RECONSTRUCTION OF ARCHITECTURAL OBJECTS FROM 3D SCANNER SURVEYCHRISTOPHE

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Abstract: This paper presents a method that aims at reconstructing a 3D building from point clouds measured by 3D scanner. It starts from the idea that it is easier to rebuild a scene using available knowledge about the scene's elements. This solution has to consider the three following aspects. How to find objects in a cloud of points? How to define a geometric and semantic coarse model? Which algorithms to use as a propagation method to find all objects in the cloud of points? In our solution the user has to assign the context by defining a coarse model of the building to be reconstructed. Then the user interactively selects a set of points in the cloud that represents an element. The selection is also mapped to the coarse model by assigning the corresponding wall in the "CM". Then the user starts the reconstruction algorithm. Within an iterative process the plane representing the wall is found and will be used to correct the model. The process starts with the mapped plane, corrects it, and continues with information in "CM" to detect an adjacent plane by propagation.

1 Introduction

In the field of civil engineering projects it is often difficult to update a building. Most of the time, information concerning its design has simply disappeared. Indeed, no process was usually defined to store digital data concerning the design of the architectural project. Such data would be helpful to estimate the update costs. For instance, the security laws evolve and the buildings have to follow them. Consequently, the buildings must be updated too. Also, the building has to be captured "as-built" using expensive geometrical measurements to improve the design and to evaluate the update costs. These measurements have to be done by engineers and comprise several steps like the establishment of a geometrical reference and a local data capture. This process is time consuming, that's why automatic algorithms are welcome in order to reduce time and cost. In principle, photogrammetry and laser scanning both have the potential for improvements and higher degrees of automatism. In this article we focus on a method based on the laser scanning survey.

Digital building plans being defined by the civil engineers with the help of CAD software mostly contain simple geometries. During various processing steps and their inevitable data exchange object information is reduced to a set of vectors using formats like DXF or DWG. As a consequence, semantic information and object structures are lost. Such problems might be avoided with file formats like IFC, defined by the International Alliance for Interoperability. This standard associates a semantic definition to geometrical elements in the field of building projects. Up to now, this standard is used as an exchange format by international leaders of CAD software. This format is of value for "as-built" problems, aiming at the digital reconstruction of real buildings. Consequently, it should be helpful to use the IFC semantic information directly

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during an “as-built” reconstruction of a building for an automatic reconstruction. In this article we focus on a method based on a 3D laser scanner and on IFC semantic definitions. These definitions are stored in an ontology which defines the semantic information of the architectural context to improve the reconstruction process.
The following section gives background information on projects that aim to reconstruct a 3D model of a building from survey data. In these projects the semantic information that describes the context of the building takes an important place. Section 3 describes our approach inspired from these projects. Section 4 focuses on this method by explaining all the important parts of the reconstruction process.

2 Background

Today, computer-driven evaluation of spatial data sets is limited by the complexity of the objects to be extracted. As a matter of fact, it is complicated and time consuming to formulate rules in order to detect and extract objects geometrically correct. It is due to one essential reason that the objects are broken down into many small geometrical pieces. Even if each piece can be treated in an isolated way, it is not possible to treat all data at one time. Therefore, the use of knowledge and its introduction into the process of evaluation is promising for global interrelations. The impact of semantic information on the reconstruction process depends on the structure of the raw data that has to be handled. Therefore, it is necessary to study those structures and reconstruction processes. A short survey is given in the two following subsections. The first subsection is concerned with reconstruction methods based on photogrammetric data and the second considers reconstruction methods based on scanning data. Each method has its own characteristics and advantages but the best choice depends on the material available, the object to be captured, the required precision, and the time available (Grün, 2002), (Bryan, 1999), (Balletti, 2004), (Boehler, 2004).

