most Right Method. It is an orthorectification and mosaiking method based in spatial resection of the perspective ray of most verticality for each terrain point, i.e. it uses the photography of better perspective for each point.
- Nadiral Profile Method. Equally it is an orthorectification and mosaiking method that resolves the spatial resection of the perspective ray free of occlusions for each point in the terrain. This method, applied to the true position of sun, also determines the shadow areas of the orthophotograph, which can be treated radiometrically, to extract detailed information within the shadow.

The system Altais LRTO resolves problems well known in orthophotography, such as the appearance of stretching areas due to the compression of the input image, where the relationship $GSD_{input}/GSD_{output}<1$ is not true, the true orthorectification of elements within the DSM with no need to use additional volumetric information, not just presenting these in its correct position, with no leaning, but automatically completing the occluded information due to this leaning with the appropriate information showed under the influence of shadows.

ACKNOWLEDGEMENTS

The results exposed in this work belong to the ones obtained in the research project “Development of a true orthoimage generation software as a base for urban territorial information” (Proyecto DATOS) (FIT-340001-2006-41) belonging to the National Plan for R+D+I within the PROFIT program of the State Secretary of Telecommunications and for the Information Society of the Ministry of Industry, Tourism and Commerce.

These activities form part of the R+D+I activities of the research group of “Photogrammetric and Topogrammetric Systems” of Jaén University partially funded by the regional government of Andalusia through the R+D+I Regional Program.

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