BUILDING OF TEXTURED MODELS OF CONSTRUCTIONS WITH IMAGING OF FACADES AND SIDEPIECES AT ORTHOPHOTOS

Prof. Oleksandr Dorozhynskyy
Department of Environmental Engineering and Geodesy
University of Life Sciences in Lublin
Lublin, Poland
e-mail: aldorozh@polynet.lviv.ua

Ihor Kolb, Ph.D.
Department of Photogrammetry and Geoinformatics
Lviv Polytechnic National University
Lviv, Ukraine
e-mail: ihor_z_kolb@lpnu.ua – contact person

Abstract

Information about type of a facade, sidepieces of buildings and constructions, about their height and spatial structure (niches, bows, balconies, etc.) is very useful for numerous practical applications of geoinformatics. Particularly, the information about conditions of buildings, available exits and entrances, window openings, breaches in walls, etc. is of great importance for topographic interpretation, planning operations of search and rescue services, planning the the activity of national security subdivisions. It is not always possible to get a three-dimensional, qualitative textured model of a building or construction due to technological, economic, organizational circumstances. The article describes the way of developing an oblique projection of a textured 3D model of a building, basing on aerial images, and visualize the model at an orthophoto. The work gives examples of practical implementation of the method. The developed model of a building presents exteriority, available entrances, windows, balconies on the facade of the building. Exterior outline of the building image corresponds to its real dimensions at the level of basement. The obtained image of the building on the back of an orthophoto practically gives the information, close to a 3D model of the LOD3 level of details according to CityGML (City Geography Markup Language) standard. In case of necessity, the depiction is supplied with abstracts (notations), defining the values of vertical coordinates of distinguished points of the building outline or elevations above the building basement to its construction elements.

Key words: topographic aerial photography, oblique aerial images, photogrammetric model, orthophoto, facade inspection

Introduction

Information about type of a facade, sidepieces of buildings and constructions, about their height and spatial structure (niches, bows, balconies, etc.) is very useful for numerous practical applications of geoinformatics. Particularly, the information about conditions of buildings, available exits and entrances, window openings, breaches in walls, etc. is of great importance for topographic interpretation, planning ~~of~~ operations of search and rescue services, planning the activity of national security subdivisions. It is not always possible to get a three-dimensional, qualitative textured model of To satisfy such needs, it is necessary to make geo-informational three-dimensional models of constructions, which normally make a part of space models of blocks of settlements or industrial objects. It is not always possible to get a three-dimensional, qualitative textured model of a separate building or construction due to technological, economic, organizational circumstances. Besides aerial photography, it is also necessary to organize a high-cost ground survey of walls, to make measuring at facades, etc. It is not always possible to secure a safe access to the very construction. Moreover, depiction of such model requires powerful computer platforms, which cannot be always applied at a location under particular conditions of rescue operations or war fighting.

Under such conditions, it is much reliable and convenient to use a paper plan or static cartographic picture on the screen of a laptop computer. Users are well acquainted with how to use common topographic plans and orthophotos. However, traditional orthophotos have sufficient restrictions concerning possibilities of representation of three-dimensional information. Texture of the walls of buildings and constructions on a relatively open location is partially and completely represented at aerial images, developed according to the law of central projecting. However, in the process of orthotransformation such information concerning the walls is completely lost, as well all other vertical parts of the objects on the location. It is worth mentioning that 3D stereo observation of aerial images by an operator and automatic digital stereoreconstruction does not always enable creating of a stereopair, representing a definite façade. Even if such stereopairs are available, points at low-contrast walls are not determined in the number, sufficient for a qualitative formation of a texture.

The authors of the article set the task to represent sidepieces of buildings and constructions at orthophotos, to demonstrate them at an orthophoto without violation of any measuring and graphic particularities of the orthophoto outside the boundaries of the buildings and constructions.

Material and methods

The proposed method expects a controlled scale and perspective deformation of the top parts of buildings image. Nevertheless, a bottom part of their representation, as well as the whole orthophoto outside the building boundaries, stays non-deformed. Thus, between the bottom and top parts of the building it gets a space in all directions, which is filled with the texture, which corresponds to a definite part of the wall. The concept of the proposed method is presented by the Fig. 1.

