PROCESSING OF PROTRUDING OBJECTS IN DIGITAL IMAGES OF URBAN AREAS

Borislav D. Marinov
University of Architecture, Civil Engineering and Geodesy, Faculty of GOEDESY
BULGARIA

Commission III, Working Group 3

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ABSTRACT

For purposes of automatic processing of digital stereo images of urban areas and architectural objects a skeleton space model is introduced. The topological and height properties are used for classification of such objects. The image areas are separated in several main classes: visible terrain, building roofs and building walls. A formal approach for creation of such model is introduced based on picture language description procedure. The diversity of relative conjunction of areas in every photo image is modelling by applying the sequential grammar rules based on PLEX-GRAMMAR. The skeleton model of photo images is suitable for purposes of terrain building separation process and for finding the correspondence between visible areas in two stereo images. The possible areas of application of such model are interpretation and verification of skeleton model of urban areas, the rejection of building influence over the produced DEM and appropriate selection of image parts for digital image mosaic creation from large scale images in processes of photo transformation and land cover classification.

1. INTRODUCTION

Digital processing of large scale images of urban regions reaches severe problems due to the high density of buildings with the different heights from the surrounding terrain. For such objects there are a great displacement of their photo-images, hiding parts of the surrounding terrain, mutual hiding of close staying buildings. Similar problems exist in close-range images of architectural objects with a lot of protruding elements on the facades. As a result a problem arises in the terrain interpolation or the orthophoto image generation for such parts of the digital images where discontinuity of the terrain function appears. Automatic creation of normalised classified images from such areas is not enough reliable and complete due to the unclassified areas in the hidden parts of the terrain. There are suggested different schemes for classification and processing of such images, taking into account geometrical, shape and height properties of buildings (Weidner, Förstner, 1995). For object with simple form a formalised procedures for scene analysis and image understanding in single image are used, based on skeleton model of objects (Waltz, 1975).

One possible solution of problems with processing of urban region images is a detailed mapping from stereo images and building contours coding under the operator's control. The building's boundaries could be excluded by defining a special type of lines for such objects - like border lines that allow to exclude the undesirable areas from the process of DEM generation). Such procedure seems to be very tedious and time consuming for high density built urban areas. Such direct approach could not be enough appropriate in cases of hiding some parts of the buildings or in very unusual relative disposition of objects because very complicated image understanding procedure have to be applied.

2. IMAGE DESCRIPTION

Another solution is to introduce a simplified model of stereo images. The description is based on the topological properties of areas in the stereo images. A picture language grammar technique could be applied to formalised the process of image description and to cover different possibilities of image configurations. Such technique is very largely used for description of two dimensional or three dimensional images (Fu, 1982). Similar approach was suggested for description of planar objects in single photos or contour maps (Marinov, 1988). It formalises the process of generating hierarchical description of contour images. For purposes of stereo image processing such approach have to be enlarged to involve additional information. The information includes the parallax of contour lines, the position of the objects relatively to centre of the photo and the topological properties of areas in both images. In that situation only the walls oriented to the centre of the photo could generate visible areas in the image. The main properties of the image description have to take into account the relation between the areas in the image and connection between the areas and the contours. Primary elements that are used for description are arcs (the segments of lines between two points of connection). From a topological point of view nodes are only points of connection of more than two arcs, taking into account the type of arcs (wall edges, foundation border and so on) the segmentation of arcs could increase. The main topological properties that have to be taken into account are the relations of the types: adjacent areas, clusters of areas, included clusters of areas, hanging areas (with only one point of connection. The specific properties of artificial objects includes areas of following types: roofs, walls, terrain and hidden parts of them.

