BUILDINGS' MODELLING FOR DIGITAL ORTHORECTIFICATION OF URBAN AREAS IMAGES

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ABSTRACT:

Orthophoto production is one of the main photogrammetric tasks. The usage of digital photogrammetric stations allows precise orthorectification based on the pixel resolution basis. Different data sources are used for production of DEM based on survey data, contour line maps, stereo images, RADAR or LIDAR data and combinations of them. This technique requires generation of DEM with high accuracy. One of the latest technologies for DEM creation is based on the correlation procedures of digital stereo pairs.
A two-steps procedure for processing of generated model is suggested to solve this problem. Initially the DEM is produced without taking into account the buildings. A complex model of buildings and surrounding terrain is suggested that is suitable for mapping, orthorectification and 3-D modelling. The suggested model has hierarchical structure and describes main part of buildings as walls, roofs and subparts like balconies, staircases. It is suitable for description of spatial information, oriented for digital processing of stereo images. The description of information is formulated, based on the methods of formal grammars. The several level of production rules are formulated, which are corresponding to separation of object into subparts, the generation of subparts and the producing of surfaces from graphic primitives. The software arrangement is discussed, that corresponds to application of grammar rules, which are convenient for automatic processing of digital stereo pairs. The introduced model is used for image interpretation and restoration of objects from their stereo images.
The generated model of objects in urban areas is applied for image orthorectification. The areas of buildings' roofs, walls, shadows and visible terrain were separated. The used vector model of buildings is projected over the initial images to separate them in areas of terrain, buildings, walls, invisible faces. The procedure is extended for roofs or balconies at different heights, which are overlapping in images. This allows the segmentation of DEM into areas and independent control of parameters for plane surfaces and curved surfaces or natural objects like terrain. The model of visible terrain is extrapolated over the shadow areas and the areas of buildings. After that separate models are superimposed to produce final surface model that is used for orthorectification. The modification of index matrix method is applied for orthophoto generation. The several levels mask is created. It takes into account the overlapping of building over terrain, over adjacent building and overlapping of parts of the same building. The orthophoto image is separated into parts – for buildings' roofs and walls and for surrounding terrain, and for overlapping parts. The superimposition and mosaic creation from rectified images is made as a final step of the procedure.

1. INTRODUCTION

1.1 Orthorectfication of Scenes Containing Buildings

The photogrammetric generation of models from scenes containing man-made objects has its peculiarities which are similar for tasks in for orthorectification of terrain and buildings and generation of photo-realistic models in architectural photogrammetry. The common problem is the method of generation of model, its complexity and level of particularity. Main problems that have to be solved for creation of photogrammetric models of buildings are used technology schemes for generation of such models, methods for their description and generation and procedures for transformation of data format of model into format suitable for corresponding hard copy products or dynamic visualization. This requires simultaneous solving of the following three basic tasks: adequate model as combination of vector and raster data, reliability of the generated model from different sources and preliminary information for objects data sets, correspondence between model formats and visualization procedures.
Digital presentation and archiving of buildings requires simultaneous usage and data fusion from aerial or close range photogrammetry, laser scanning, digital photogrammetry and image processing techniques. Main tasks to be solved are photometric and geometric reliability between the object and the model. The process of generation of 3D models of architectural objects requires solving the task of generation of 3D skeleton models, decomposition the images of the object into separate parts and appropriate processing of decomposed parts and adequate method for interpolation of object surfaces.
For processing of photogrammetric information is typical usage of space information. The analysis of images in urban areas is very difficult due to the buildings and artificial objects. The large displacements, hiding of terrain and hiding the parts of adjacent objects and influence of the shadows generate very complicated images. Similar problems arise for processing of images in close range photogrammetry for which there are important protruding parts of objects. This produces problems for automatic identification of corresponding parts in stereo images of such objects or territories.
The influence of quality of DEM over the geometric precision of orthoimage is analysed in (Pala V., Albiol R., 2002). A geometric correction algorithm is applied for combination of separate parts of orthoimages from different views of the same area to solve the problems with the hidden parts of terrain. Importance of including DEM in orthorectification process is analysed in (Jauregui M., Vilchez J., Chacon L., 2000).
Usage of digital building model for accurate orthophoto generation is presented in (Bock-Mo Y., Eui-Myoung K., In-

Tae Y., 2000). The process of orthorectification is preceding by automatic building extraction.