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2.1 Photogrammetry

Reconstruction methods based on photogrammetric data are of two kinds. The semi-automatic methods consist of the interaction with the user during the whole process. The automatic methods consist in the initiation of the process by the user at the beginning so that later the process runs without user interaction. Semi-automatic reconstruction methods can be found in the projects: Realise (Zitova, 2003), TotalCalib (Robert, 1995), (Bougnoux, 1997), (Faugeras, 1997), Marina (Cantzler, 2002), (Nüchter, 2003) and Rekon (Frasson, 1999), (Loscos, 1999), (Poulin, 1998). Automatic reconstruction methods have been developed by Pollefeys et al. (Pollefeys, 2000) and Zisserman et al. (Werner, 2002). They use the projective geometry on non-calibrated images. Pollefeys' system combines various algorithms from computer vision, like projective reconstruction, auto-calibration and depth map estimation. Of special interest for our work was the project Aida (Weik, 1996) because it uses a semantic network to guide the reconstruction. This method opens a new way by using semantic information. The automatic reconstruction remains a difficult task in spite of many years of research (Backer, 1981), (Fleet, 1991), (Grimson, 1981), (Jones, 1992), (Marr, 1979), (McMillan, 1995). The major problems are the impact of the viewpoint onto the appearance of the object in the image. This is due to the changes with respect to geometry, radiometry, occlusions and the lack of texture. Strong variations of the viewpoint may destroy the adjacency relations of points, especially when the object surface shows considerable geometrical variations. This dissimilarity causes confusion in the determination of correspondence and it is worse when partial occlusions result in a disappearance of object parts. In cases of weak texture the algorithms do not have sufficient information to solve the correspondence problem correctly. Usually, this is the reason why the reconstruction fails.

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2.2 3D Scanning

Accurate reconstruction of a surface model from unorganized points of clouds provided by scanning systems are complex and are still not completely solved. Problems arise from the fact that the points are generally not organized, contain noise and do not reflect directly the object characteristics, for example. Computer-based processes of object extraction are therefore limited in their efficiency. F. Remonido gives a good overview of existing algorithms (Remondino, 2003). Close attention is given to the work of Cantzler et al. (Cantzler, 2002) and to the work of Nüchter et al. (Nüchter, 2003) because these projects use semantic information. Planes which are being reconstructed are associated to a semantic interpretation which has to fit to a network model (Grau,1997). A tree of "backtracking" allows to find the best mapping between the scene interpretation and the semantic network model. A coherent labelling exists if all surfaces are labelled.
Compared to photogrammetry, problems seem to be fewer in the field of scanning but an automatic reconstruction is just as impossible as it is within image based techniques. One important reason for this is the complexity of objects in combination with redundancy, incompleteness and noise within the clouds of points. Improvements can be expected when knowledge about the scene is used, as is shown in the work of Cantzler and Nüchter. This is the reason why the nature of the geometrical objects and the existing constraints between them make it possible to support computer based detection.

3 Ontology-driven reconstruction

As the work presented in the previous section shows, a semantic context may support considerably a 3D reconstruction. This might be helpful for the reconstruction within clouds of points where some elements of the object have already been detected and need to be combined to a final structure. Semantic knowledge is also useful for photogrammetric tasks. This might either help to group 2D points in the images or to form the spatial structure when several images are available. The semantic structure of the spatial object model is the same, only the use and the interaction with the data are different. In the following section our vision of the use of semantic definition for 3D reconstruction will be sketched. Our main idea is founded on the duality between context and constraints. It starts from the idea that it is easier to rebuild a scene using available knowledge about the scene's elements. Therefore, in order to define the knowledge about the context, a coarse geometrical and semantic model has to be established. We call this

Coarse Model “CM” and it is a spatial structure that defines a building and the semantics about the elements that compose the building.