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

The form of description proposed here is based on defining the different types of arcs elements and topological description of relations between them. The primary topological elements are arcs separating adjacent areas. There are involved four types of arcs based on changing the height of their end points (estimated by parallax in the two images) - border and skeleton lines of roofs (with almost equal height), foundation lines of walls (with almost equal height), border lines of walls (with high difference of height along their length) and terrain lines (with smooth change of height of line). The description of every arc contains address information (pointers) to the subsequent arc in the outer contour and in the inner contour. The isolated set of adjacent contours contain outer contour of whole set and inner contours of separate areas. For outer contours is used clockwise direction of contour elements connection and counter clockwise direction for inner contours. For such definition of contour following is ensured the opposite direction of contour tracing on opposite sides of the arc. For contours lying along the outside contour such description produces the list of contours in cluster. For inside contours is necessary to scan all inside lines of the areas. The description of the correspondence between the areas and the arcs and the topological state of connectivity and adjacency and is ensured by pointers attached to every arc. For every arc are used two pointers to the internal and the external contour. The arc is presented as a vector with a head joint point (1) and a tail joint point (2). The pointer corresponding to node 1 ensure connection to next arc element of internal contour (in counter-clockwise direction) and the pointer corresponding to node 2 ensure connection to external contour (in clockwise direction). The direction of outer contour arcs is corresponding to internal contours (counter clockwise). If increasing the speed of processing is necessary to every node of arc is possible to attach two pointers to ensure bi - directional scanning of every contour but this tends to enlarge the amount of used memory. For the main arcs of the external contours the definition of external and internal contour is obvious. For the non-main arcs of the external contour and the arcs separating contours from equal level the internal contour is an own contour and the external is an adjacent to the arc. The pointer is used to point the main arc of the internal contour. In such way the orientation of the arc is defined and the appropriate pointer is used to form a contour. It is assumed that the main arc of a scanned contour is known when the contour is formed. For internal contours the pointer of the main arc is used for a connection with the contour from a higher level. For the non-main arc the pointer ensure a connection to the main arc of the own contour depending on the arc orientation. (own contour could be the contour from higher or lower level). For every isolated cluster one of the external contours is marked as a leading contour by its main arc. It has connections to the next cluster (if exist) or to the previous cluster (if it is not first) or to the higher level of included clusters. Every contour from external ring is connected to the next one by its external arc that is usual main arc. For internal contours it is not always possible to define a ring of contours but it is possible to find a path to them from some of the external contours. For the non-main arcs of the external contour is used an additional pointer to the main arc of the contour, respectively to which the first arc pointer (node 1) is oriented. The same rule is used for the main arcs of external contours but for them such pointer is not necessary to be used. In such way the clockwise following the external contour and the counter clockwise direction for internal contours from the external ring is used.

To produce a hierarchical description of the image it is necessary to introduce additional information about contour sets lying inside or outside from the defined contour. To describe such relations it is necessary to formulate a restriction over the sets of the clusters. Inside of every contour it is possible to exist a set of separate clusters of adjacent contours. To describe such type of information for every cluster is chosen a contour that is marked by a leading arc element (start element in the arc list for contour). For the leading arc elements are defined two additional pointers - first to the next element in the list of the isolated clusters that are lying inside the contour at a higher level and a second pointer to the list of inside clusters.

Such approach is convenient for generation of a contour description from arcs and gives possibility to generate high level description convenient for usage in the relational data base environment.

3. FORMULATION OF PICTURE GRAMMAR

The necessity of two dimensional elements description involves usage of corresponding type of grammar. Suitable for that purposes is PLEA-GRAMMAR (Feeder, 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);

$V_T \cap V_N = 0;$

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.

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

$q_0 \in Q$ 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 introduced that is implied connected to the main arc of the contour. This additional joint type is used for contour definition that could involve only one connected non-zero element. According to the above definitions the presentation for 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:

$$V_1V_2V_3V_4(q_1q_2q_3q_4, q_1q_2q_3q_4, q_1q_2q_3q_4, q_1q_2q_3q_4; q_1q_2q_3q_4)(q_1q_2q_3q_4, q_1q_2q_3q_4)$$

The terminal grammar elements are corresponding to the basic elements of the topological description. They are defined based on the order of the connectivity of the element. Two kinds of links are present - direct links to consecutive arcs in contour and links to the clusters of the same level or different levels (upper or lower) and with their properties as boundary of plane regions. It seems to be very attractive to separate the plane region with finite arcs and edge line properties of three dimensional objects but it is not possible due to the fact that photogrammetric image is two dimensional projection of three dimensional objects and the complexity of the solution is respectively as the problem of finding of the visible and the invisible lines in computer graphics. 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:

I. Arcs without changes in height between two areas or with relatively low difference in slope - a type arcs separating different areas.

