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MEASUREMENT OF PIPING INSTALLATIONS WITH DIGITAL PHOTOGRAMMETRY

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ABSTRACT

This paper discusses the design of a photogrammetric measurement system for piping installations. The system is designed as a semi-automatic measurement system that integrates digital photogrammetry in a CAD environment.
Constructive Solid Geometry (CSG) is used to model the piping elements. The piping installation is assumed to be built with standard elements of which models are available in a database. The measurement process starts with the interactive selection of piping elements from the database. Then an interactive manipulation of the 3D elements takes place in order to match the projections of the element with the image data. Automatic matching of the contour lines of the CAD model to the gradients of the images leads to the final estimation of the shape and pose parameters of the element. In this estimation process constraints on the shape of the element and constraints between elements are taken into account. The paper focuses on the object modeling aspects and the interactive manipulation part of the system.

1. INTRODUCTION

There are numerous applications for an accurate as-built 3D-model of a piping installation. The main reasons for reconstruction are the absence of an up-to-date CAD model of the as-built situation and the need for replacement of parts or the modification of a part of the plant, a so-called revamp. Also there is the need for an accurate model of the installation for inspection and maintenance purposes.

A lot of effort has already been put into the development of methods for the reconstruction of piping installations in a CAD system. See for example (Jones, et al., 1996). Chandler (1994) is using a traditional photogrammetric approach to model the installation while Jones (1996) develops a line photogrammetric approach for the reconstruction of straight pipes. In (Benning and Schwermann, 1997) a line-photogrammetric approach is applied for the reconstruction of piping installations as well. The reconstruction of pipes from image lines instead of points improves the efficiency of the measurement process (Veldhuis and Vosselman, 1998). Therefore this approach is also adopted for the system described in this paper.

Piping installations are generally very complex and images of these installations can show many piping elements. Problems can arise when piping elements are occluded by others or when reflections and shadows are disturbing the edges needed for photogrammetric measurements. The environment of the plant can be hazardous or can have small compartments that constrain the image acquisition.
These characteristics of the piping application do not allow for a high degree of automation of the measurement process. Therefore a semi-automatic method is used that integrates photogrammetry with CAD. Piping installations are usually built from standard components of which a CAD model is available. This is exploited in the system by using a database with piping elements. The operator selects an element to be measured from the database and positions it in the model approximately and then invokes an automatic matching procedure which will snap the model to the edges in the images. The method is not necessarily restricted to piping elements, but these are the objects of primary concern in this research project.

In the next section the architecture of the system will be outlined, section 3 will discuss the use of CAD models and modeling techniques, and in section 4 some manipulation techniques for CAD models will be presented. In section 5 conclusions are drawn.

2. SYSTEM OVERVIEW

The measurement process can be outlined as follows. The operator selects the images in which the object is present. To do so the operator needs an overview of the available images. This holds for the image content as well as for the location and orientation of the images (Chandler and Deacon, 1997).
The first step of the measurement process is the image interpretation. In this step it is decided what type of object is visible. The type of object – a straight or curved pipe for instance – is then selected from the database with template CAD models.
This template is then used in the second stage of the measurement process, the object manipulation. An instance of the template model will now be generated and projected onto the images. The operator manipulates the

pose and shape of the model until the projections of the model are corresponding with the edges in the images.
In the last stage of the measurement process the operator can be assisted by automatic matching to achieve an accurate fit between image data and projected wireframe (Veldhuis, 1998). In (Vosselman, 1998) several methods are presented for the manual correction of errors in the result of the automatic fitting procedure. This type of functionality for the correction of fitting errors will be part of the system. Finally the shape and pose parameters of the measured model are stored in a database.

The interior and exterior orientations of the images are assumed to be known so that a CAD model can be projected onto the images with the correct perspective. An example of such a backprojection is depicted in figure 1. The object views are rendered with a hidden-line removal algorithm to project only the visible edges onto the images.

