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O. Al Khalil, Pierre Grussenmeyer

SINGLE IMAGE AND TOPOLOGY APPROACHES FOR MODELING BUILDINGS

O. Al Khalil & P. Grussenmeyer

ENSAIS - Photogrammetry and Geomatics Group, 24 Boulevard de la Victoire, 67084 STRASBOURG Cedex, France
alkhalil@ensais2.u-strasbg.fr pierre.grussenmeyer@ensais.u-strasbg.fr

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ABSTRACT:

The paper presents a method and strategy for building reconstruction and visualization from single images and topologic approaches. In our method, geometric and semantic data of entities to be modeled are extracted. The structuring of geometric, topologic and semantic data is done within the measuring process.
In most applications, the model contains only information about the shape and the texture of the object while its topologic and semantic data are not processed. We combine this information to reconstruct outdoor and indoor scenes.
Single image techniques based on projective geometry aspects as vanishing points and homography are adopted. This configuration was preferred to the traditional stereoscopic and multi-image techniques considering the particularity of the environment to be modeled and application difficulties of these techniques.
Indoor scenes are structured in blocks like rooms, corridors, etc. with their own orthogonal coordinate systems. A block is presented in an abstract way using a Data Conceptual Model to identify the entities and the relations to include in the database. The 3D model can then be reconstructed automatically from the information stored in the database. Coplanarity conditions between entities as windows or doors and the compatible walls are taken into account. The outdoor and indoor blocks are merged by the use of "virtual doors" (or windows). These doors are defined in function of the wall thickness and the translation direction according to the local coordinate systems of the blocks. The final model offers several applications:
- topologic navigation in the model,
- visualization and extraction of the geometric characteristics of given types of entity (areas, perimeters, etc.),
- visualization of " virtual doors ", used to calculate the parameters of the transformation (rotation and translation) between the reference coordinate system and the local systems attached to the different blocks,
- generation of photo-realistic models
As examples, the method has been applied to the modeling of the exterior part of the old Zurich city hall (CIPA dataset from 1999) and to the modeling of a part of the ENSAIS buildings.

1. INTRODUCTION

Building modeling methods are of interest for urban planning and for projects in civil engineering. These methods consist in reconstructing the exterior parts of buildings: roofs and façades. The 3D geometric data are usually extracted using stereoscopic or convergent images rays.

The goal of this paper is to present a strategy for 3D indoor modeling based on the combination of single image photogrammetry and topologic approaches. In this method, data structuring is done within the measurement process.

Using single image configuration allows to:

- reduce the number of images;
- avoid the establishment of conditions required for the traditional approaches (stereoscopic and convergent images rays);
- use archive images.

Our test object for indoor modeling is a building at ENSAIS. Each floor of the building is structured in a reference component (the corridor) to which simple components are attached (classroom and offices) by interconnection surfaces (doors). These surfaces were used to merge the different components.

Although the proposed strategy is applicable to indoor scenes, it can also be applied to outdoor ones. To show this possibility, our method was used to establish the 3D model of the old Zurich City Hall building from a dataset proposed by CIPA.

2. DESCRIPTION OF THE METHOD

Our research is in the field of 3D modeling and representation of indoor scenes. This approach is based on:

1. The organization of the indoor part as being composed of simple unit components or reference unit components;
2. The representation of the information in hierarchical form;
3. The simultaneous structuring of data in a relational database.

The 3D geometric data are obtained from single images. Data structuring, which includes the geometry, the topology and the semantic aspects of the modeled scenes, is done during the geometric modeling process.

The Conceptual Data Model (CDM) represents the information in three geometric, semantic and topologic levels.
The geometric level of modeling (and its relations with the topology), is a graphic representation, which only reports the position and the shape of objects and the spatial relations between these objects (neighborhood, intersection, slope, etc.).
The topologic level is an intermediate level used to define the relations between geometric primitives (points, lines and surfaces) presented in the previous level. The topology allows an effective structuring of the graphic elements. In this context, a point represents a nod, a segment represents an edge, a surface represents a face and the unit component itself represents a 3D body.
With regard to the semantic level, it allows to define objects to be modeled and their attributes, in answer to modeling needs and in accordance with the available geometric data.

2.1 Geometric modeling

The surface is the fundamental unit in our 3D-modeling approach. The modeling process indicates here the use of volumes bounded only by their surfaces. Planes entities are dominant in the interior parts of buildings (wall faces, door faces, windows faces, etc.). Every entity will be modeled by means of its boundaries (B-rep representation). Therefore only the points that constitute the outline of a given entity will be measured in the image. The resulted surface model can be completed by means of geometric primitives (cone, cylinder, prism and sphere).