II. Arcs with jump in the height between two adjacent areas:
r - roof/terrain border (or roof/roof);
v - wall edge / terrain border (or wall edge/roof);
p - roof / wall border;
w - wall / wall border (between different buildings);

III. Arcs defining break in surface slope, not in height:
h - wall / roof edge;
t - terrain / wall edge (or roof / wall edge in situation when a part of the building is lying over the roof or terrace);
e - visible edge between surrounding walls.

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. The arcs of this type are:
j - right arc of type wall / terrain (sequence v,t);
l - left arc of type wall / roof or terrain (sequence t,v);
u - arc of type single wall (sequence of v,t,v arcs);
n - arc of type internal roof (sequence p,t,p);
f - left part of internal roof (sequence p,t);
g - right part of internal roof (sequence t,p);

The different topological type of arcs is established by usage of different subscript index with following meaning:
k - main external arc of leading contour of last cluster;
m - main external arc of leading contour of non-last isolated cluster;
c - main arc of external contour of non-leading contour;
b - non-main outside contour arc of isolated cluster;
i - internal arc between two different contour from equal level;
s - non-main arc of contours from different levels;
d - main arc of internal contour, oriented in direction to point the contour of upper level.
o - single or last isolated contour;
q non-last isolated contour from set of isolated contours or area clusters.

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

1. Non connected elements:

s_e - empty initial area;

2. First order connected elements:

s_q-initial outside area, containing sub areas (isolated areas or area clusters.

3. Second order connected elements (one pointer to inside cluster list and one implied connection to own contour):

a_o - separate (or last) isolated area.

4. Third order connected elements containing two pointers to the next arcs of the own and adjacent contour and one pointer to the main arc of the own contour, or to the main arc of the upper level contour for an element of type d.

5. 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.

6. 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.

The non-terminal elements set could be defined based on formulation of the main processes of generation of the topological configuration. The generation processes could be separated in several main steps. The image generation starts with transaction from initial element to sets of isolated contours. Every contour could converts to cluster of adjacent contours by attaching of areas (only by outside not self-closed arcs following clockwise direction). This process allows to form not only outside ring of contours but inside contours of arbitrary levels. To model the process of generating of hanging contours (attached in point) a zero length arc is involved (with coincide head and tail node points). The process of growing of cluster stop when the main element of leading contour changes to round state. As a result the main arc element of every contour is defined and non-main arc elements transfer to terminal. The last step is transition to mode of generation of isolated sub-contours or conversion to terminal elements.

The presentation of different generation processes is done by usage of additional subscript index corresponding to the special activated state of the arc:
ρ - generation state of isolated contour;
Ω - generation state of the external contour arc;
Σ - last isolated arc by the moving external arc;
Ψ - scanning state of the new external arc over the isolated arcs;
Φ - isolated arcs scanning state;
χ - generation of hidden contours state.

The main group of non-terminal elements could be defined as set of elements, corresponding to the terminal ones. It had to be enlarged to take into account their different states of generation. It is convenient for that purposes to use subscript index. To every one generation process corresponds a set of the rewriting rules. To restrict the number of the non-terminal elements not only context free but context dependent rules are used too.

The first set of rules formulate the generation of isolated contours and sets of isolated contours, transition between hanging contours and main arc element in generation state. Only for initial few production rules the full form of presentation will be used because it takes a lot of space. The generation of initial contours and the chains of isolated contours is describe by the rules:

$$\begin{aligned} &S_0() \to s_E() \qquad\qquad S_0() \to S_Q A_O(11)(02) \\ &A_O(1,2) \to R_O(1,2) \\ &A_O(1,2) \to A_{O\rho}(1,2) \qquad R_O(1,2) \to R_{O\rho}(1,2) \\ &A_O(1,2) \to A_Q A_O(21)(10,30,02) \\ &A_Q(1,2,3) \to A_{Q\rho}(1,2,3) \\ &A_Q(1,2,3) \to R_{Q\rho}(1,2,3) \end{aligned} \tag{1}$$