In semi-automatic procedures for orthorectification of building images it is possible excluding of special kind of lines for such objects – like border lines, which allow excluding of unwanted parts of object model. The structure of spatial information is very important for reliability and speed of processing in such systems.

1.2 Automatic Building Reconstruction

Building detection and reconstruction is based on different techniques and uses wide variety of procedures. Different classification schemes are suggested for image processing and interpretation, taking into accounts the shape and height characteristics of buildings (Weidner U., Förstner W., 1995). The semi-automatic procedures for building detection are developed, which are based on LSQM matching, usages the geometric characteristics in object space (Zhang, Z., Zhang, J., 2000). Involving the geometrical constrains of building roofs gives possibilities for semi-automatic building extraction. There are a lot of investigations in which the shadow information is connected with geometric characteristic of objects.

The building analyses process is based on object models, which are using the verification of feature sets (Ameri, B., 2000). The development of this ides is realized in procedure taking into account the topological and geometric characteristics of objects in reconstruction of regular shape faces, which approach is implemented in (Heuel, S., Förstner, W., Lang, F., 2000). Some problems of structural approach to man-made objects are discussed in (Michaelson, E., Tilla, U., 2000). Model based methods are considered using geometric, topologic and structural knowledge based on polyhedral parametric or generic models. Increasing the accuracy of processing is achieved by applying of data base for roof corners (Chio, S.H., Wang, S.C., Wrobel, B., 2000). The procedure for building extraction from high-resolution Digital Surface models containing terrain and buildings information is suggested in (Weidner U., 1996). The building reconstruction is based on the usage of parametric and prismatic building models. There are developed integrated algorithms, which apply data fusion of stereo images, GIS data or digital map information (Suveg, I., Vosselman, G., 2000].

The down to up procedure for building detection is introduced in (Zhao, B., Trinder, J.C., 2000). The hierarchical approach consists of three major stages: building detection, building segment extraction, 3D feature matching and building modelling. The hierarchical approach for building reconstruction using 3D information, such as color, texture, or shadow and reflectance is introduced by (Seresht M.S., Azizi A., 2000). The structural approach for generation of object model from aerial images of urban scenes is suggested in (Stilla U., Jurkiewitcz K., 1996). A bottom to up solving procedure is tested for these purposes.

Utilization of reliable procedure for building extraction and reconstruction which is compatible with processed images is very important for quality of orthorectification process.

2. MODEL STRUCTURE

2.1 Image Description

Main method of description is based on the topological properties of areas in the stereo images. A picture language grammar technique could be applied to formalise the process of image description and to cover different variants of image configurations. Such approach is very large used for description of two dimensional or three dimensional images [Fu, 1982]. The formalised the process of description of contour images and generation of hierarchical description of image has to be enlarged for images of 3D objects and to involve additional information. The information that has to be taken into account includes the parallax of contour lines, the position of object relatively to centre of the photo and topological properties of areas in separate images. In this situation only the walls oriented to the centre of photo could generate visible areas in image. The main properties of image description have to take into account the relation between areas into image and connection between areas and contours. The arcs are used as main primary elements for description. Arcs present the segments of lines between two points of connection. From topological point of view such points are only points of connection of more than two arcs by taking into account the type of arcs (wall edges, foundation border and so on). By this reason the segmentation of arcs has to be applied. The main topological properties that have to be taken into account are the relation of adjacent areas, clusters of areas, included clusters of areas, hanging areas (with only one point of connection). To take into account the specific properties of artificial objects have to be involved areas of types roofs, walls, shadows, hidden terrain or roof areas).

For purposes of contour description only the tie points and arcs could be used. In such situation it would be difficult to generate relation between areas. Usage of only topological properties of areas and their relation would increase difficulties in contour generation and arcs processing.

In general case the solution is very complicated but applying the restriction of relatively small angles between the projection rays and vertical planes (as walls) the presentation could be simplified. Taking into account such restriction the following groups of arcs could be formulated:

1. Arcs without changes in height between two areas or with relatively low difference in slope;
2. Arcs with jump in height between two adjacent areas;
3. Arcs defining break in surface slope, not in height.

