

## METHOD FOR CREATING DIGITAL ORTHOPHOTOMAPS OF INCREASED INFORMATIONAL VALUE

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### Summary

The paper discusses how to apply the information on the density of three-dimensional point cloud, obtained as a result of computer stereo reconstruction of an area, based on aerial images. Images of high objects – particularly walls, treetops, bushes, etc. – in a particular area are used to create a point density map by means of GIS instruments. The information enables redistribution of the weight of cloud points in order to intensify or reduce their impact on the digital model of an area, or orthophotomap. The proposed method has been used to create orthophotomaps based on aerial images obtained from UAS.

### Keywords

aerial photography • dense stereo reconstruction • digital orthophoto • building footprint extraction

### Introduction

A substantial impact on the tendencies of modern photogrammetry development is made by some significant conditions, including:

- introducing the methods of computer stereo reconstruction into photogrammetric process, supplying automation of the imaging processes, measured both for the images orientation, and for obtaining three-dimensional models of a location; a three dimensional cloud of high density points is a particular result of computer stereo reconstruction, and the cloud is the base for developing other digital models of the location, i.e. 2D orthophotomaps, topographic plans, 3D models of cities and separate objects;
- wide spreading of aerial photography by unmanned aircraft systems, supplying survey of a location with the set photo overlap, direct geo-referencing while surveying; such approach is simple and economically beneficial, in organizational context, because of the way the aerial images are obtained;
- an opportunity to apply photogrammetric software modules in the instrumental GIS environment, supporting simplification of the processes of obtaining aerial im-

ages, and automation of photogrammetric processing. Application of the above results in digital 2D and 3D models of a location for geographic information systems, particularly orthophotomaps.

It is a well-known fact that orthophotomaps occupy a leading position in the line of modern photogrammetric products. Their widespread popularity is supported by the demand for topographic materials of a definite range of geometric accuracy, informational capacity and level of availability at the market of geospatial data, which can be used in geographic information systems, both for selection of information about separate objects, and for obtaining quantitative and qualitative information about the landscape (the territory) in general. Photogrammetric technology for obtaining orthophotomaps admits application of images of completely different kinds (Space, Aerial, Terrestrial), made by nonmetric and calibrated cameras. Almost all processes in the photogrammetric technology are automated. At the same time, the procedure of making a quality orthophotomap, meeting the requirements of technical standards (including national or industry-wide norms), still remains in the scope of high professionalism [Braun 2003].

It is worth mentioning that orthophotomaps include also a substantial excess of information, from the point of view of classical topography (for example the colour of roofs, puddles on the roads and streets, as well as temporary, mobile objects, such as automobiles, etc.). Some useful information, registered on aerial images, cannot be depicted in orthophotomaps. Orthophotomaps are burdened with the presence of invisible zones, caused by high objects, typically treetops and protruding parts of buildings' roofs.

That latter peculiarity is a serious obstacle to a wider application of orthophotomaps, particularly in Cadaster Information Systems, where it is necessary to reproduce contours of buildings and other structures according to their foundations, or the position of their walls, with a complete depiction of the elements of infrastructure and utility networks, and other boundaries of natural and man-made objects.

## Related Work

In the modern automated technology of orthophotomap making, application of a dense stereo reconstruction is expected, which results in the creation of a three-dimensional cloud of points. Among the methods of stereo reconstruction, the SGM algorithm, proposed by Heiko Hirschmuller [Hirschmuller 2005] is widely used. It has many variants of implementation in photogrammetric software packages [Rothermel et al. 2012]. The method produces reliable results, while developing three-dimensional models of a location, based on various materials, i.e. images taken from space [Sonyushkin 2016], aerial images taken from the plane [Haala and Rothermel 2013], and images obtained from the UAS [Rothermel et al. 2014], whereas it has prospects for fast online processing of the images [Gehrig 2009]. The aforementioned method, and other modern findings in the field of computer stereo reconstruction, based on digital imaging, supply geometrically accurate and extremely dense (commensurable with distinction of the

very images) three-dimensional clouds of points [Remondino et al. 2013]. Practically, this provides us with identification and measurement of corresponding points of digital stereo pairs even under unfavourable conditions of photography, such as low contrast, presence of few texture plots in the location, etc. [Sauerbier 2004]. Processing of dense three-dimensional clouds of points can facilitate the extraction of structural peculiarities of objects, the development of relief models, and the performance of other procedures of geographic information modelling, including the design of orthophotomaps [Maltezos, Ioannidis 2015; Karantzalosa et al. 2015; Cho, Snavely 2013].