The generation of internal contours of existing contour starts from isolated contours or main arcs in state ρ:

$$\begin{aligned}
&Y_{O\rho}(1,2) \rightarrow Y_O A_O (21)(10,02)\\
&Y_{Q\rho}(1,2,3) \rightarrow Y_Q A_O (3,1)(10,20,02)\\
&W_{K\rho}(1,2,3,4) \rightarrow W_{K\Lambda} A_O (41;30)(10,20,02)\\
&W_{D\rho}(1,2,3,4) \rightarrow W_{D\Lambda} A_O (41;30)(10,20,02)\\
&W_{M\rho}(1,2,3,4,5) \rightarrow W_{M\Lambda} A_O (51;30)(10,20,30,40,02)
\end{aligned} \quad (2)$$

where symbol $Y \in (A, R)$ and W is arbitrary arc from the external contour symbol set (A, R, U, J, V, T).

The second set of rules is connected with generation of adjacent contours to the arcs by applying the rules for creating of surrounding arcs. Initial set of production rules includes rules for generation of adjacent contours from single contours of type A or R.

$$\begin{aligned}
&A_0(1,2) \rightarrow Y_I A_K Y_C (011,102,220;330,003)\\
&\qquad\qquad (040,004)\\
&A_Q(1,2,3) \rightarrow Y_I A_M Y_C (011,102,220;330,003)\\
&\qquad\qquad (040,004,050)\\
&R_0(1,2) \rightarrow R_I R_K Y_C (011,102,220;330,003)\\
&\qquad\qquad (040,004)\\
&R_Q(1,2,3) \rightarrow R_I R_M Y_C (011,102,220;330,003)\\
&\qquad\qquad (040,004,050)
\end{aligned} \quad (3)$$

A separate set of rules is formed by rewriting rules for generating of external or internal self-closed contours. The rules for external touching contour have the form:

$$\begin{aligned}
&A_O(1,2) \rightarrow A_K Y_C (12,21;30,03)(40,04)\\
&A_Q(1,2) \rightarrow A_M Y_C (12,21;30,03)(40,04,50)\\
&R_O(1,2) \rightarrow R_K Y_C (12,21;30,03)(40,04)\\
&R_Q(1,2) \rightarrow R_M Y_C (12,21;30,03)(40,04,50)
\end{aligned} \quad (4)$$

Such type of internal and external contours, attached in single point, does not belong to special type of image description because specified joint elements in grammar are arcs and contours instead of connecting nodes. Similar form have the rules for internal self-closed contour.

$$\begin{aligned}
&A_O(1,2) \rightarrow A_D Y_K (11,22;30,03)(40,04)\\
&A_Q(1,2) \rightarrow A_D Y_M (11,22;30,03)(40,04,50)\\
&R_O(1,2) \rightarrow R_D Y_C (11,22;30,03)(40,04)\\
&R_Q(1,2) \rightarrow R_D Y_M (11,22;30,03)(40,04,50)
\end{aligned} \quad (5)$$

The process of area cluster growing continues with generation of an additional external arc in clockwise direction (according to external contour arc connection). It could be divided into four steps: generation of a moving arc with a fixed initial node, moving the end node of the arc, transformation of isolated external arcs into new type and scanning of contours of isolated arcs for finding of entire isolated contours.

The generation of a moving arc could start from a node between the arcs or from internal point of the arc. The rules are similar for the arcs of type A and R. For arc of type A the rules have the form:

$$\begin{aligned}
&A_X \rightarrow A_X A_{I\Sigma} Y_{C\Psi} A_X\\
&A_X \rightarrow A_X A_{I\Sigma} Y_{C\Psi}\\
&A_X \rightarrow R_X R_I Y_{C\Omega}\\
&A_X \rightarrow A_X Y_C A_B\\
&W_X A_X \rightarrow W_X Y_{I\Sigma} Y_{C\Psi} R_X\\
&W_X A_X \rightarrow W_X Y_{I\Sigma} Y_{C\Psi}\\
&W_X A_X \rightarrow W_X Y_I Y_{C\Omega}\\
&W_X A_X \rightarrow W_X Y_C A_X
\end{aligned} \quad (6)$$

where index X means arc of type K, M, C or B and symbol Y arcs of type A or R and symbol W arc of type A, R, U, J, V. The presentation of the rules for the arcs of type "roof" is as follow:

$$\begin{aligned}
&R_X \rightarrow R_X R_{I\Sigma} W_{C\Psi} R_X\\
&R_X \rightarrow R_X R_{I\Sigma} W_{C\Psi}\\
&R_X \rightarrow R_X R_I Y_{C\Omega}\\
&R_X \rightarrow R_X Y_C R_B\\
&W_X R_X \rightarrow W_X R_{I\Sigma} Y_{C\Psi} R_X\\
&W_X R_X \rightarrow W_X R_{I\Sigma} Y_{C\Psi}\\
&W_X R_X \rightarrow W_X R_I Y_{C\Omega}\\
&W_X R_X \rightarrow W_X Y_C R_X
\end{aligned} \quad (7)$$