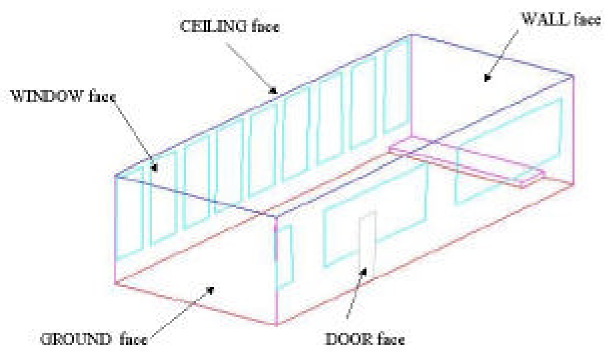

Figure 1. Essential entities of a room

In the indoor parts, the establishment of stereoscopic or convergent image rays conditions is difficult. In this environment, shots are mainly influenced by the distance between the camera and the object but geometric constraints (parallelism, perpendicularity, symmetry, etc.) are numerous. This favors the adoption of a single image technique as a source of 3D geometric data required for modeling. It is, however, necessary to clarify that it is almost impossible to extract 3D characteristic quantities of a scene from a single image except when the scene is plane, at least locally (Burns, 1990).

The technique of 3D single image modeling adopted in our method is partly based on former researches (Criminisi, 1999). Data acquisition is done by using an application called Mono Image Modeling (MMI). To extract 3D data from one image, the following algorithms are proposed (figure 2):

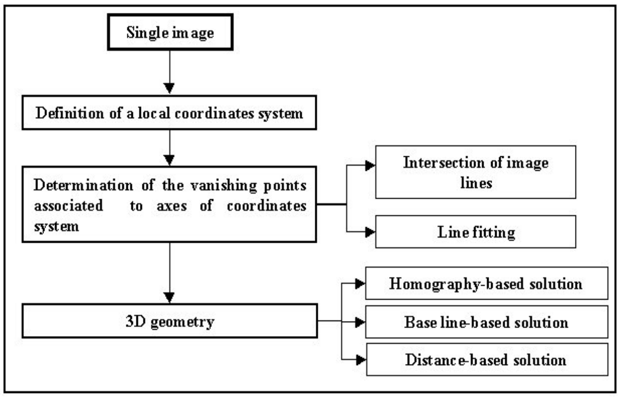

Figure 2. Steps of the geometric modeling

2.1.1 Determination of vanishing points

The first step consists in determining the vanishing points associated to the axes of a local coordinate system. Two algorithms are proposed to compute these points:

2.1.1.1. Algorithm based on the intersection of image lines

Homogeneous coordinates are used to represent the end points of measured lines. A series of lines parallel to each axis is measured in the image. The corresponding vanishing point is the intersection of those lines. If the intrinsic parameters of the used camera are known, the vanishing point is directly given in metric coordinates and radial distortions' corrections are applied.

A linear regression is applied to evaluate the accuracy of measurements. If the camera is not calibrated, the three vanishing points resulting from the previous stage can be used to calculate the intrinsic parameters (principal point and focal length) of the camera (Caprile, 1990).

2.1.1.2. Algorithm based on line fitting

Cartesian coordinates are used to express the measured lines. A line fitting approach is applied to compute vanishing points associated to the axes of the local coordinate system.

2.1.2 Calculation of the 3D geometry

To carry out a complete 3D reconstruction from a single image, object space must be described as a combination of three planes. The plane, which contains the axes X and Y, is the reference plane whereas the direction (Z) is the reference direction (Criminisi, 1999).

Three solutions are proposed to compute the 3D geometry from one image:

2.1.2.1. Homography-based modeling

Modeling is based on the homography of the reference plane. To apply the algorithm, four control points situated in the reference plane and a distance along the reference axis, are necessary. The control points allow to compute the parameters of the homography of the reference plane. If more than four points are known, a least square solution is possible. By using the vanishing point of the reference axis (Z-axis in our case) and the known distance, the scale factor associated with this axis is calculable by applying the algorithm proposed in (Criminisi, 1999). To determine the 3D coordinates of the point (P), it is necessary to measure its projection (P') in the reference plane. The coordinates of (P) are determined in two steps (Figure 3):

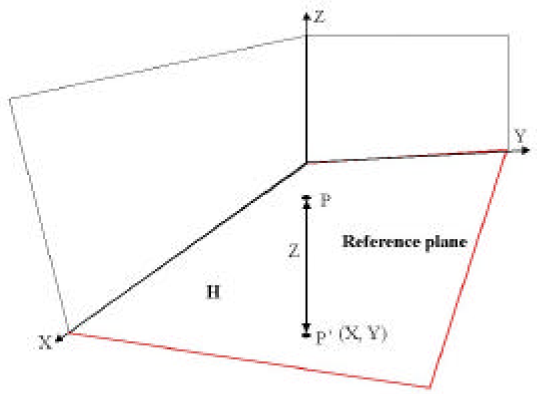

Figure 3. Steps of 3D coordinates computing

1. The coordinates (X, Y) are determined by using (P') and the homography of the reference plane;
2. The coordinate (Z) is computed by using the scale factor along the (Z) axis and the image coordinates of the point and its projection (P').