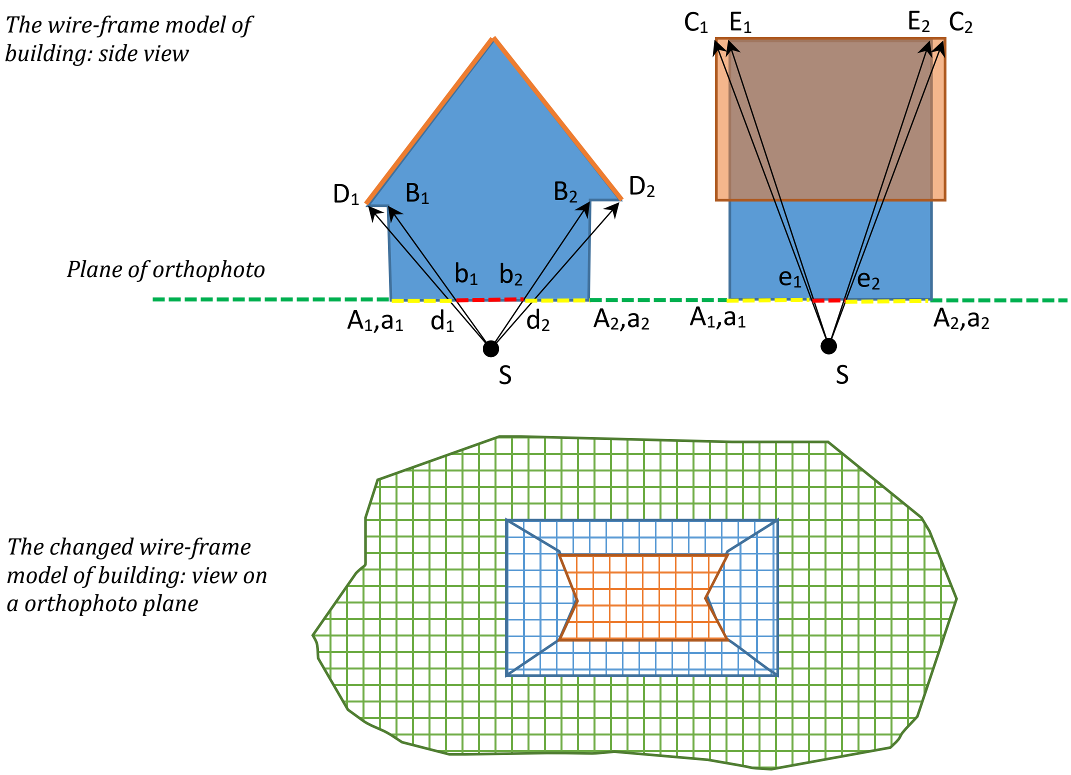

Fig. 1. Geometrical interpretation of the proposed method of formation of a perspective image of a building at an orthophoto.
Source: Own study.

Such representation of buildings and constructions can be done by design of a vector wire-frame model of a building, its further scale transformation according to the mathematical model of perspective geometrical transformation. Afterwards, it is necessary to select an aerial image with the best conditions of representation of a definite plane of a wire-frame model and to design a texture of the plane for representation at the orthophoto.

Implementation of the proposed idea is possible in the environment of GIS-programs, without application of special photogrammetric software.

At the Fig. 1 and Fig. 2, color elements mark:

- Green – non-deformed part of the orthophoto, i.e. area outside the boundaries of a wire-frame model of the building;
- Blue – sidepieces of a wire-frame model, i.e. walls of the building;
- Red – planes, which make roof of the building.