An additional group of rules is connected with moving of the node of external arc and finishing of moving:

$$\begin{aligned}
&Y_{C\Omega} W_X \rightarrow W_X Y_{C\Omega}\\
&Y_{C\Omega} W_X \rightarrow W_X W_{I\Sigma} Y_{C\Psi}\\
&Y_{C\Omega} W_X \rightarrow W_{I\Sigma} Y_{C\Psi}\\
&Y_{C\Omega} W_X \rightarrow W_X W_{I\Sigma} Y_{C\Psi}\\
&Y_{C\Omega} W_X \rightarrow W_{I\Sigma} Y_{M\Psi}
\end{aligned} \quad (8)$$

A special group of rules are connected with generation of the arcs presenting visible walls. They could be produced starting from a roof arc.

$$\begin{aligned}
&R_X \rightarrow U_{C\Omega} R_X\\
&R_X \rightarrow R_X U_{C\Omega} R_X\\
&U_{C\Omega} R_X \rightarrow R_I U_{C\Omega}\\
&U_{C\Omega} R_X \rightarrow H_{I\Sigma} U_{C\Psi} R_X\\
&R_I U_{C\Omega} \rightarrow H_{I\Sigma} U_{C\Psi}\\
&R_I U_{C\Omega} R_X \rightarrow R_I H_{\Sigma I} U_{C\Psi} R_X\\
&R_I U_{C\Omega} R_X \rightarrow R_I H_{\Sigma I} U_{C\Psi}\\
&R_I U_{C\Omega} R_X \rightarrow H_I R_{\Sigma I} U_{C\Psi} R_X\\
&R_I U_{C\Omega} R_X \rightarrow H_I R_{\Sigma I} U_{C\Psi}\\
&R_I U_{C\Omega} R_X \rightarrow H_I R_{I\Sigma} R_{C\Psi} R_X\\
&R_I U_{C\Omega} R_X \rightarrow R_I R_I J_{C\Omega}\\
&R_I J_{C\Omega} R_X \rightarrow R_I R_I R_{C\Omega}\\
&R_I J_{C\Omega} \rightarrow R_{I\Sigma} R_{C\Psi}\\
&R_I J_{C\Omega} R_X \rightarrow R_I R_{I\Sigma} R_{C\Psi} R_X\\
&R_I U_{C\Omega} Y_C \rightarrow H_I J_{C\Omega} Y_C\\
&R_I U_{C\Omega} R_X Y_C \rightarrow H_I R_I J_{C\Omega} Y_C
\end{aligned} \quad (9)$$

where symbol $Y \in (V, J, U)$.

There is a peculiarity in application of the above rules. During the arc head movement a change of the arc type could happen, depending on the sequence of isolated arcs. The finishing rules for producing the right part of the wall arcs depend on the relative position of the adjacent walls (on same building, on the near or far from the projection centre.

$$
\begin{aligned}
&J_{C\Omega} V_X \rightarrow E_{I\Sigma} J_{C\Psi} V_X \\
&J_{C\Omega} V_X \rightarrow W_{I\Sigma} J_{C\Psi} V_X \\
&J_{C\Omega} V_X \rightarrow W_{I\Sigma} U_{C\Psi} \\
&J_{C\Omega} J_X \rightarrow E_{I\Sigma} J_{C\Psi} T_X \\
&J_{C\Omega} J_X \rightarrow W_{I\Sigma} J_{C\Psi} J_X \\
&J_{C\Omega} J_X \rightarrow W_{I\Sigma} U_{C\Psi} T_X \\
&J_{C\Omega} U_X \rightarrow E_{I\Sigma} J_{C\Psi} L_X \\
&J_{C\Omega} U_X \rightarrow W_{I\Sigma} J_{C\Psi} U_X \\
&J_{C\Omega} U_X \rightarrow W_{I\Sigma} U_{C\Psi} L_X
\end{aligned}
\tag{10}
$$

The similar form have rules for generation the left part of the wall border when the lower part of the wall is hidden by the part of the staying in front building. The starting rules have similar form if the wall is hidden by wall or by the roof. The more usual situation when the whole walls are visible tends to another set of production rules.