Our application gives also the possibility to measure in the following planes:

1. The reference plane;
2. A plan parallel to the reference plane;
3. The plane (XZ);
4. The plane (YZ).

Measuring the 3D coordinates of four points in one of these planes allows computing its homography. Thereafter, the 3D digitalization in this plane is possible.

2.1.2.2. Base line-based modeling

When applying the previous algorithm, the determination of the 3D coordinates of a point requires one of its projections in one of the three planes of the scene. The manual determination of this projection is not always possible on the image. Our algorithm consists in determining automatically the projection, in the reference plane, of points located in the planes (XZ, YZ) or in a free plan which meets the reference plane. This is done using the base lines. A base line can be defined as the intersection of a given plane with the reference plane.

2.1.2.3. Distances based modeling

3D modeling is done by using the algorithm proposed in (Criminisi, 1999). Three distances are required to calculate the scale factors associated to the axes of a local coordinate system. Axes' vanishing points are used with the resulted scale factors to compute the 3D geometry.

2.2. Topologic and semantic modeling

Because the topology is an effective way of data structuring, the adoption of the topologic modeling in our method facilitates data exploitation and avoids graphic redundancy. The topology in our approach allows carrying out topologic and geometric requests (surface and perimeter of a given face, the normal on faces, co-planarity between a given window or door and a given wall, etc.).
The application of the semantic modeling rules to the 3D modeling of the indoor scenes, has to take into account the following points:

- The definition of the model to be set up and the semantic properties of the entities. This task is based on the architectural knowledge and on the geometric characteristics of the scene;
- The extracted data is function of the level of details required in the model. The semantic aspects are taken into account in the geometric measurement process.
- The relations between the geometric, topologic and semantic levels define the modeling concepts. The concepts to be modeled are three-dimensional ones. In our approach, the general concept represents the interior part of a building.

The logic phase of modeling consists in translating the Conceptual Data Model into a Data Base Management System (DBMS). In the relational model, data are organized in 2D tables in which lines are recordings and columns are attributes. In this system, the basic element is a table, which represents a relation between various fields. Every attribute takes its values in the corresponding field. To distinguish the various recordings in a table, one or several attributes are indicated as keys or identifiers. The relational model is easy to implement and the addition of new tables, new attributes or new relations between existing tables can be carried out easily. Considering these advantages, our Conceptual Data Model has been translated into a Relational Data Base Management System.

2.2.1. Algorithm for semantic and topologic data extraction

The surface is the fundamental unit of modeling in our approach. For a given surface, the operator extracts the limit points and then he specifies the semantic type of this surface. We distinguish the following type of surfaces: wall, ceiling, ground, window, door, column. The last stage consists in clarifying the numbers of the contour points of this surface, extracted in the same direction.

With regard to the surfaces of type window and door, other information have to be specified to take into account the co-planarity relationships between these surfaces and the corresponding WALL.

At the end of the geometric and semantic restitution, a partial database is generated. This one is not complete but it contains all data necessary for generating a complete database and reconstructing the 3D model. This database contains the following tables:

1. The table T_ROOMS that contains the modeled component (room, corridor, etc.) identifier and the identifiers of faces which constitute this component.
2. The table T_FACES_EDGES that contains faces identifiers; faces types and edges identifiers.
3. The table T_EDGES that contains edges identifiers and the corresponding nodes' identifiers.
4. T_DOORS and T_WINDOWS that contain the numbers of doors / windows with the numbers of the walls which contain them.

We notice the absence of the tables that describe the different types of faces. These tables are created automatically.

After completing the database, the generation of the component 3D model is carried out automatically.

2.2.2. Algorithm for components merging

This algorithm allows transforming the components of the interior part of a building in the same geometric reference. This reference is attached to the component which can be defined as the one containing the maximum number of interconnection surfaces (doors, windows, etc.). The relations between a reference component and a simple one attached to it can be described by a 3D conformal transformation. We can use the virtual doors to calculate the parameters of this transformation. In fact, these doors represent the doors of the simple components translated by the value of the corresponding wall thickness. These doors have their corresponding in the reference component defined in the reference coordinate system. Using this idea, the seven parameters of the 3D conformal transformation can be calculated.