At the Fig. 1, points *A, B* and *a, b* are corresponding points of a wire-frame model of a building and representation of the points at an orthophoto. The latter ones are obtained by means of central projecting of the wire-frame model at the plane of an orthophoto with the center in *S* point. Plan *Xs, Ys* coordinates of the point are the coordinates of the ground centroid in the base of the building. *Zs* coordinate is chosen in relation to the building height. Distance from the orthophoto plane to *S* point is the analogue of the focus *f* distance in formation of the image of central projection with application of optic system lens. That parameter is crucial for measuring of the value of scale deformation of the orthophoto representation. Let us make a collinearity equation for the above-described situation (DOROZHYNSKYY, TUKAJ, 2009):

$$Fx = x - x_0 = -f\,\frac{a_1(X - Xs) + b_1(Y - Ys) + c_1(Z - Zs)}{a_3(X - Xs) + b_3(Y - Ys) + c_3(Z - Zs)}$$
$$Fy = y - y_0 = -f\,\frac{a_2(X - Xs) + b_2(Y - Ys) + c_2(Z - Zs)}{a_3(X - Xs) + b_3(Y - Ys) + c_3(Z - Zs)} \qquad (1)$$

Considering the fact that plane of an orthophoto is horizontal, position of the main point coincides with the plan coordinates of the point of *S* centroid (Fig. 1), the equation (1) for measuring of the position of projection of *X′Y′* points of a wire-frame model in an orthophoto plane will have the following expression:

$$Fx = X' = X - f\,\frac{X - Xs}{Z - Zs}\,, \qquad Fy = Y' = Y - f\,\frac{Y - Ys}{Z - Zs} \qquad (2)$$

where

X,Y are space coordinates of the points of the wire-frame model;

X'Y' are the corresponding coordinates of projection of the wire-frame model points at the orthophoto plane.

Thus, having a wire-frame 3D model of the building, represented in the scale of an orthophoto, it is possible to perform the searched scale-perspective transformation of the orthoimage, using the formulas (GRÖGER et al., 2012). Methods of such model formation are studied in the works of numerous researchers of modern photogrammetry. The researches are first focused on satisfaction of the needs of three-dimensional modeling of cities, where quality of wire-frame models of buildings is of essential importance (ТУЖИЛКИН, 2016; ABDOULAYE, 2015).

There is a classification of wire-frame models according to the degree of detailing (Fig. 2).

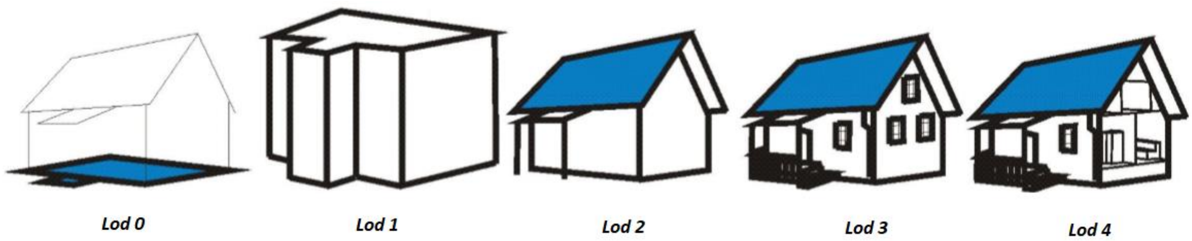

Fig. 2. Modeling of a building in relation to the levels of detailing according to the CityGML standard.
Source: (ТУЖИЛКИН, 2016).

According to the classification, a wire-frame 3D model of a building corresponds to LoD2 level of detailing. Such level of detailing expects a generalized representation of a building geometry by means of the surfaces, limiting its external envelope with the accuracy of up to 2 m. The next level of detailing expects application of an external envelope of an object, which is geometrically more accurate (accuracy of specification of coordinates of the model points is up to 0,5 m), supply of the contours of essential constructive elements of the building, i.e. window and door openings, balconies, stairs, etc. According to technical parameters, models of LOD3 level are best suitable for applied use in emergencies, planning of the efforts of national security subdivisions, assessment of a destruction degree, etc. The proposed method of formation of buildings representation at orthophotos should probably occupy an intermediary position by its functionality between the models of LOD2 and LOD3 detailing levels.

