HIERARCHICAL MODELLING AND PROCESSING OF SPACE OBJECTS IN ARCHITECTURAL PHOTOGRAMMETRY

B. D. Marinov

UACEG, Faculty of Geodesy, bul. Hristo Smirnenski 1, 1046 Sofia,, Bulgaria - marinovb_fgs@uacg.bg

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ABSTRACT:

A spatial model of objects is suggested, which is suitable for 3D architectural modelling. The model has hierarchical structure that allows description of vector and raster information and their mutual fusion. The model is adapted to processes of forming and visualization of information for the object. A procedure is formulated, which is based on the suggested model that allows the effective generation of model in situation of mutual hiding of its parts and missing of information for some of them.The suggested model 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. A picture language is formulated, which is based on the theory of formal grammars. Is, is used for the formal description of the model and its generation. 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 used vector model of buildings is projected over the processed images to separate them into sub-areas of terrain, buildings, walls, invisible faces. The procedure is extended for roofs or balconies at different heights or protruding sub-objects, which are overlapping in images. This allows the segmentation of space model into areas and independent control of parameters for plane surfaces and curved surfaces or natural objects like terrain. The model for transformation of curved surfaces is used for generation of photo texture from images over the cylindrical or spherical surfaces. A procedure for generation of orthoimage is formulated. The modification of index matrix method is applied for orthoimage generation. The used procedure is applied for generation of photo-realistic model. The different levels of elongation from viewing point are estimated for proper generation of orthoimages or dynamic views. It takes into account the overlapping of adjacent building and overlapping of parts of the same building. The superimposition and mosaic creation from rectified images is made as the final step of the generation procedure.

1. INTRODUCTION

1.1 Rectification the Images of Architectural objects

Digital presentation and archiving of architectural monuments requires simultaneous application of close range photogrammetry, 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. The problems of segmentation and interpolation of model surfaces are very important in process of solving of this task. In process of archiving of monuments with wall painting additional complications arises due to the mutual influence of geometrical structure and presence of images on the surfaces.

The procedures for digital image segmentation and transformation are formulated. The special attention is paid on the processing of images, which are laying not only over the plane surfaces, but also on the cylindrical and spherical surfaces. The artificial objects cause negative influence over the process of automatic model generation. Problems arise in digital rectification of images of architectural objects. All these methods require the usage of appropriate model of the objects.
Main problems that have to be solved for creation of photogrammetric models in architecture are used technology schemes for generation of such models, methods for description of such models and for their generation and for procedures for transformation of data format of model data into format suitable for corresponding vizualizers. This requires joined solving of the following three basic tasks: adequate model as combination of vector and raster data, reliability of forming from different sources and initial data sets, correspondence between model formats and used vizualizers.

For processing of photogrammetric information it is typical the usage of space information. The analyses of images in urban areas are very complicated due to the buildings and artificial objects. The large displacements, hiding of terrain and hiding the parts of adjacent objects and shadows influence. Similar problems arise in close range photogrammetry for in cases when there are protruding parts of objects. This produces problems for in automatic identification of corresponding parts in stereo images of such objects or territories.

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 precise orthophoto product is also suitable for archiving of architectural monuments (Baratin, L., Bitelli, G., Unguendoli, M., Zanutta, A., 2000). Its advantages are high metric accuracy and good interpretation possibilities.

The models of cured surfaces are used for rectification of images over the non-planar faces (Wiedemann, A., 1996,; Karras, G.E., Patias, P., Petra, E., Ketipis, K., 1997). Virtual reality systems are perspective direction of development in the area of information and training systems. They use multimedia human-computer interface, which allows transmission of visual, audio and other data components to user in natural way (Samoilov, D., Bakhtina, T., Grigoriev, R., 2000). The reconstruction of 3D building models is made either using aerial images or close range images. The resultant 3D model has been represented in Virtual Reality Modelling Language (VRML) in (Huang, H.-H., 2004).

In semi-automatic procedures is possible excluding of special kind of lines for such objects – like border lines, which allow excluding of unwanted parts of object model. This direct approach is not suitable in cases of hiding the adjacent objects that requires complex procedures for image interpretation. The structure of spatial information is very important for reliability and speed of processing in such systems.

1.2 Models used for Buildings’ 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 down – up procedure is formulated that starts from object’s primitives trough face elements to whole object description.

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 characteristics. 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 DESCRIPTION BASED ON PICTURE GRAMAR

2.1 Picture Description Languages

Picture description languages are widely used for presentation of 2D and 3D objects and their images. The necessity of two dimensional element descriptions involves usage of extended type of grammar. Suitable for that purposes is PLEX-GRAMMAR (Feder, J., 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);

$$V_T \cap V_N = 0; \qquad (1)$$

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.

$$Q \cap (V_T \cap V_N) = 0; \qquad (2)$$

$q_0 \in Q$ 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.