In situation if nodes are marked only at that points where more than two arcs are connected some combination of height arcs could appear and should be added to terminal arcs set.

It is necessary to be mentioned that not all topological types for different height types of arc exist. According to this the following extended set of topological and height types of arcs are possible that are forming the set of finite elements of grammar.

1. Non connected elements:
2. Second order connected elements (one pointer to inside cluster list and one implied connection to own contour):
3. Third order connected elements containing two pointers to the next arcs of the own and adjacent contour and one pointer to main arc of the own contour, or to the main arc the upper level contour for element of type d:
4. Fourth order connected elements (two pointers to internal and external contour and one pointer to internal isolated cluster list and one implied connection to own contour):
5. Fifth order connected elements (two pointers to internal and external contour, one implied connection to own contour, one pointer to internal isolated cluster list and one pointer to the next cluster).

2.2 Description in 3D Space

The basis of description is presentation in 3D space, i.e. the presentation of objects as 3-dimentional. The topological and geometrical dispositions are substantial. For topological description it is applied a hierarchical structure, which is based on dividing the objects into object groups. Every object group can contain the adjacent set of objects cluster of objects) or area of sub-objects, which distributed regularly or randomly. At the lowest level are used sub-objects, which are described by their surfaces. The object groups and sub-objects contain information about the relation and connection between them. Two main groups of factors are taken into account – the possibility for storage the description into data base and formal structural description and its generation by picture grammar. The corresponding tables forming structural description are separated in following groups: Objects, Sub-objects, Faces, 3D Arcs and Nodes. Such description is presented in (Marinov B.D., 2002). Extension of this idea to cover description of group of buildings and the objects that consists of sets of objects groups. A simple description of building object includes: roofs, walls, foundation and stairs.

Object coordinates define the base point position in coordinate system of scene (area of description). Object consists of parts named ObjGroup. Object Group may contain another Object groups or SubObject. The quadruple tree is used for production of this description.

The table of sub-objects contains information about the object and its neighbours. They are described by their faces. The table has the form

Arc table contains information for arcs with two faces from both sides of the arc:

Table defining nodes has the following form:

There are additional tables, which are describing coordinate information. They are vectors of origin (Position) and orientation (Rotation). Another two tables describe surfaces and arc segments. (Surfaces, Segments).

Such organization of information is compromise between memory requirements and speed of data access. The cluster arrangement of information requires more memory allocation for description but increase the speed of processing. This organization is adopted for presentation analyses and presentation of space information for object and sets of objects. Larger segment size increases the speed of processing but consumes more memory for short segments.

3. FORMULATION OF PICTURE GRAMMAR FOR MODEL DESCRIPTION

3.1 Picture Description Languages

Picture description languages are widely used for presentation of 2D and 3D objects and their images (*Fu, K.S.*, 1982). The necessity of two dimensional element descriptions involves usage of extended type of grammar. Suitable for that purposes is PLEX-GRAMMAR [Feder, 1971]. A N-attaching-point element (NAPE) is introduced in it. The grammar is represented by the six-tuple $(V_T, V_N, P, S_O, Q, q_O)$, where

V_T - is a finite non-empty set of terminal (non-productive) elements;

V_N - is a finite non-empty set of non-terminal elements (productive);

$$V_T \cap V_N = 0; \tag{1}$$

P - is a finite set of productions (generating rules);

$S \in V_N$ is a special NAPE - initial;

Q is a finite set of symbols called identifiers that form joint lists (of internal joint points of NAPE set) and tie-point list (consisting of external points of NAPE set) - identifying the links between elements. The identifiers could be represented by integer corresponding to the number of tie-points of single NAPE.

$$Q \cap (V_T \cap V_N) = 0; \tag{2}$$

$q_0 \in Q$ is a special NULL identifier that is used to show that corresponding NAPE from NAPE list is not connected to the described joint or tie point.