In ortho-rectification, a cloud of points is used as a digital surface model, DSM for short. A DSM model contains information about location and geometry of buildings, and it is very important for geographic information modelling, and particularly for the development of a correct orthophotomap. There are well-known approaches to the development and application of DTM and DSM models, for instance, a method of developing altimetric model gradient for the formulation of a hypothesis about the building's presence [Baltsavias, Mason, Stallmann 1995]. However, the method is very sensitive to geometrical distinction of an initial surface model. In the work by Nex, Rupnik, and Remondino [2013], the hypothesis about the identity of a point at a vertical plane of walls is checked based on the assessment of horizontality (up to  $10^\circ$ ) of a normal line to the local plane (area of  $1 \text{ m}^2$ ), developed around the point. After the filtration and rasterization, a planimetric raster image of the building's footprints is obtained. The authors pay attention to the concentration of wall points in such an image. The process enables approximate detection of the building's footprints, because most of the points belong to the pixel, which defines the planimetric position of the walls. However, inaccurate determination of the plan's coordinates of points in the cloud, revealed in a noise near the real position of the façades, prevents us from obtaining an exact position of each wall. Afterwards, the authors estimate the distribution of points in the area, and thus, they detect the points, belonging to plants, balconies and other elements of landscape and buildings. The work by Hsua, Jhanb and Rau [2012] also applies the effect of points' consolidation on the horizontal  $XY$  area, belonging to the façades. The authors propose to develop an index map, which provides colour information concerning a façade point according to the local exceeded heights, while the other pixels, not belonging to the façade, are marked with 0 colour. Afterwards, the image is segmented according to the colour, having been averaged for each segment. The method is tested at perspective images, but only according to one stereo pair, i.e. in such case, consolidation effect is poorly expressed, and there are many zones of shading.

Although each point in the cloud, obtained by computer stereo reconstruction of spatial coordinates, is supplied with the values of RGB colours [LAS specification 2013], in the process of new orthophotomap making, new values of colours are found by interpolation from the pixels of the initial images. There is an exception, i.e. in the method of orthophotomap making, where a three-dimensional point model, generated through computer stereo reconstruction based on aero-spatial or surface images, is projected on the definite area [Skarlatos 1998; Skarlatos, Kiparissi and Theodoridou 2013]. The expectation of the method is to generate a DSM with the density that is

commensurable with the spatial distinction of the designed orthophotomap, and to subsequently apply it in short-base photogrammetry, securing the production of a true orthophoto [Georgopoulos, Makris, Dermentzopoulos 2005]. Radiometric distortions of images of location objects, by mixing the points' colours in the interpolation of a colour for pixels of an orthophotomap, as well as some other problems, constitute substantial drawbacks of this particular method.

Approaches to the detection of vegetation structures and buildings using point classification are well developed for the processing of the data, which is obtained from laser scanning. They mainly apply the analysis of local geometrical properties (that is, the local geometry features analysis), such as height, local level of a point's height over the neighbouring points, intensity of reflection, and intensity of the registered brightness (return intensity, and image intensity) [Maltezos et al. 2015]. Some authors focus their attention on the methods of complex application of LIDAR data, and multi-spectral photography as well as aerial surveying of high geometric differentiation in RGB format with spectral data of distant probing. The first sources supply the development of a high quality geometric model, and the latter are needed for the detection of a type of object according to spectral peculiarities of its depiction [Acar et al. 2017; Avbelja et al. 2013]. Ok [2009] proposes to use vegetation indexes, measured according to RGB depiction, for the classification of vegetation and man-made layers in order to use only the images, and no other sources of data.

Great opportunities to determine boundaries of buildings and other objects are supplied by aerial photography with the application of perspective cameras [Nex, Rupnik, Remondino 2013]. However, such surveying systems are still not much used for the UAS-platforms, and they tend to be applied in particular cases when it is necessary to develop a high-detailed 3D model of cities with façade texturing.

## Methodology

The aim of the work is to develop a methodology for the application of a dense point cloud, obtained by stereo reconstruction of aerial images, and the development of the way of depicting topographic information, partially enclosed within high objects (building roofs, canopy of trees, etc.) on orthophotomaps. It is helpful in depicting real contours of building walls and objects of underlying surface, as well as in the automatic elimination of images of objects that were mobile at the moment of photography (i.e. non-topographic objects such as automobiles, people, etc.), from orthophotomaps.