3. APPLICATIONS

3.1. Example of an indoor scene

Our approach was used to model the first floor of a building at ENSAIS (Strasbourg) (figure 4). The 3D reconstruction was made by using 3D geometric data and topologic relationships recorded in a partial database.

Elements of the corridor are walls, windows and doors. This geometry is the ideal environment to apply our modeling method. However, the weak distance between the object and the camera, has made the data extraction and recording rather difficult.

Corridor dimensions are approximately of (2.2m x 50.0m).

Figure. 4. Test building (ENSAIS)

3.1.1. Modeling data

Shots were made with a non-calibrated digital camera (FUJI DS 300) and seventeen images were necessary to cover the corridor.

Some control distances were measured in the reference plane (in our example the plane XY of a local coordinate system). Distances along the (Z) axis were also required to determine the scale factor associated to this axis.

Additional measurements, realized by means of a simple ribbon and directly made on some parts of the corridor, were necessary to complete the 3D model.

3.1.2 Modeling steps

Defining a local coordinate system

A local coordinate system was defined in object space. The reference plane (XY) is defined as the corridor's ground plane. The axis (Z) was chosen as a perpendicular direction to the reference plane (XY).

Extraction of the 3D geometric data

Extraction of the 3D geometric data was made by means of our application of single image modeling. First of all, vanishing points associated to the various axis of the local coordinate system were computed. Then, the homography parameters of the reference plane were determined using control points. Extracted 3D geometric data are recorded in a text file. This file constitutes the node table in the resulted partial database.

Extraction of the topologic and semantic data

During the modeling, the operator extracts simultaneously the geometric, topologic and semantic data of a given surface. He specifies the numbers of points, which constitute the limits of this surface as well as its semantic type. These data are recorded in a database generated automatically. This database is then used with a GUI integrated into a CAD system to reconstruct the 3D model.

Data Combination and 3D surface model generation
The 3D geometric data associated to the topologic relationships and semantic types (recorded in four partial databases) were used to generate the following 3D surface model of the corridor:

Adding classrooms and offices
The same steps, applied during corridor modeling, were followed to model classrooms and offices attached to this corridor. For each classroom and office, a local coordinate system has been set up. In the reference plane of each system, some control points were measured by means of a simple ribbon.

Classroom and offices were modeled in their local coordinate systems using single image photogrammetry (figures 4 & 5) and components were merged thanks to the virtual doors (figures 6 & 7).

Figure 5. Two shots only are used for the modeling of one room

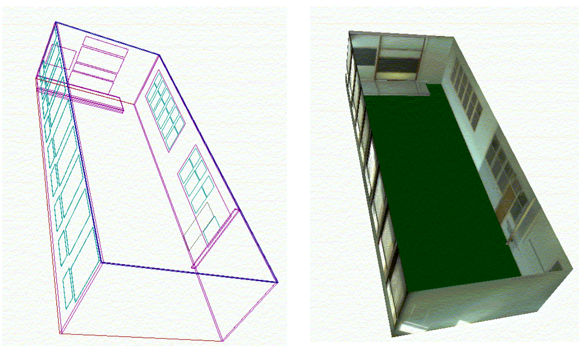

Figure 6. 3D model of a classroom (computed from two single images)

The virtual doors were specified during data extraction in order to know which door belongs to which classroom or office. The tables, which represent theses doors in the databases of the different classrooms and offices, were then used with their corresponding in the corridor's database to calculate the parameters of the 3D similarity transformation which links the various local coordinate systems to corridor's coordinate system.

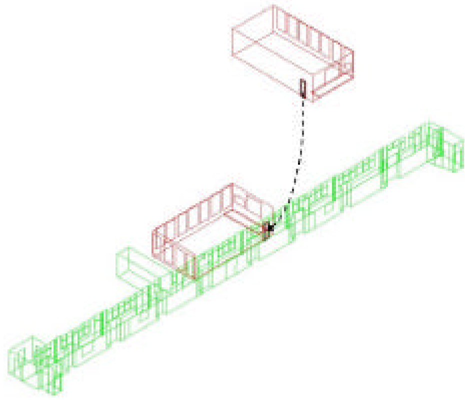

Figure 7. Linking a classroom to the corridor's coordinate system using the virtual door (indicated in bold)