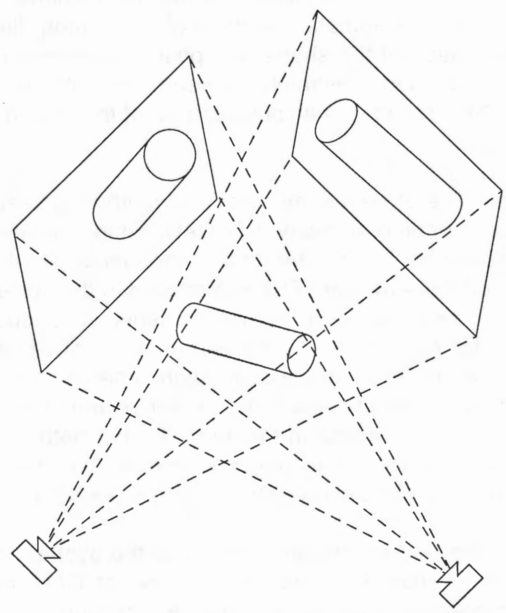

Figure 1: Projection of a CAD model

The measurement system can be divided into five parts:
1. a database with the images of the site, including interior and exterior orientations
2. a database with template CAD models
3. a viewer for the images and the projected CAD models
4. functionality for the manipulation of the CAD models
5. a database for the measurement results

The system is currently under development on a Silicon Graphics workstation. The programming language that has been chosen is C++. The 3D modeling system Acis is used as a CAD environment. Acis is an object-oriented software library with CAD functionality, such as object modeling and hidden-line analysis. For the visualization of the images and the CAD models OpenGL is used. OpenGL is a software interface for the graphics hardware on a computer. It allows the fast and interactive viewing of the image data and the CAD models.

3. GEOMETRIC MODELING

3.1 Why use CAD models?

When a plant is designed and built, the use of standard components is preferred over the use of custom made parts for economic reasons. As a result, most of the parts that are used in the piping industry are standard components. The variety of standard components however is huge. Databases have been created that contain typically 100.000 components or more. The components do not all differ in geometry but can also have different specifications such as material or possible applications. The components with different geometries can be subdivided into groups with corresponding object topologies but different dimensions. The database could have a large variety of, for example, straight pipes with all kinds of lengths and diameters but they all belong to one type of object, a straight pipe.
From the above it can be concluded that most parts used in the piping industry can be modeled with only a limited number of deformable CAD models.

3.2 Geometric modeling techniques

Many object modeling techniques have been developed but two of the most prominent ones are CSG (Constructive Solid Geometry) and B-rep (Boundary Representation) modeling. B-rep describes the boundary of an object in terms of vertices, edges and surfaces while CSG is using a set of geometric primitives such as spheres, cubes and cones that are combined in a binary tree where the tree nodes are Boolean set operations such as union, intersection and difference. B-rep modeling is more generic than CSG modeling but is also more verbose. For the representation of a cube for example, the positions of the eight corners are needed as well as a topological graph that connects the surfaces to the edges which are in turn connected to the vertices. The parameters of a CSG model can be easily identified. Each primitive in the CSG tree has its own shape parameters and its position and orientation parameters. For example a cylinder has two shape parameters; radius and length, three position parameters, x, y and z, and two parameters that define its orientation (since it is rotationally invariant). In general, a B-rep model requires more parameters to describe a shape than a CSG model, therefore we will restrict ourselves to CSG models.

3.3 Geometric constraints

Not all the degrees of freedom of a CSG model that are obtained by collecting the parameters of the composing primitives might be useful to model an object. For example a CSG model of a pipe with flanges can be seen as a union of three cylinders; one long cylinder (the pipe itself), and two short thick cylinders (the flanges). Not all the positions of a flange will result in a valid model of a flanged pipe. Constraints have to be applied to ensure that the axes of symmetry of the pipe and the flanges coincide and the flanges have to be located at both ends of the pipe. It is also likely that both flanges are identical and thus have the same length and radius. For each CSG model these constraints can be formulated and they will reduce the degrees of freedom of the model which will facilitate the manipulation of the model.

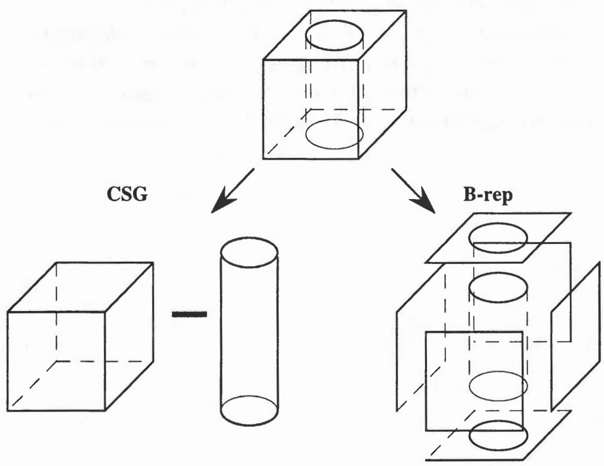

Figure 2: An object modeled with CSG and B-rep

Another approach to describe a model is to use only as many parameters as there are degrees of freedom of the model instead of using all parameters of the CSG model and applying constraints to them. This will result in a more simple mathematical description of the model but the drawback is that none of the (now implicit) constraints can be loosened. For example a T-junction has the constraint that the two pipe parts have to be perpendicular to each other but in the case that the as-built situation is less perfect this constraint can be removed or weakened (Hirschberg and Streilein, 1996).