A point model of a visible land surface (a cloud of points) is considered the initial model, developed by computer stereo reconstruction, based on the aerial images of location, made by UAS. In the model, there is an effect of point consolidation on the land plots with high objects, such as buildings, fences, or high plants. In many cases, this results in the depiction of the same object of location from different perspectives, relating to the centres of projection of the images, on which the point is depicted. The effect is highly intensified when the images are inclined, or when they have large mutual overlap that is typical of aerial photography made by UAS or by applying special

cameras for perspective survey. For a location point, having  $(X, Y)$  coordinates and a high object on it, the images, which are obtained from different spatial viewpoints, depict different parts of a vertical profile of the object and the information can be used for the reproduction of spatial structure of the building's model. Thus, a map of the density of DSM model's points in the area  $(X, Y)$  demonstrates consolidation of points in the places, where the points with similar plane coordinates have different marks of height, and thus, the map actually shows contours of the external walls of buildings, and the external boundaries of treetops. Unlike this particular kind of map, common maps of vertical gradient of the surface demonstrate high objects in full (such as roof of a building, or top of a tree).

Then, weight coefficients of the points of a visible land surface model are redistributed according to different approaches to land plots, where local consolidation of the cloud of points and for land plots are found (i.e. in which external contours the high objects are present), and where there is no such consolidation (open places of location, roofs above the internal parts of buildings).

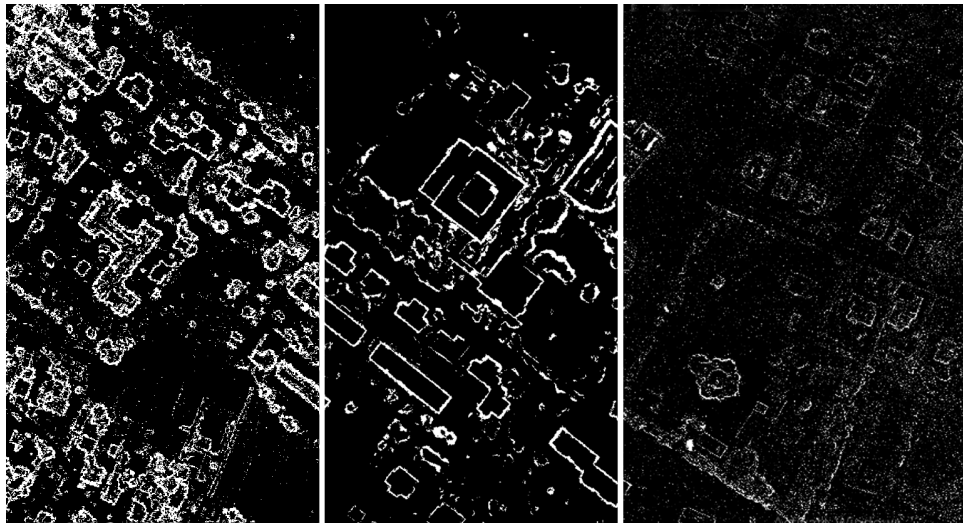
For land plots of orthophotomaps, where there is no substantial consolidation of DSM model, colour coordinates are determined by traditional methods of direct and reverse projecting [Dorozhynskyy, Tukai 2008, p. 259]. In other cases, the rule of assignment of weight coefficients for the points, for which they are applied in colour measuring for pixels of the designed raster orthophotomap, is defined depending on the vertical spatial distribution of points. Increasing weight for the points, which are located lower than the determined threshold exceeding in a circle of a particular diameter around the centre of the developed pixel of a raster orthophotomap, values of colours for pixels of the designed orthophotomap are interpolated. If the points, which are located within the boundaries of particular land plots with considerable local consolidation of the model, and which have the height above the determined local threshold (determined by the type of the location and the character of the building) in the given circle around the developed pixel of raster orthophotomap, are assigned with a high weight coefficient, the resulting orthophotomap will depict surface of high objects, i.e. roofs, canopy of trees, etc. In other cases, the orthophotomap will demonstrate lower parts of objects, that is walls and foundations, underlying the surface under the canopy of trees.

In order to eliminate the images of mobile objects (such as moving vehicles), it is possible to apply the effect of colour balancing for points of the location, with an almost uniform colour on many images, but a different one on the images, where moving cars occur.

## Experiments

The proposed method of orthophotomaps' development has been tested on the materials from the aerial photography of a village by the UAS of airborne type. Level difference on the location constitutes 15 m. Height of photography is 200 m. Inclinations of images constitute  $\pm 9^\circ$  in relation to the horizontal plane. Pixel size of images on the location constitutes  $gsd = 0,05 \text{ m/pixel}$ .

A map of density of a point DSM model, designed in the *ArcGIS* geographic information system, gives a clear contour depiction of buildings and the canopy of trees (Figure 1). A threshold value of density for the abovementioned example is determined at 20 points/m<sup>2</sup>. This enables the development of a raster binary mask-map of high objects. Figure 1 gives comparison of a map of point density versus maps of high objects, obtained through morphometric analysis of the DSM surface. All presented raster maps have spatial distinction of 0.1 m.