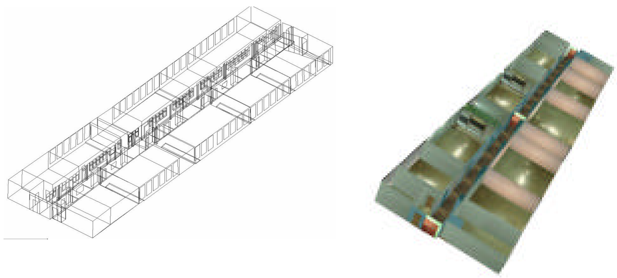

Figure 8. 3D surface and photorealistic models of the corridor and the classrooms or offices

3.2. Example of an outdoor scene

Although the method of 3D modeling proposed in this study is intended for indoor scenes modeling, it can also be applied to exterior scenes if their geometry is described by means of plane surfaces. To show this possibility, this method was used to establish the 3D model the old city hall of Zurich (Switzerland) from images proposed by CIPA in a dataset (Streilein, 1999).

3.2.1. Steps of 3D single image modeling of the old Zurich city hall

Used images
Two images, taken from the dataset, were used to carry out the geometric model of the building. The first one covers the north and east façades whereas the second covers north and west facades. With regards to the south facade, it can be modeled by means of points measured on the east and west ones.
Both selected images satisfy a perspective projection. This allows the calculation of vanishing points associated to the various axes of the local coordinate system.

Local coordinate system
To configure the scene for a single image modeling, a local coordinate system was set up and control points were defined (figure 9). This system must not be a right hand system. Four control points were chosen on the north façade, considered as the reference plane of the scene.

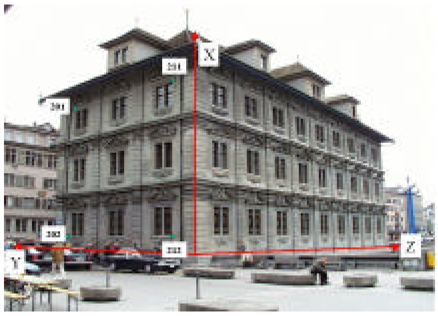

Figure 9. Local coordinate system and control points

The same coordinate system was used to extract 3D coordinates of points measured on both images indicated in figure 9.

Modeling with our application of single image modeling

To extract the 3D geometry of the Zurich city hall of by using our application of single image modeling, the following stages were applied:

1. Definition of two single image projects. Each project requires an image, a file of control points and a camera file (optional);
2. Computation of the vanishing points associated to the local coordinate system axes. This is done by measuring a series of parallel lines for each axis in the image;
3. Calibration of the camera by means of vanishing points resulted from the previous stage;
4. Computation of the homography of the north façade. This is done with the four control points given in the dataset (figure 9);
5. Computation of the scale factor associated to the reference direction(Z) by using a reference distance measured along this direction;
6. Determination of the 3D coordinates of the points measured on the various façades;
7. Establishment of a relational database by means of the interface integrated into the application of single image modeling. This database contains the semantic and topological data of the building;
8. By means of the interface intended for topology-based modeling and integrated into the main shape of a CAD system, the visualization of building 3D surface model was done automatically. In this database the WALL as a semantic type represents the various façades whereas the semantic type CEILING represents the faces of the roof;

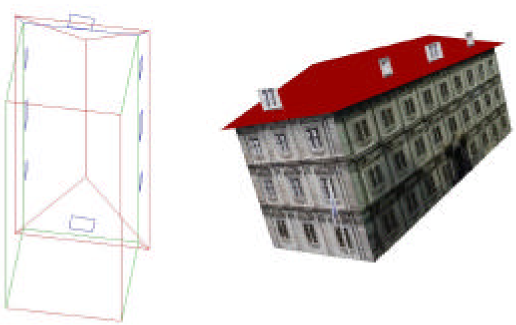

Figure 10. 3D surface and photorealistic models of the city hall of Zurich

By means of the CAD system, textures were attached to the various faces and the 3D-photorealistic model was generated (figure 10). The textures of the various faces were calculated by means of 3D points measured on these faces.

4. CONCLUSION

An approach has been proposed to realize interior and exterior 3d modeling of buildings from single images.

This approach can be summarized in the following points:

1. The approximation of the interior part as being composed of simple and reference unit components;
2. The representation of the information in hierarchical form
3. The simultaneous data structuring in a relational database. The RDBMS was chosen as the data processing tool.

Considering the geometric characteristics of the buildings, a single image photogrammetry configuration was adopted as a source of the 3D geometric data.

Three solutions were proposed to compute the 3D geometry from one image using our application for single image modeling, partly based on former researches. The 3D reconstruction and visualization of the imaged scene are based on the topologic relationships recorded in a relational database. To validate our method, the method has been applied on an indoor scene and an outdoor one.

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