Another set of rules is formulated for generation of arcs, corresponding to the projection of the roof over the wall. Three groups of rules could be mentioned for generation of roof / wall border: for arcs in the middle of the wall (type N), left side arcs (type F) and right side arcs (type G).

A special groups of transition rules are connected with conversion from external to the internal contours. To ensure this process two stage procedure is used. At the first stage the scanning of all the isolated arcs from the new formed contour is applied. The rules use state modifier of type Φ. For every contour is applied a procedure for internal contour scanning.

After internal contour scanning it is possible to apply two type of production rules. - the rules for transition to terminal elements or the rules for generating of invisible lines. The procedure of generation of invisible lines starts from the main contour of the external level and moves around the all arc to convert them in status of generating the hidden lines. Such conversion is possible only for element of type "border" (excluding e and h arcs). During the conversion process the generating procedure finds the lowest level contour in the processed cluster. For that contour is generated contour of arcs of type t or hidden arcs from the border type arcs. The concurrent description of contours is produced that is similar to the description for the visible one but without elements of type "edge" (h, e). If contours from lower level are not attached to the upper level by element of type r, a change of the main element of the contour is produced. After that all arc elements of internal contour are converted to terminal state. The scanning proceed with the contours of the upper level until the highest level for current cluster is reached. During that process the description of internal contours is produced for which some arcs of type r or v could be included several times in the contours of different levels. The process of image description generation for simple block of three buildings with different height and disposition is shown in Fig.1. The corresponding producing rules are shown in the right part of the Figure 1.

4. MAIN STEPS OF PROCESSING

The first step of processing includes contour finding procedure. To ensure reliable closing of the contours it is appropriate to apply edge detector procedure after image segmentation step. In that case the contour detector could be applied only to that arcs of the image where preliminary area boundaries pass.

The second step applies contour matching between two stereo images. To ensure good height accuracy a method for arc chain coding with subpixel resolution have to be used. This procedure is applied only to those arcs that are visible in two images if correspondence could be estimated. The estimated height properties of the arcs are attached to the generated arcs.

The third step of processing is application of producing rules of the above defined grammar to connection of arcs with their height properties. The goal is to produce an image description that is allowed in terms of the defined grammar. The last stage of this step is the creation of a separate object description.

5. DISCUSSIONS

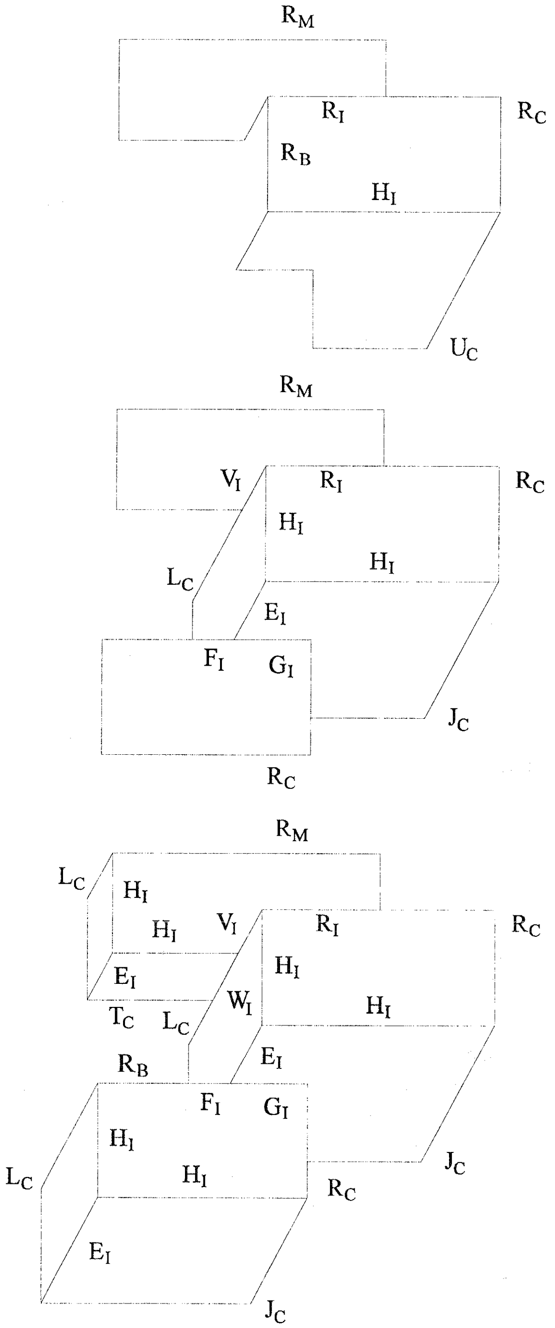
The suggested approach of description of images of urban areas could be applied after procedure of automatic contour extraction and contour matching in digital stereo images or after collection of vector data by a digital or an analytical plotter. The generation procedure could be applied for creation of a skeleton model of the object or for verification the accuracy of the arc labelling