Source: authors' study

Fig. 1. Maps for the determination of boundaries of high objects in the location: Left: Classification of slopes with steepness (> 55°). Centre: Classification of DSM surface according to local height exceeding (> 3 m). Right: Map of density of three-dimensional cloud of points

For pixels of an orthophotomap, which are located within the mask of high objects, measuring of colour coordinates (Red, Green, Blue) for pixels of the designed orthophotomap is conducted by means of interpolation, that is by applying the method of inverse distance weighting (IDW) [Watson and Philip 1985], where weights are determined according to the values of Z coordinates of the points in the DSM model. For other pixels of the orthophotomap (other than the high objects), the values of colours are determined according to the principles of direct and reverse projection of an aerial image pixel on the orthophotomap. The resulting orthophotomap depicts walls of buildings (Figure 2, right), and partially – underlying surface under the canopy of trees (Figure 3, right).





Source: authors' study

**Fig. 2.** Fragments of a building's image on a traditional orthophotomap (left) and on the orthophotomap designed using the proposed method (right)



Source: authors' study

**Fig. 3.** Depiction of tree canopy on a traditional orthophotomap (left) and on the orthophotomap designed using the proposed method (right)

The orthophotomap, designed using the method described herein, can depict sheds, and roofs of buildings without walls. Images of such structures, tents and roofs produce a less dense texture, comparing to the roofs of buildings with walls (Figure 4). Images of mobile objects are also automatically eliminated.

Figure 5 provides depiction of a fragment of a road on the orthophotomap designed according to the existing (traditional) technology, followed by a depiction of the location's fragment on the orthophotomap designed using the method proposed by the authors, which helps to eliminate non-topographic information (such as moving vehicles) from the presentation.

The proposed technique is much simpler in the way of implementation, compared to, for example, the probability method of formation of orthophotomap presentation, which also helps to eliminate mobile objects out of the image [Strecha, Van Gool and Fua 2008].



Source: authors' study

**Fig. 4.** Depiction of a tent on a standard orthophotomap (left) and on the orthophotomap designed using the proposed method (right)



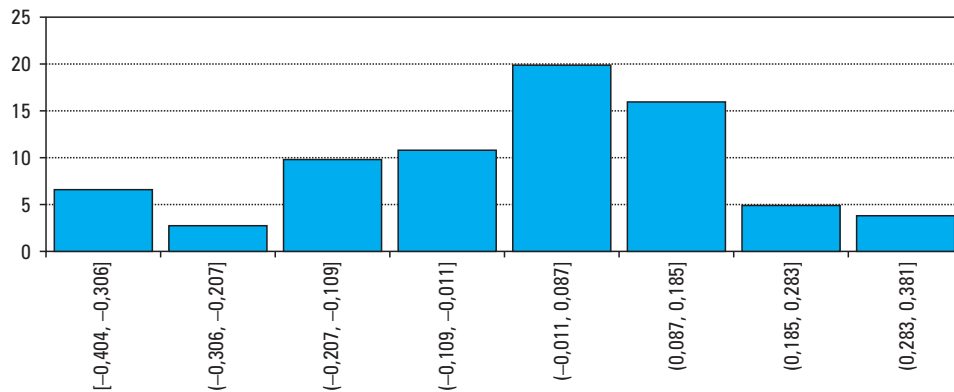
Source: authors' study

**Fig. 5.** Depiction of roads on a traditional orthophotomap (left) and on the orthophotomap, designed using the proposed method (right)

An orthophotomap, designed using the method described by the authors, was vectorized in the *ArcGIS* software in order to develop a topographic plan of the location. The obtained contours of the buildings, particularly the length of their walls, were compared to the length values, measured on the location with a laser distance meter. Control measuring of length of 77 walls has been conducted. Distribution of errors of wall length measurements is demonstrated in Figure 6.

As demonstrated by the histogram, in the aforementioned example, the principal weight of errors of wall length measurements does not exceed 0.2 m. The average error of the measurement of walls' length constitutes  $m_L = 0.19 \pm 0.04$  m. The obtained estimates correspond to the requirements to topographical and cadastral plans in 1 : 1000 scale, remaining in force in Ukraine.





Source: authors' study

**Fig. 6.** Histogram of the distribution of errors of wall length measurements according to the orthophotomap

## 6. Conclusion

The proposed approach supplies a possibility to depict the contours of buildings' walls, which are covered by roofs, and objects under the canopy of trees on orthophotomaps, as well as helping to eliminate the images of mobile non-topographic objects from the orthophotomaps. The orthophotomaps, designed using the proposed method, include new information, which is important to consumers, and they can be further used for reliable and more accurate geometrical detection and vectorization (contouring) of topographic objects.

In the proposed methodology, all technological processes can be performed in the environment of instrumental geographic information systems, without the application of expensive technology of collecting spatial information at digital photogrammetric stations.

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