Fig. 1: Example of an architectural CM

The “CM” (e.g. fig. 1) defines the rough geometry and the semantics of the building without any real measurement. Such a "CM" will then be updated by means of real measurements representing the building. In order to achieve this, knowledge has to represent the real world by reflecting entities and relations between them. Therefore, knowledge constitutes a model of the world and agents use their knowledge as a model of the world. In addition, to model the semantics of knowledge as well as the structure where this knowledge is stored, it is necessary to reach a higher conceptual level. For that, knowledge representation is independent of knowledge use. Thus, knowledge representation and inferential mechanisms are dissociated (Guarino & al., 1994). On the other hand, domain conceptualization can be performed without ambiguity only if a context of use can be given. In fact, a word or a term can designate two different concepts depending on the particular context of use (Bachimont, 2000). The semantic of knowledge is strongly constrained by the symbolic representation of computers. Therefore N. Guarino (Guarino, 1994) introduced an ontological level between the conceptual level and the epistemological level. The ontological level forms a bridge between interpretative semantics in which users interpret terms and operational semantics in which computers handle symbols (Dechilly, 2000). Some projects presented previously have used a semantic network to model the semantics of a scene. We will use an ontology as a meta-data diagram. The role of a meta-data diagram is double (Amann, 2003). On the one hand, it represents the knowledge shared on a domain. On the other hand, it plays the role of a database schema which is used for the formulation of requests structured on meta-data or to constitute views. In addition, the ontologies allow to dissociate knowledge representation and inferential mechanisms. We have sketched a generic definition of semantic elements that permit to dynamically add new elements in the ontology without changing the code. Those new elements are also taken automatically into account in the storing process and the inferential mechanisms. Finally, once the “CM” has been corrected, geometric and semantic information in the ontology can be exported into an IFC file format. So, the 3D model can be used directly in civil engineering processes and CAD software.

4 Method Definition

Our method aims at developing a solution to reconstruct automatically a 3D building from a point cloud measured by a 3D scanner. This solution (Fig. 2) has to consider the three following aspects. How to define a geometric and semantic coarse model? How to find objects in a cloud of points? Which algorithms to use as a propagation method to find all objects in the cloud of points? In our solution the user has to assign the context by defining a coarse model of the building to be reconstructed. Then the user interactively selects a set of points in the cloud that represents a wall. The selection is also mapped to the coarse model by assigning the corresponding wall in the "CM" (Fig. 3). Then the user starts the reconstruction algorithm. Within an iterative process the plane representing the wall is found and will be used to correct the model. The process starts with the mapped plane, corrects it, and continues with information in "CM" to detect an adjacent plane by propagation. A final stage should aim at the detection of smaller parts like doors, windows, etc.

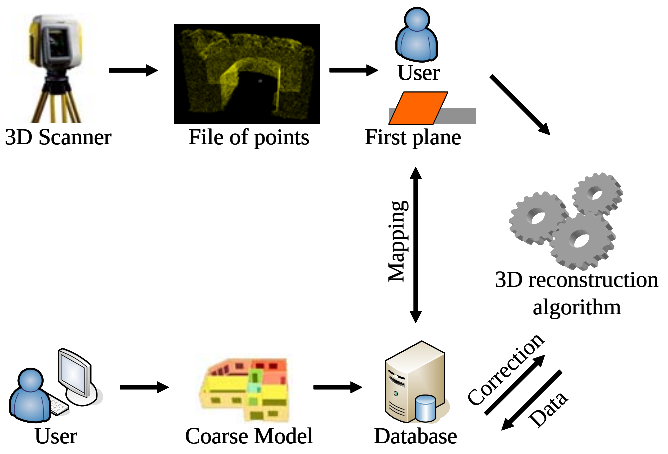

Fig. 2: global view of our method

The three following points give an overview of our solution to achieve the final goal consisting of the definition of a "CM", the plane detection that allows to find objects in the cloud of point, the search of objects by propagation permitting the correction of the "CM".