An extension of grammar is used in which except traditional joint point for which are necessary at least two non-zero element in joint list a special type of joint is used for contour definition joint which could involve only one connected non-zero element, belonging to the main arc of the contour. According to the above definition a set of four NAPEs with five joint points (four for arc connection and one for contour definition) and two tie-points is represented by set of components and two lists (of joint and tie-points) of the form:

$$V_1 V_2 V_3 V_4 (q_1 q_2 q_3 q_4, q_1 q_2 q_3 q_4, q_1 q_2 q_3 q_4, q_1 q_2 q_3 q_4; \\ q_1 q_2 q_3 q_4)(q_1 q_2 q_3 q_4, q_1 q_2 q_3 q_4) \tag{3}$$

3.2 Picture Grammar for Projective Images of Buildings

Defining of picture grammar with such type characteristics, which satisfies generation of projective images of buildings is formulated in (Marinov B.D., 1996) and is further developed in (Marinov B.D., 2004). The following set of arcs is defined.

1. Arc without height change on two sides of areas.

m − border of different cover;

s − shadow over terrain, wall or roof.

2. Arc, which separates two areas with different heights (roof-terrain, roof-wall, roof-roof).

r − border roof/terrain (roof/roof);

v − border between wall edge/terrain (wall edge/roof);

p − border roof / wall;

w − border wall / wall (between different buildings or their parts).

3. Arc, which divides two faces with different slope of surfaces.

h − edge wall / roof (at eaves);

t − edge terrain / wall (roof / wall in cases when part of building lies over the lower roof or terrace);

e − visible edge between surrounding walls;

k − edge between different roof faces.

It is possible to add combined types, which include sequence of two arcs with different heights.

4. Arcs, which are combination of two arc segments: j, l (wall arcs), f, g (roof arcs).

5. Arcs, which are combination of three segments: u (wall), n (roof).

Definition of different type of generation rules requires additional indexes for main or auxiliary arcs.

K, M, C, D – main external arcs of last or non last contour;

B, S – auxiliary arcs of external contour or different level contours;

I – internal arc of contour at same level;

O, Q – single or isolated contours.

Identification of different state of generation is made by second index that shows the specific state of the arc:

ρ - state of generation of isolated contour;

Ω - state of generation of external contour arc;

χ - generation of hidden contours;

and states for arc shift - Σ, Ψ Φ.

3.3 Producing Rules Examples

The following examples for producing rules include several main groups of rules. The first group defines generation of contours and set of isolated contours.

$$I_0(\ ) \to i_E(\ ) \qquad\qquad I_0(\ ) \to I_Q A_O (11)(02)$$
$$A_O(1,2) \to A_{O\rho}(1,2) \qquad R_O(1,2) \to R_{O\rho}(1,2) \tag{4}$$

Generation of internal contours begins from main contour or from main arc in state ρ:

$$Y_{O\rho}(1,2) \to Y_O A_O (21)(10,02) \tag{5}$$
$$W_{K\rho}(1,2,3,4) \to W_{K\varLambda} A_O (41;30)(10,20,02)$$

where symbol $Y \in (A, R)$ и W is arbitrary arc from set of internal contours (A, R, U, J, V, T).

The second group of rules is connected with generation of adjacent contours by applying of rules for generation of surrounding arcs. Initial set of producing rules includes generation of adjacent contours of type A or Y.

$$A_0(1,2) \to Y_I A_K Y_C (011,102,220;330,003)\ (040,004) \tag{6}$$
$$A_Q(1,2,3) \to Y_I A_M Y_C (011,102,220;330,003)\ (040,004,050)$$

The separate set of rules produces external or internal self-closed contours. External adjacent contours are produced by following rules:

$$A_O(1,2) \to A_K Y_C (12,21;30,03)(40,04) \tag{7}$$
$$A_Q(1,2) \to A_M Y_C (12,21;30,03)(40,04,50)$$

The rules for generation of internal isolated contours have similar form.

$$A_O(1,2) \to A_D Y_K (11,22;30,03)(40,04) \tag{8}$$
$$R_O(1,2) \to R_D Y_C (11,22;30,03)(40,04)$$

The generation of moving arc begins from node between arcs or from internal arc point. For arcs of type A they have the form:

$$A_X \to A_X A_{I\varSigma} Y_{C\varPsi} A_X \qquad\qquad W_X A_X \to W_X Y_{I\varSigma} \tag{9}$$
$$A_X \to R_X R_I Y_{C\varOmega} \qquad\qquad W_X A_X \to W_X Y_I$$

Rules for arcs of type R are identical.
Additional set of arcs define shift of end of external arc. Another set of rules are connected with generation of external visible walls and finalizing the producing sequence in cases when they are independent or their images lie over the parts of adjacent objects. The rules for transformation of including or surrounding contours are added. Another set of rules transforms external into internal contours. Two stages transformation procedure are used, which modifies arc types.