The problems that arises are that it is not possible to ensure height information for all visible arcs in two images. The second problem that arises is related with contour disconnection due to the presence of noise in input image and unperfected contour tracing procedure. As a result gaps in the model appear. To solve that problems an improvement of the grammar by adding of stochastic rules have to be done.

Another problem is due to the fact that the suggested approach is based on height information of the arcs and especially the relation of arc heights in joint points. For such points a contour matching procedure could failed and to avoid this the height information have to be determined in the nearest to the connection point area of the image that produces some limitations for low resolution images or relatively small objects.

The produced image model could be used for excluding the building areas from generation of DEM or for purposes of mosaicing of two stereo image during the process of digital photo transformation. 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.

The filled up model containing information for the terrain and the artificial objects (buildings and etc.) could be applied also in a similar way for purposes of an improved land cover classification. The mosaicing of the areas of the two images could be done to complete the classified image of the terrain.



The initial steps of model image forming shows convertion from isolated area R_Q to left shown image by applying the following rules:

generation of attached roof
$R_Q \rightarrow R_I R_M R_C$
generation of wall from roof
$R_C \rightarrow R_C U_{C\Omega} R_B$
$U_{C\Omega} R_B \rightarrow H_{I\Sigma} U_{C\Psi} R_B$

The second image is produced as a result of following rules:

generation of roof covering wall
$U_C \rightarrow J_C U_{C\Omega} L_B$
$U_{C\Omega} L_B \rightarrow G_{I\Sigma} U_{C\Psi} V_B$
generation of wall starting from covering roof
$R_C \rightarrow R_C L_{C\Omega} R_B$
$L_{C\Omega} R_B \rightarrow H_I L_{C\Omega}$
$H_I L_{C\Omega} V_B \rightarrow F_I V_I L_{C\Omega}$
$V_I L_{C\Omega} R_X \rightarrow E_I H_I L_{C\Omega}$
$H_I L_{C\Omega} R_M \rightarrow H_I V_{I\Sigma} L_{C\Psi} R_M$

The third image is produced as result of following rules:

generation of surrounding wall starting from wall
$L_C \rightarrow L_C E_I L_{C\Omega}$
$E_I L_{C\Omega} R_M \rightarrow W_I H_{I\Sigma} L_{C\Psi} R_M$
generation of adjacent wall
$L_C \rightarrow T_C E_I L_{C\Omega}$
$E_I L_{C\Omega} R_M \rightarrow E_I H_{I\Sigma} L_{C\Psi} R_M$

generation of surrounding walls starting from roof:
$R_C \rightarrow R_C U_{C\Omega} R_B$
$U_{C\Omega} R_B \rightarrow H_{I\Sigma} U_{C\Psi} R_B$
generation of adjacent wall
$U_C \rightarrow J_C E_I L_{C\Omega}$
$E_I L_{C\Omega} R_B \rightarrow E_I H_{I\Sigma} L_{C\Psi} R_B$

Figure 1. Production rules, creating simple block of buildings.

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