2.2 Picture Grammar for Generation the 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., 2002). The following set of arcs is defined.
1. Arc without height change on two sides of areas: border of different cover; shadow over terrain, wall or roof.
2. Arc, which separates two areas with different heights (roof-terrain, roof-wall, roof-roof), wall edge/roof.
3. Arc, which divides two faces with different slope of surfaces. 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.

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.

3. STRUCTURE OF SPATIAL MODEL

3.1 Description of Stereo Images

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, K.S., 1982]. The formalised 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).

3.2 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.

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.

3.3 Generation of Model Parts in 3D Buildings' 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. The simple model of buildings is 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.

The process of generation of object model consists of four steps. First step creates sub-object from initial object I. Second step produces surfaces from objects. Third step produces arcs from object faces. The last fourth step produces stereo images from arcs. Producing rules could be formulated avoiding the intermediate steps of model generation

More extended set of combinations include different protruding objects or sub-objects. (Marinov, B.D., 2004). The production rules for creation of main surrounding surfaces of sub-objects are defined. Main production rules are for building's roof (BR) and building's body (BB).

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.

For generation from roof surfaces (RS) can be used following rules:
RS→RF (roof) - no attached objects;
RS→RF,MN; (3)
RS→RF,CM.

The production rules for chimney and mansard are:
CM→ wall, wall, wall, wall, sill, internal ceil (4)
MN→ RF, wall, wall, wall, internal floor.

For side objects can be generated following rules:
WL→WL,BY;
WL→WL,BL; (5)
WL→ WL, SH;
WL→ wall, eaves, wall;

For bays (BY) are possible different rules for generation of surrounding sub-objects:
BY→ cornice, cornice, cornice, sill, eaves;
BY→RF, cornice, cornice, cornice, eaves (6)
BY→ cornice, cornice, cornice, eaves, internal floor;
BY→ cornice, cornice, cornice, eaves, internal ceil;

Similar sets of production rules are formulated for balcony sub-object (BL), shelter sub-object (SH).

The generation of external staircase requires intermediate symbols Staircase ST, Parapet (PR) and combination (sill-cornice) (SC).

The generation of set of columns (CS) requires intermediate symbol too. Finally the model of column is produced (CL). This set could be produced from cornice or bay objects.

The generated rules produce different combination of adjacent faces to defined type of edge. Such combinations are:
- wall, wall), (wall, terrain), (wall, eaves), (wall, roof),
- (roof, roof), (sill, wall), (wall, par), (par, par), (par, floor),
- (cornice, eaves), (cornice, cornice), (cornice, wall), (eaves, wall);
- (column, wall), (column, cornice), (column, ceil).

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.

The connection of three edges of different type creates different types of nodes. Some examples of such nodes are:
N(sill, sill, cornice); N(cornice, cornice, eaves); N(cornice, eaves, wall); N(par, wall, sill); N(par, wall, floor).

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).

Edges between not adjacent faces create another type of problems. The main types of combinations include roofs, walls, shadows and terrain (Marinov, B., 2002). These combinations produce main type of arcs between adjacent faces of the object.

More extended set of combinations include different protruding objects or sub-objects. Such combinations are:
- roof over terrain/wall/roof/floor/sill;
- wall over wall/terrain/roof;
- cornice over terrain/wall/roof/sill/cornice;
- sill over terrain/wall/roof/par;

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 or operator controlled data input.

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.

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 photorealistic modelling in architectural photogrammetry.

3.4 Rectification of images laid on the curved surfaces

Different geometrical models are used for rectification of images disposed on the curved surfaces. The geometrical model for cylindrical model is simpler. The figure of cross section orthogonal to cylinder axis is used for transformation of images.

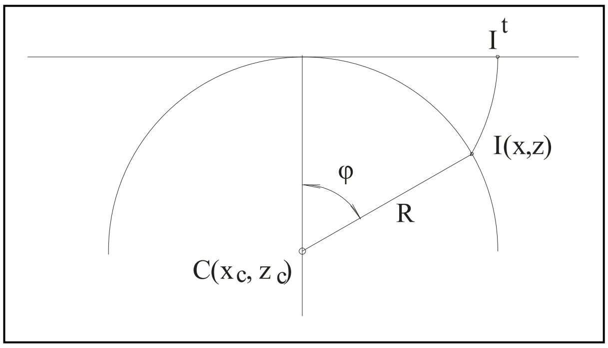

Figure 1. The geometrical model for cylindrical surface.