Such construction of grammar allows modelling the hiding of building parts depending of view point and the shadow influence and their covering. This procedure is applied at topological level.

4. RELATIONS BETWEEN MODEL PARTS IN 3D BUILDING MODELS

In three-dimensional model there are only relations of connectivity between areas. The corresponding 2-D model has adjacent and overlapping areas. For modelling of overlapping areas it is necessary to extend the possible relations between types of areas with different lines. The application of formal picture languages is appropriate techniques for analyses of images of such object configurations (Marinov, B., 1996).

The simple model of terrain and buildings consists of terrain and buildings. The buildings are constructed from walls and roof. More sophisticated model includes balconies on the walls, terraces on the top roof and tower over the roof and adjacent buildings or parts of them with different height. To define this model the following groups of plane objects can be formulated:
A. Top covers: roof, peak, floor, terrain (ground);
B. Side faces: wall, parapet, cornice, internal wall, curved shells
C. Bottom covers: foundation, eaves, ceil.
D Internal faces (invisible)

In space model of objects there are different combinations of surfaces to produce whole object.

For nodes of order four the combination are more complicated but from practical point such nodes are not so much. Some examples are: N (roof, roof, cornice, cornice); N (roof, roof, wall, wall); N (roof, roof, roof, roof); N (wall, wall, sill, cornice).

Main production rules generate building's body, roof, surrounding walls. Other types of rules include production of objects that are attached to the surfaces of main object or sub-object. Such objects are chimneys, mansards, stairs, platforms, shelters, and bays. The special types of objects are groups of columns or monuments under external shelters or internal bays. Some examples of different types of faces are shown in figure 1
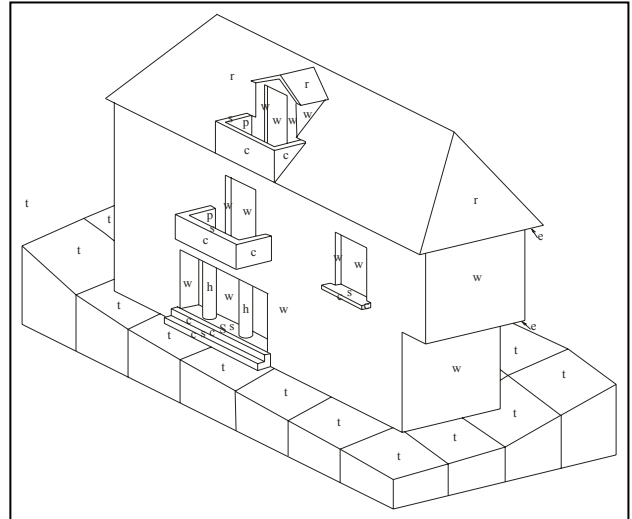

Figure 1. Examples of some face types

It is important to note that generation of nodes of specific type is feature of defined production rule and that usually the production rules of specific types generate usually couples of nodes. It is important for reconstruction of object model in cases when not all nodes are visible. This requires modules for analyses of corresponding types of nodes and production of invisible nodes. Such processes arise in mapping of architectural objects when some nodes are not visible.

Edges between not adjacent faces create another type of problems. The main types of combinations include roofs, walls, shadows and terrain (Marinov, B., 2002). More extended set of combinations include different protruding objects or sub-objects.

Taking into account of these relations is very important for analyses of data and for control of data coding. From another side including of this information in data stream will create additional efforts for automatic recognition of types of boundary and types of nodes. This requires definition of data structure for input of photogrammetric information that is suitable for automatic of operator controlled data input.