Application of plan aerial images and photogrammetric methods in the practice of three-dimensional modeling of cities is normally restricted by LoD2 levels of modeling, i.e. by creation of a wire-frame model.

Cartometric manipulations or photogrammetric measuring of the points of a stereopair (BALTSAVIAS et al., 1995.) or points of one aerial image (MURTIYOSO et al., 2014) can determine presence of buildings at a location basing on aerial images and can define space coordinates of the elements for a wire-frame model of LOD2 level. Such model is designed by combination of a number of typical constructive elements, i.e. parametrized patterns. The described technology is expected in the digital photogrammetric system «Delta/Digitals» (http://www.vingeo.com), which has 17 pre-determined types of roofs, and it is widely used by other researchers and designers. Automated systems for wire-frame models making operate on the base of the analysis of dense clouds of the points, obtained from the data of LIDAR laser scanning and from stereo representations of perspective aerial images, made by special "oblique cameras" (MC GILL, 2015). It is the known systems «CyberCity-Modeler» («CyberCity 3D Inc.», USA), Rapid 3D Mapping (C3 Technologies, Sweden; Apple, USA), tridicon®BuildingFinder (Geoinformatik, Germany), «Leica Modeling Studio (LMS)» (Leica Geosystems), «CityEngine» (ESRI, USA), PCI Geomatics (Canada), DroneDeploy App., 3D City Database, Building Reconstruction (virtualcity SYSTEMS, Germany) and others. The existing technologies are supplied with the methods of comparison of the corresponding points and common photogrammetric processing of aerial images to ground images (ROTH et al., 2017) and (CAVEGN, HAALA, 2016), data of aviation and ground light identification, archive topographic plans (Chen et al., 2008.), and by inclusion of non-metric images into the process of modeling (CHO, SNAVELY, 2013). There is a current research concerning the potential of the technologies of three-dimensional modeling of cities by space images of extremely high space resolution (TACK et al., 2012).

Results and discussion

Let us give an example of implementation of the proposed way of creation of buildings representation at orthophotos, made by the data of aerial photography with UAV. The authors of the article have designed a wire-frame model of a building in the interactive regime of GIS environment. Contour of the walls base is built on the ground of the map of density of DSM model points (at the Fig. 3 on the left) (NEX et al., 2013; ДОРОЖИНСЬКИЙ, КОЛБ, 2017).

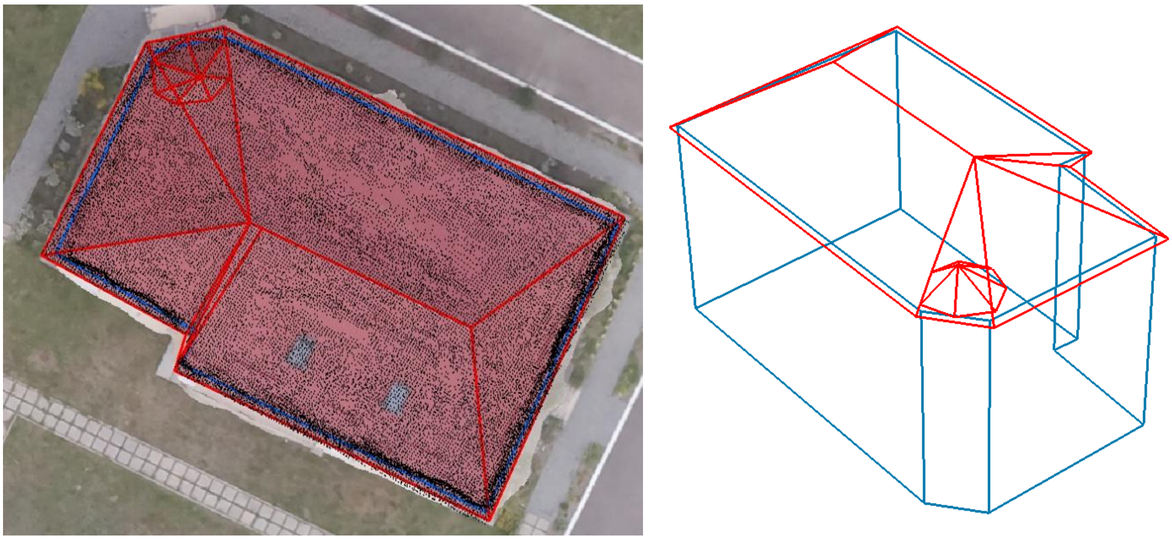

Fig. 3. Vector wire-frame 3D model of a building. Blue color marks wall fragments, red – roof fragments.
Source: Own study.

