Primitives Merging For Rapid 3D Modeling

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ABSTRACT: Developing three dimensional models of infrastructure and construction in progress can be useful for designing modifications, for tracking work completed, and for facilitating advanced equipment control and safety functions. An emerging 3D modeling method involves scanning scenes with laser ranging devices. The resulting dense or sparse point clouds are converted to primitive geometric objects. Merging those objects is useful for visualization and advanced manipulation. Factors that influence this merging process are identified here. Heuristics are proposed for automated merging, and initial results presented.

KEYWORDS: RAPID, 3D MODELING, PRIMITIVES, MERGING

1. INTRODUCTION

Methods for modeling the "as-built" condition of facilities and construction in progress have been emerging for several years. Most are based on data acquired using full area scanning laser radars (Ladars). Typical processes involve stochastic based dense point cloud merging, manual identification of volumes of interest, and conversion of point clusters within those volumes to CAD objects that are eventually integrated into a full CAD model of the facility of interest (Stentz, 1998; Stone, 2001; Cyra, 2003).

An alternative approach has been emerging to provide more rapid 3D modeling for construction (Kim, 2000; Cho, 2002 and 2003). Its main characteristics are the use of sparse point clouds, the utilization of the operator's scene recognition skills, and the division of the environment into target and peripheral objects. While peripheral objects can be roughly modeled by using convex hulls and bounding boxes (McLaughlin, 2003), target objects must be more accurately modeled. For target objects, geometric primitives are used: cuboids, cylinders, spheres, planes, and lines (Feddema, 1997; Kwon, 2003). In many instances of environments, the geometric primitives need to be merged in geometric objects of higher complexity. Therefore, primitive merging methods and algorithms need to be developed.

2. MOTIVATIONS FOR MERGING PRIMITIVES

Motivations for using merging algorithms include:

- Correcting modeling errors
- Visualization
- Improving the richness of models

Modeling Corrections

By saving relationship information between modeled primitives, model corrections can be implemented. For instance, two contiguous pipes in a pipe-spool are very likely to have identical diameters. If the primitives corresponding to the two pipes are very close and present almost identical diameters, they can be adjusted. Similarly, a column and a beam are very likely to be perpendicular to each other. Then, the angle between them can be adjusted if not exactly equaling 90°. However, such rules must be used with judgment, since some structured elements deflect significantly and, for instance, some pipes and conduit are not hung horizontally or perfectly in line.

Visualization Improvement

Knowing that some primitives are actually components of a whole can be useful to improve their screen display. For instance, primitives constituting a building structure can be displayed using a different color than those constituting the pipe-spool supported by that structure. The step 1 and 2 in Figure 1 show how that type of information can improve model visualization.

Modeling Improvements

Contrary to the first motivation which is to improve models by correcting primitives, this one aims to model the parts of objects that were not scanned. For instance, elbows are the parts of pipe-spool that are not scanned, so they are not initially modeled. However, since the dimensions of elbows are standardized according to the diameters of the pipes that they connect, it is possible to deduct them from the characteristics of the modeled pipes. As a consequence, models can be improved by connecting all the pipes affiliated to one pipe-spool, like the example illustrated in the step 3 in Figure 1.

Now that the goals of using merging algorithms have been explained, the second part of the paper presents some essentially heuristic methods that are used to reach them, and the initial results obtained with pipe spools.

3. SOLUTIONS FOR IMPLEMENTING PRIMITIVES MERGING

While group affiliation information is gotten by a user's input during the scanning phase, identifying and processing merging opportunities is an automated process. The heuristics used for this purpose are presented here for the case of pipe-spools.

Specifically, four merging phases that respond to the motivations mentioned previously have been identified. Each phase occurs when its application criteria are met. These criteria are based upon the intensive use of geometrical standards in construction (layout and dimensions), and consist in comparing models to standards and comparing the orientations and dimensions of contiguous primitives to each other. The four merging phases are:

- *Cylinders' diameters correction:* The method used to efficiently adjust diameters requires a) analyzing diameters of contiguous cylinders and b) comparing the average value to standard values stored in a database. Some fundamental model improvement results from this first phase, and it is necessary for implementing the last merging phase described below.

- *Pipe spool Planarity correction:* Since pipe spools or portions of pipe spools are by nature and design co-planar, this characteristic can be imposed on a group of related pipe sections. A least square method is used to evaluate the optimum average plane from the primary axes of all the pipes constituting a pipe spool. Once this optimum plane is defined, the primary axes are projected on it. Some improvement in pipes orientations result from this process.