Based on this model the following extensions for description of 3D information can be suggested:
1. The hieratical structure must include the conjunction faces between main object and sub-object.

2. For every planar face the orientation vector of surface must be calculated and added as attribute information.

3. For every object or sub-object is defined and calculated the surrounding parallelepiped body, which includes entirely object.

4. For every arc are added as attributes the identifier codes for two adjacent surfaces.

This structure is convenient for solving the tasks for visibility and for creation of index matrixes for orthophoto transformation in photogrammetry.

5. PRESENTATION AND FORMING OF ORTHOPHOTO BASED ON BUILDING MODEL

The advantage of suggested complex model is the possibility to decrease the number of checks or visibility of processed pixel. To solve the problem a surrounding parallelepiped bodies are used.

The results for one complex building (church) are shown on the following figures. The digital images with superimposed vector model are shown in figure 2.
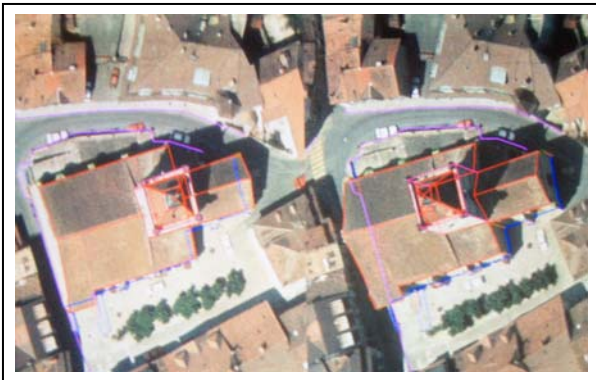

Figure 2. Source stereo couple with vector model

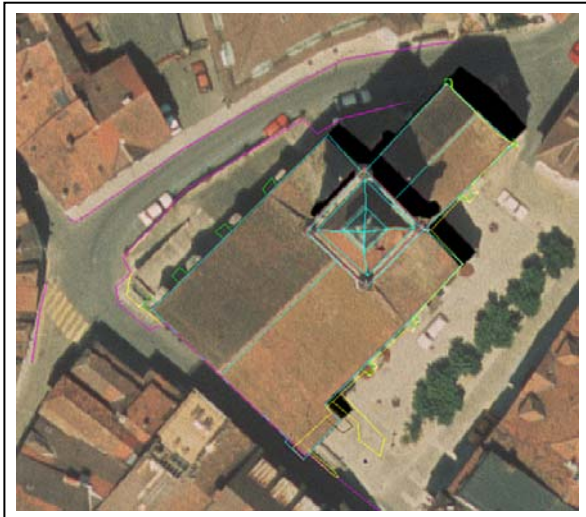The basic part of the orthoimage is produced from left image.

Figure 3 Orthorectified image generated from left image

The problem of generation of full model is that some lines are not visible in stereo or are not visible. For such lines the fictitious addition of model has to be generated.

The reverse scheme of orthorectification is used. The check for visibility of pixels is made based on calculation the limits of parallelepiped bodies surrounding every sub-object. For

projection ray from pixel in orthoimage corrected by height from model is checked the visibility by comparison with limits of surrounding bodies of adjacent parts of same building or nearest buildings. If tested pixel is not visible in current digital image the test for coupling image is made. It is possible to make checks not only in strip direction – longitudinal overlap but also for side overlap of images.

Additional part of orthoimage is produced from another stereo image. The processing of pixels from other images is made only for hidden pixels in base image. It is possible to generate separate orthoimages from every of neighbouring image. Which pixel is used is coded in extended index matrix. The used codes are visible terrain, visible roof, visible balcony for every different visible surface. The index matrix for usage of pixels is generated during this process. The extension of index codes includes not only invisible pixels of terrain but also identification number of slope roofs, flat roofs or external stairs and balconies. The generated codes allow usage the most appropriate nearest pixels of visible parts: terrain, roofs, balconies and corresponding codes for surfaces of invisible pixels. Additional part of index code is number of image from which the source data are taken.