The transformation of images on the cylindrical surfaces are presented by relations (7)

$$x_i^t = \begin{cases} x_c + R_c.\arctan\dfrac{x_i - x_c}{z_i - z_c} & z_i \geq z_c \\ x_c + sign(x_i\text{-}x_c).\left[\frac{\pi}{2}.R + (z_c\text{-}z_i)\right] & z_i < z_c \end{cases}$$

$$y_i^t = y_i \qquad (7)$$

$$z_i^t = z_c + R$$

The relations for spherical surfaces are more complicated. They are based on the usage of the map projection relation. The appropriate choice of transformation depends on the part of sphere that is processed.

4. GENERATION OF PHOTO TEXTURES

Artificial textures generated from color images of surfaces are used for production the photo textures of faces of sub-objects.

4.1 Production of Surface Images with Hidden parts behind the Front Lying Objects

The advantage of suggested complex model is the possibility to produce the correct model in cases of hiding the parts of the object from another sub-objects. The experiments are made with front facade of the building of Popular Theatre "Iwan Wazov" in Sofia. The frontal image of entrance with front set of columns is shown in figure 2.

The elimination of hidden part of faced is made by usage of two side images taken from left and right photo station. After creation of vector ad structural model the rectification of these images are made. he analyses of spatial disposition of model parts allow to exclude the images of front columns. The rectified images are shown in the next two figures. The image from left station is shown in figure 3.

Figure 2. Frontal image of the theatre entrance.

Figure 3. Rectified left image with excluded front objects.

Figure 4. Rectified right image with excluded front objects.

The image from right station has similar form. It is shown in figure 4.

The processed images are separated in parts and the overlapping of parts from different images is analysed. The modified index matrix is used to determine the overlapping of the subparts. It is based on their space coordinates and their correspondence in spatial model. There are determined thevboundaries of adjacent subparts of images taken from different stations. The mosaic from different parts is produced with analyses of non-covered parts of the facade. The final result of facade with corresponding projection of vector model is presented in figure 5.

Figure 5. Rectified mosaic of front entrance facade.

The influence of the side columns could not be eliminated because the side front columns are too near one to another. The solving of such complicated situation requires usage of stations, which are positioned aside from the central station. The images taken from such stations usually have large deformations due to the large orientation angels.

The application of hierarchical model allows producing the photo texture images of model surfaces. 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.

4.2 Production of rectified Images from Images over the Curved Surfaces

The results for rectification of images over the cylindrical ceiling of entrance of old church of the Dragalevci monastery "The Assumption of the Virgin Mary". The result after rectification of one part of the mosaic is shown in figure 6.

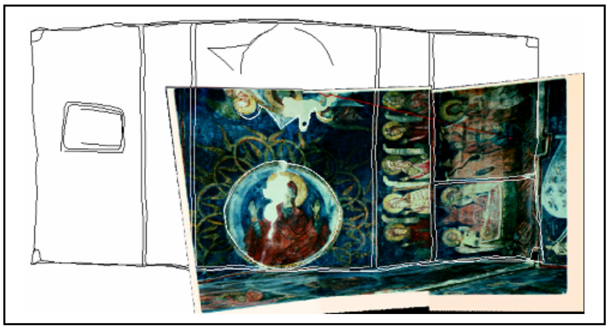

Figure 6. The rectified part of mosaic and vector model.

The rectified images from set of input images are produced. They are tied together by procedure image to image and are rectified. The mosaic of all rectified images on the ceiling of the church is shown in figure 7.

The generated photo textures of plane or curved surfaces are used for Cultural heritage documentation or for photo realistic modelling in the Internet environment.

Figure 7. Paintings over the Ceiling in church "The Assumption of the Virgin Mary".

5. DISCUSSIONS AND CONCLUSIONS

The suggested method for description of 3D spatial data information is suitable for solving the task for visibility analyses in GIS and for generation of photo realistic models in close-range photogrammery. The spatial model of objects is appropriate for 3D architectural modelling. The model has hierarchical structure that allows description of vector and raster information and their mutual fusion. The formulated procedures allow the effective generation of model in situations of mutual hiding of its parts and missing of information for some of them.

For purposes of orthophoto transformation a mosaic of the selected parts of the processed images could be created in which the hidden areas in one of the stereo images are taken from another image if corresponding area could be found in it. Such structure is possible to be applied for generation of index matrixes in process of orthophoto production.

The efficiency of model allows its application for extraction the information with different accuracy and resolution that could b used for presentations with variable degree of generalization., This model is suitable not only for restoration of spatial data but for archiving and dynamic visualization in Internet environment. It is possible the usage of the model for description of objects with languages for virtual reality modelling (VRML) and with 3D XML languages.

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