Representation of a standard orthophoto with 0,07 m resolution helps to depict the grounds which correspond to the plane elements of the building roof. *Z* coordinates are taken as the elements of a wire-frame model on the base of the corresponding values of DSM point model (at the Fig. 3, 3D wire-frame model of a building is depicted on the right).

Using the formulas 2, let us make a project transformation of the coordinates of a wire-frame model points, wich belong to the elements of the building roof. The calculations will help to find of a new position for the points at an orthophoto (Fig. 4a). According to the model, designed by the obtained points, geomentic project transformation of a fragment of a standard orthophoto will cause creation of a new representation of the building roof (Fig. 4b), which corresponds to the idea, demonstrated at the Fig. 1. The changes of the roof image will result in release of a zone at the orthophoto, available for representation of a perspective scale picture of the texture of walls of the building, taken from aerial images.

Fig. 4a. New positions of the points of a contour model of a roof, determined by the formulas 2, define essence of the projective transformation.
Source: Own study.

Fig. 4b. Results of projective transformation of roof representation.
Source: Own study.

Fig. 4c. Results of projective transformation of representation of the top part of a building model. Formation of the grounds for walls texturing.
Source: Own study.

Fig. 4d. Texturing results in obtaining of a new image of a building at an orthophoto.
Source: Own study.

The next step is to make similar projective transformation of coordinates of the points of a wire-frame model, which belong to the top elements of walls of a wire-frame model of the building. Results of that transformation are demonstrated by the Fig. 4c. Thus, there are designed grounds for walls texturing. To create the textures, the authors of the article use fragments of non-processed aerial images, depicting a building from different perspectives. Various scales of aerial images are not the obstacle for performance of the process of transformation of the texture images (Fig. 5).

One should note that orthophotos are normally designed with the resolution, which is less than the resolution of aerial images. Such upscaling of the image makes negative impact on quality of the textures of building facades. Thus, the authors propose to keep separate files of the images of an orthophoto and the images of buildings, designed by the proposed method. While representing the images at screen or using them in preparation of the plan to printing, they overlap as separate raster cartographic layers (Fig. 6).

Conclusions

The developed model of a building represents exteriority, available entrances, windows, balconies on the facade of the building. Facade colors are correctly represented. Exterior outline of the building image (marked by blue color at the Fig. 6) corresponds to its real dimensions at the level of basement. The obtained image of the building at an orthophoto practically gives information at the level of a 3D model of LOD3 level of detailing. In case of the necessity to represent the height, the picture is supplied with abstracts (notations), which define the values of height exceeds over the basement of the building in relation to constructive elements of the building. Some of land surface images, covered by bows of buildings roofs, can also be substituted by the fragments of representations of aerial images, as it is made in photogrammetric programs (HOW TO IMPROVE..., 2018).

Finally, the proposed idea of representation of building facades has been experimentally proven and such way of modeling can be used for fast and visible 3D representation of facades and sidepieces of buildings.

Fig. 5. Set of fragments of non-processed aerial images, selected for texturing of a wire-frame model of a building.
Source: Own study.

Fig. 6. Comparison of the two methods of formation of buildings images at an orthophoto: on the left – the traditional method, on the right – the proposed method.
Source: Own study.

References

ABDOULAYE, A. D., 2015. *Application des cartes combinatoires à la modélisation géométrique et sémantique des bâtiments. Modélisation et simulation. (Application of combinatorial maps to the geometric and semantic mode of buildings. Modernisation and simulation).* Thesis, Universite Claude Bernard - Lyon I, p. 202.