- *Cylinders' orientations correction:* Once pipes are projected on one plane, the angles between contiguous pipes are checked and corrected if necessary. Angles close enough to standard values like 30°, 45°, 60°, or 90° are corrected by rotating the pipes around their centers and within the common plane. Nonetheless, this method is still not optimized because treating angles one by one. A more global approach could be envisaged, in which the total angle adjustments of all pipes would be minimized. But this would be very computationally intensive.

- *Elbows modeling:* The final merging level consists in modeling the parts of pipe spools that are not scanned: elbows. Elbows cannot be characterized as geometric primitives and therefore have not been addressed in the development of methods that model primitives from scanned data. However, adjoining pipes characteristics can provide enough information to derive the elbows. Since all the parameters necessary to model an elbow are standard and based on pipes diameters, they can be deducted as soon as the closest standard diameter of the contiguous pipes has been determined. Thus, the elbow can be positioned and the lengths of the connected pipes recalculated in order to completely reconstitute this section of pipe-spool.

4. FIRST EXPERIMENTAL RESULTS

The presented phases have been coded and tested within the MATLAB software environment. An example of experimental results is provided in Figure 2. Although the figure displays a very simple case of pipe spool, it must be noticed that, once the pipes are scanned (the small cylinder sections on the figure), the code only takes a couple of seconds to generate the final model (the long cylinders). This model doesn't display the elbows since generating elbows in a MATLAB environment requires tedious programming. Nonetheless, their dimensions and positions are provided by the code, and a more convenient interface is currently under development.

5. CONCLUSIONS AND RECOMMENDATIONS

The approach to merging primitives introduced in this paper show potential for improving 3D models in key ways. It can be used to correct errors generated during the primitive modeling phase, but also to deduct complementary information to improve the quality and precision of models.

However, although the principle of using merging methods is validated, its implementation is far from completion. Some encouraging results were obtained. Significant computational model improvements can be made at a low cost. But, the algorithms still need to be improved and tests performed.

6. REFERENCES

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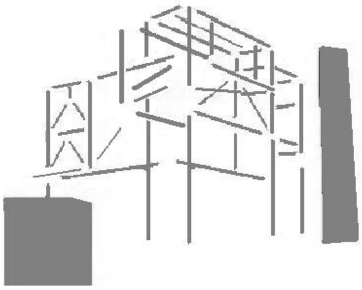
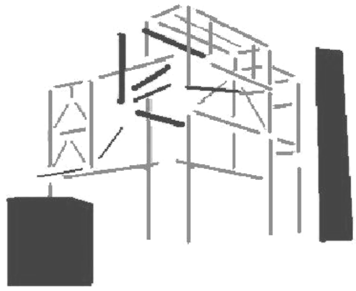
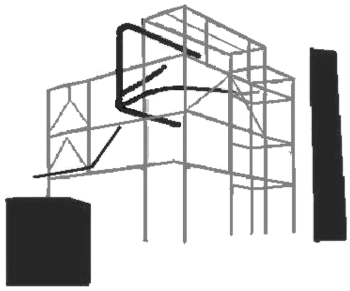


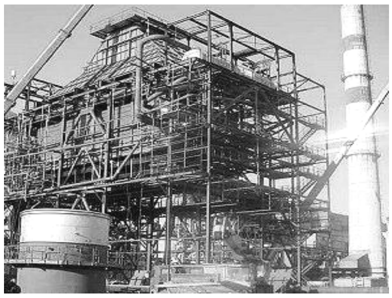
Step 1: No Primitive Merging Process



Step 2: Only Primitive Affiliation Process



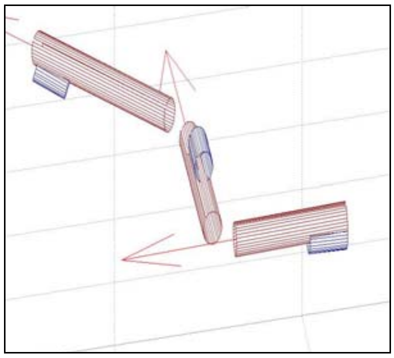
Step 3: Complete Primitive Merging Process



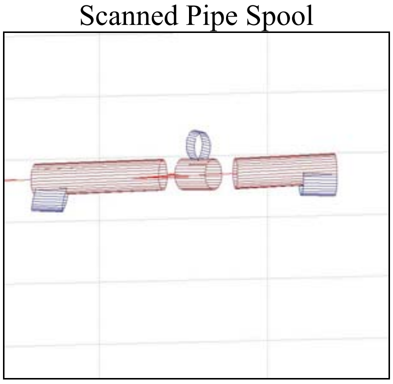
Original Scanned Environment

Figure 1: Example justifying the use of merging processes in environment modeling

Scanned Pipe Spool



Modeling Result (2)



Modeling Result (1)

Figure 2: Experimental Results of the Merging Method