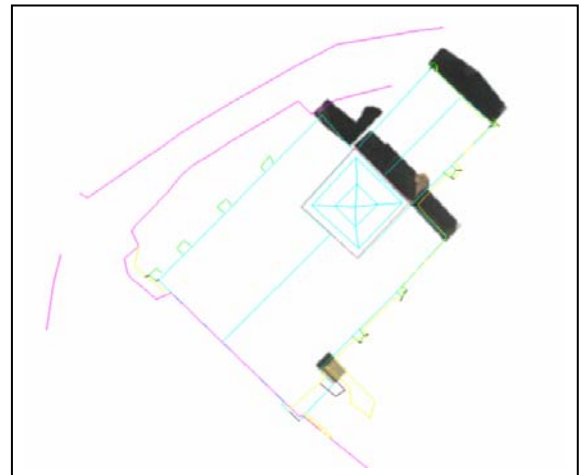The hidden parts from right image are shown in figure 4.

Figure 4. Ortho chips from right image

The final orthoimage produced as combination of two orthorectified images with superimposed vector model is shown in figure 5.
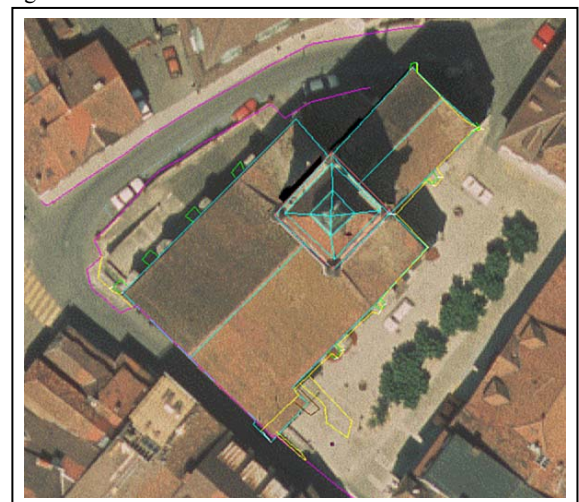

Figure 5. Composition of orthoimages from suitable parts of adjacent images

Substantial advantage of this model is possibility for simultaneous analyses of two images of stereo couple and search of corresponding areas based on structural description. This allows enhancing the reliability and accuracy of obtained information.

6. DISCUSSIONS AND CONCLUSIONS

The suggested method for description of 3-D spatial data information is suitable for solving the task for visibility analyses in GIS and for orthophoto production in Digital Photogrammetry. The main problems are level of complexity of the model, the structural extension of model for invisible surfaces and lines for which the virtual lines are produced to ensure the concordance of the model. The computing efficiency for generation of orthoimage depends on additional information for consisting parts of object and the nearest object which can influence the pixels in the neighbouring objects.

It is possible to be used in cases of different resolution of model with variable degree of generalization. This model is suitable for objects with different complexity and particulars.

The suggested method enlarges the possibilities for DEM generation and orthorectification with systems for digital photogrammetry for urban areas. The suggested method could be used in procedures for archiving and dynamic visualization of architectural objects. The produced orthophoto is more accurate and adequate of the objects that are presented on it. As a final result the technology based on orthophoto production and digitising of accurate orthophotos could be applied successfully for urban areas mapping and planning.

REFERENCES

Ameri, B., 2000. Feature Based Model Verification (FBMV): A New Concept for Hypothesis Validation in Building Reconstruction. In: *IAPRS,* vol. XXXIII, Part B3, Amsterdam, pp. 24-35.

Bellman C.J., Shortis M.R., 2004. A Classification Approach to Finding Buildings in Large Scale Aerial Photographs. In: *IAPRS (XXth Congress of ISPRS),* vol. XXXV, Part B3, Istanbul, Turkey, pp. 337-342.

Bock-Mo Y., Eui-Myoung K., In-Tae Y., 2000. Generation of Digital Orthophoto for Urban Area Using Digital Building Model, In: *IAPRS, (XIXth Congress of ISPRS),* vol. XXXIII, Part B4, July 2000, Amsterdam, Netherlands, pp. 462-468.

Chio, S.H., Wang, S.C., Wrobel, B., 2000. Interactive Roof Patch Reconstruction Based on 3-D Linear Segments. *In: IAPRS, (XIXth Congress of ISPRS)*, vol. XXXIII, part B3, Amsterdam, Netherlands, pp. 183-190.