BALTSAVIAS, E., MASON, S., STALLMAN, D., 1995. *Use of DTMs/DSMs and Orthoimages to Support Building Extraction*. In: Workshop on "Automatic Extraction of Man-Made Objects from Aerial and Space Images", Ascona, Switzerland, 24-28, April, 1995. https://www.researchcollection.ethz.ch/bitstream/handle/20.500.11850/146261/eth-25207-01.pdf?sequence=1&isAllowed=y (access 28.03.2018)

CAVEGN, S., HAALA, N. 2016. *Image-Based Mobile Mapping for 3D Urban Data Capture*. Photogrammetric Engineering & Remote Sensing, 82 (12): 925–933.

CHEN, L.-C., TEO, T.-A., KUO, C.-Y. AND RAU, J.-Y., 2008. *Shaping polyhedral buildings by the fusion of vector maps and LiDAR point clouds*. Photogrammetric Engineering & Remote Sensing, 74(9):1147–1157.

CHO, P., SNAVELY, N., 2013. *3D Exploitation of 2D Imagery*. Lincoln laboratory journal, 20(1): 105-137.

DOROZHYNSKYY, O., TUKAJ, R., 2009. Fotogrammetria (Photogrammetry). Wydawnictwo Politechniki Lwowskiej, Lwow-Krakow., p. 315.

GRÖGER, G., KOLBE, T. H., NAGEL, C., 2012. OGC City Geography Markup Language (CityGML) Encoding Standard, Version 2.0.0. Open Geospatial Consortium Inc.(OGC Doc. No. 12–019), p. 326.

H*OW TO IMPROVE the Visual Aspect of Buildings in the Orthomosaic with the Mosaic-Editor*. https://support.pix4d.com/hc/en-us/articles/202559939-How-to-improve-the-Visual-Aspect-of-Buildings-in-the-Orthomosaic-with-the-Mosaic-Editor. (access 28.03.2018).

MC GILL, A. 2015. *LOD2 From Vertical & Oblique Imagery*. Oblique Cameras & Dense Image Matching. Southampton 19-20 Oct 2015. http://www.eurosdr.net/sites/default/files/images/inline/08_mcgill-eurosdr_isprs-southampton2015.pdf. (access 28.03.2018).

MURTIYOSO, A., REMONDINO, F., RUPNIK, E., NEX, F., GRUSSENMEYER, P., 2014. *Oblique aerial photography tool for building inspection and damage assessment*. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XL-1, p.309-313.

NEX, F., RUPNIK, E., REMONDINO, F. 2013. *Building footprints extraction from oblique imagery*. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, II-3/W3, p. 61-66.

ROTH, L., KUHN, A., MAYER, H. 2017. *Wide-Baseline Image Matching with Projective View Synthesis and Calibrated Geometric Verification.* PFG – Journal of Photogrammetry, Remote Sensing and Geoinformation Science, 85: 85-95.

TACK, F., BUYUKSALIH, G. AND GOOSSENS, R. 2012. *3D building reconstruction based on given ground plan information and surface models extracted from spaceborne imagery*. ISPRS Journal of Photogrammetry and Remote Sensing, 67:285–290.

ДОРОЖИНСЬКИЙ, О., КОЛБ, І. 2017. *Специфічний спосіб побудови ортофотозображень* (*The special method of orthophoto plane construction*). Environmental Monitoring, Photogrammetry, Geoinformatics – modern technologies and development perspectives. Lviv 14–16 September 2017. https://drive.google.com/drive/folders/0B2JnhO95MVjeOGhLSlhNQWxNZU0 (access 28.03.2018).

ТУЖИЛКИН, А. Ю., 2016. *Модели и алгоритмы реконструкции трехмерных сцен на основе спутниковых изображений и априорной информации (Models and algorithms for reconstruction of three-dimensional scenes based on satellite images and a priori information)*. Thesis, Nizhny Novgorod State Technical University, p. 141.