- With the application that has been developed (Fig. 3) the user can define geometrical elements of a building like the position and the size. Moreover, the interaction with our application allows to define automatically constraints between elements of the "CM" which are described by the architectural ontology. For instance, a window is a concept that composes the architectural ontology. This window has a constraint which is "the window must be in a wall with a bigger size". Our model is divided into two levels which are the semantic level and the instance level. The semantic level allows to store the description of the ontology classes from a OWL (Web Ontology Language) file. The instance level allows to store the description of the instances from the classes of the ontology. The storing process and the graphical interface are then not modified when a new class has to be added. In addition, we defined predefined behaviors and then associate those behaviors of the future elements to the existing behaviors. For example, a new class column has the same behavior as a wall. It is indeed located on the ground and touches the ceiling. Thus, it was necessary to locate the types of behavior according to the possible interactions.

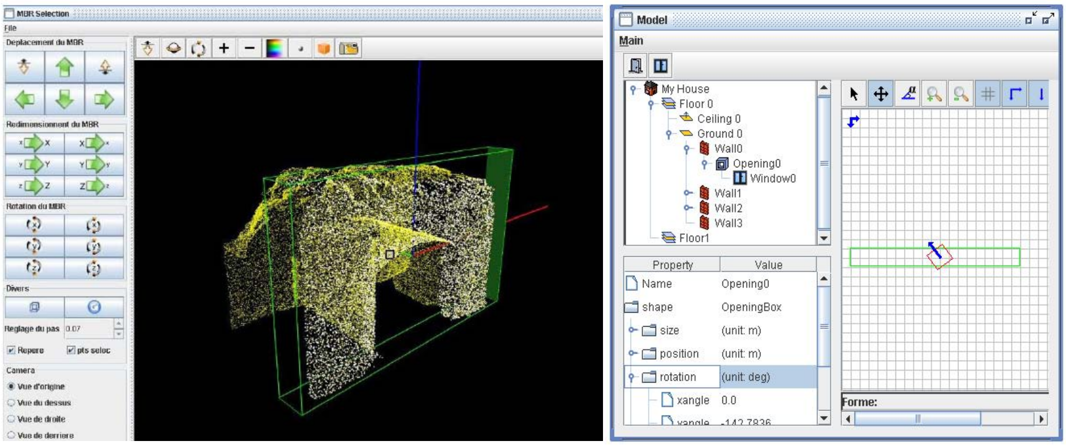

Fig. 3: On the left, there is a snapshot of the application allowing the selection of a subcloud of points. On the right, there is a snapshot of the application allowing the definition of the “CM”.

- The objects which we look for in the point cloud are planes. This geometric primitive is the easiest one to search and also the fastest one (Remondino, 2003). During the plane search process, there are several stages that have to be carried out. The first stage is the partitioning of the point cloud. After initial planes are found, they have to be extended within the point cloud. This is achieved by starting from the plane equation for one voxel and looking at the adjacent voxels if there are points possibly belonging to the same planar surface part. There are several methods to support such a decision. One solution is to calculate a plane for each voxel by means of “least square adjustement”. This is relatively simple to set up, but needs to define a threshold for the different angle of orientation to define the similarity. A better solution starts with the voxel having the best residual error and then it consists in checking the distance to this plane, beginning with the direct neighbours. If the sum of the distance is lower than a certain threshold then the voxels are fused. For the fused group a new equation has to be calculated in order to refine the result.
- The principle of the project is to use a point cloud coming from a building survey to correct a coarse model that defines the context. Although the improvement of the coarse model is the most interesting result, the initial model - and the knowledge contained therein - is of basic importance for the update process. Therefore, two aspects are of interest in the context of model improvement: first, readjusting the initial wall definition compared to the “CM”, and, secondly, the support for the propagation of the plane detection in the whole cloud of points. To propagate the “CM” modification a direction was defined. The propagation is made left towards right then bottom towards top. The

"CM" contains information of the neighbourhood. Indeed, the neighbourhood relations are automatically defined during the "CM" definition.

5 Conclusion

This paper presented briefly our solution for the 3D reconstruction driven by an architectural ontology. At this time, most of the huge issues were resolved and the complete process was prototyped. The following issue to be resolved is the use of the other primitives like the cylinder to reconstruct automatically more complex scenes. Furthermore, we are also working on a solution to reuse a partial "CM" that allows to define more easily a complex "CM".

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