Heuel, S., Förstner, W., Lang, F., 2000. Topological and Geometrical Reasoning in 3D Grouping for Reconstructing Polyhedral Surfaces. *In:IAPRS, (XIXth Congress of ISPRS)*, vol. XXXIII, Part B3, Amsterdam 2000, pp. 397-404.

Fu K.S., 1982. *Syntactic Pattern Recognition and Applications.* Prentice-Hall, Englewood, Cliffs, New Jersey, pp.129-162.

Feder, J., 1971. Plex Languages. *Information Science*, 3, pp.225-241.

Jauregui M., Vilchez J., Chacon L., 2000, Digital Orthophoto Generation. In: *IAPRS, (XIXth Congress of ISPRS),* vol. XXXIII, Part B4, Amsterdam, Netherlands, pp. 400-407.

Marinov B., 1996. Processing of Protruding Objects in Digital Images of Urban Areas. In: *IAPRS*, vol. XXXI, Part B3, Vienna, pp. 497-502.

Marinov B., 2002. Structure of 3-D Information for Processing of Digital Stereo Images. In: *Proc. of the Jubilee Scientific Conference "60 Years UACEG"*, vol. 8, Sofia, November, pp. 6978. (in Bulgarian)

Marinov B.D., 2004. Structure and Usage of Photogrammetric Information in Spatial Information Systems. In: *Papers on International Symposium: "Modern technologies, education and professional practice in geodesy and related fields"*, 4-5 November, Sofia, Bulgaria, pp. 213-222.

Michaelsen E., Stilla U., 2000. Problems in Geometric Modelling and Perceptual Grouping of Man-Made Objects in Aerial Images. In: *IAPRS, (XIXth Congress of ISPRS)*, vol. XXXIII, part B3, Amsterdam, Netherlands, pp. 577-583.

Pala V., Albiol R., 2002. True Orthoimage Generation in Urban Areas. In: *Proc. of the Third International Symposium Remote Sensing of Urban Areas*, vol. 1, Istanbul, Turkey, pp. 309-314.

Seresht M.S., Azizi A., 2000. Automatic Building Reconstruction from Digital Terrain Images. In: *IAPRS, (XIXth Congress of ISPRS),* vol. XXXIII, Part B3, Amsterdam, Netherlands, pp. 792-798.

Stilla U., Jurckiewicz K., 1996. Structural 3D-Analyses of Urban Scenes from Aerial Images. In: *IAPRS (XVIIIth Congress of ISPRS)*, vol. XXXI, Part B3, Vienna, Austria, pp. 832-838.

Suveg I., Vosselman, G., 2000. 3D Reconstruction of Building Models. In: *IAPRS, (XIXth Congress of ISPRS)*, vol. XXXIII, Part B2, Amsterdam, pp. 538-545.

Weidner U., Förstner W., 1995. Towards Automatic Building Extraction from High-Resolution Digital Elevation Models. In: *ISPRS J. of Photogrammetry and Remote Sensing*, 50 (4), pp.38-49.

Weidner U., An Approach to Building Extraction from Digital Surface Models, In: *IAPRS (XVIIIth Congress of ISPRS)*, vol. XXXI, Part B3, Vienna, Austria, 1996, pp. 924-929.

Woestyne I.V.D., Jordan M., Moons T., Cord M., 2004. A Software for Efficient DEM Segmentation and DTM Estimation in Complex Urban Areas, In: *IAPRS (XXth Congress of ISPRS)*, vol. XXXV, Part B3, Istanbul, Turkey, pp. 134-139.

Zhang Z., Zhang J., 2000. Semi-automatic Building Extraction Based on Least Squares Matching with Geometrical Constraints in Object Space. In: *IAPRS, (XIXth Congress of ISPRS)*, vol. XXXIII, Part B3, Amsterdam, pp. 1022-1025.

Zhao, B., Trinder, J.C., 2000. Integrated Approach Based Automatic Building Extraction. In: *IAPRS, (XIXth Congress of ISPRS)*, vol. XXXIII, Part B3, Amsterdam, pp. 1026-1031.