Constraints can not only be applied within a model, but between models as well. For example a connection between two pipes can yield several constraints. The pipe ends of both pipes have to meet and the orientations of the two pipes have to coincide. It is also likely that the radii of both pipes is equal thus leaving only the length of the pipe to be modified. Benning (1997) also describes other continuity conditions for pipe measurements in a photogrammetric system.
Whether a constraint is applied within a CAD model or between models makes no difference for the manipulation of the object. The degrees of freedom that remain after the constraints are applied can be used to manipulate the object.

4. OBJECT MEASUREMENT

The actual measurement of an object is performed in different steps. First the operator interprets the images to decide what type of object is shown and selects the corresponding CAD model from the template CAD model database. This step we will refer to as the `object interpretation`. The next step is the `object manipulation` stage. Its purpose is to determine the shape and pose of the CAD model such that the projected model is approximately aligned with the images. The approximate position of the CAD model will then be used in the last step; the automated fitting. The gradients of the images will be used to calculate a precise fit of the model with the images.

4.1 Manipulation of the object

During the manipulation of an CAD model, several parameters have to be modified. Each model has its pose parameters (position and rotation) and its shape parameters. The model also has to fit in multiple images, each with its own orientation, see figure 3.

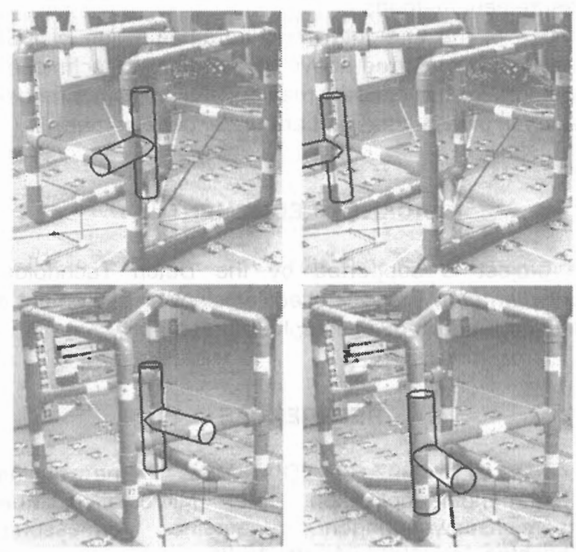

Figure 3: Simple object manipulation. In the upper images the object moves to the left, corresponding with a movement towards the viewer in the lower images.

It is clear that the object manipulation can be cumbersome and can eventually become an iterative process for the operator. The modification of an object in one image will also change the projection of that object in another image and vice versa.
A CAD model can be manipulated in several ways. The most straightforward one is to modify the individual parameters of the model. Although a simple method, it may be complicated for the operator to find out which parameter to modify to establish a good match with the images.
A more sophisticated approach is proposed by Vosselman (1998). The presented method allows the operator to drag both vertices and edges of the projected model in order to align these features with the images. The method is slightly changing the parameters of the model and recalculating the projection in order to calculate the partial derivatives of the positions of the edges relative to the model parameters. With the partial derivatives the effect on the model parameters of a change of an edge can be calculated. Using this method there is no need for the operator to specify which parameters of the CAD model need to be modified.

The operator does not need to manipulate the model until a precise alignment is achieved but once an approximate alignment is made, an automated fitting algorithm can be called to calculate a precise fit of the edges of the model to the gradients in the images. (Veldhuis, 1998) The outline of the algorithm that is used for the fitting is essentially the same as in Vosselman (1998).

5. CONCLUSIONS

In this paper we discussed the current and planned functionality of a software environment for the efficient measurement of piping installations with the use of digital photogrammetry. The system integrates CAD modeling and visualisation techniques with photogrammetric measurement methods.
Because of the straightforward parametrisation of CSG modeling it is preferred above other modeling techniques. Algorithms for the efficient manipulation of object models have been investigated and are under development.

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