DEFORMATION DETECTION IN PIPING INSTALLATIONS USING PROFILING TECHNIQUES

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ABSTRACT:

As-Built surveys of buildings and installations have received greater attention in recent years. An example is the 3D digital reconstruction of existing piping installations at chemical plants for plant maintenance, upgrades and safety standard concerns. This paper is directed at the reconstruction of piping installations with particular emphasis on the detection of deformities in pipes. Reconstruction begins with the automatic detection of individual piping elements which requires a prior segmentation. For segmentation, the profile intersection technique is used. Surfaces are considered as a network of intersecting curves as opposed to surface patches. Recreating such curves on a point set, and intersecting them, segments are identified. The entire scan is partitioned into a series of scan planes referred to as profiles. Points are then connected in each profile based on the surface they represent forming line segments. The line segments, which represent curves, are then intersected to identify segments. For pipes, line segments are elliptical. The centre of an ellipse lies on the pipes' axis and the semi minor axis is equivalent to the radius of the pipe. Therefore together the centres and semi minor axis are used to describe the position, orientation, size and radius of a pipe. For deformed pipes, the line segments deviate from the elliptical shape. By identifying deviations of the line segments from the elliptical shape deformations are identified. The algorithm allows for cylinders, spheres, cones and tori to be detected including deformities in their shape. Experimental results show the effectiveness of the algorithm.

1. INTRODUCTION

The high accuracy achieved by laser scanning together with the high spatial resolution makes possible the digital reconstruction of man-made structures. Currently most digital reconstruction algorithms emphasise on the reconstruction of as-built Computer Aided Design (CAD) models for the purposes of planning and archiving. These algorithms do not cater for detection and modelling of deformations/dents in structures such as pipes. Data acquired by Laser Scanning is a massive cloud of points numbering in the millions. These points represent the scanned surfaces. Most surfaces found in installations are of piping elements namely elbows, t-junctions, straight pipes and flanges. All these piping elements are subject to deformation. Revamping, upgrading and safety standard concerns outline the need for detecting these deformations. To facilitate the detection of deformations in piping elements, point clouds have to be segmented. The work presented here proposes a semi-automatic/automatic method for detecting deformations in pipes and describes a method for segmenting point clouds to aid the detection.

2. PREVIOUS WORK

Considerable work has been done in the segmentation and detection of piping elements from laser scanner point clouds. A review of these algorithms is given below.

2.1 Segmentation

Segmentation involves the partitioning of a point cloud into sets of regions with homogeneous geometric or radiometric characteristics or a combination of both. Fitting is then carried out on the identified regions or segments to digitally reconstruct the scanned surfaces. Segmentation eliminates the task of point by point classification which reduces the overall time required for detection. Most of existing algorithms can be classified as either surface based or scan line based. Surface based segmentation techniques begin by selecting a seed point set or point neighbourhood from the point cloud and establishing a similarity measures on the neighbourhood. Point neighbourhoods are then selected from the point cloud and their geometric properties are compared with the seed point set. Point neighbourhoods that exhibit similar geometric properties are merged into segments. The merging process is referred to as region growing. An example is presented and Rabbani et al. (2006). Scan line based segmentation involves grouping scan lines which exhibit similar geometric properties. Laser scanners measure point data as a series of scan lines. Together these scan lines form range images. By fitting a curve to points in a scan line and comparing curve properties between scan lines, segments are identified (Jiang et al., 1994). Points from curves which exhibit similar surface measures are given the same label. A variation to scan line based segmentation to cater for unstructured 3D point clouds is presented by (Sithole, 2005), were artificial scan lines are created as profiles in many different directions. Points are then connected in each profile according to surfaces they represent. Finally profiles are overlaid to define the surface segments. After establishing the different segments in a point cloud, the next step is to determine the surface types represented by the points in each segment. This is achieved through a detection/fitting procedure.

2.2 Detection

Detection is the process of identifying the type of surface represented by a segment (e.g. planar, curved). Various fitting /detection techniques have been proposed for detecting piping elements. The Hough Transform (HT) is used to identify lines, circles and ellipses in *n* dimensions, where n is the number of parameters being sought. The HT maps every point from a parameterized primitive to a Hough space, where a voting by the points is done for the best fitting parameters vector (Schnabel et al., 2007: p. 215). Primitives are then extracted using the parameter vector with the most votes. The HT is reliable in the presence of noise. The HT is efficient for primitives with three or less parameters (Rabbani et al., 2005). Some detection algorithms are based on RANSAC which is an algorithm used for parameter estimation of mathematical models from a set of observations. RANSAC based algorithms continuously search the entire point cloud for primitives using point neighbourhoods. Example is presented by Chaperon and Goulette (2001) and Schnabel et al., (2007). Photogrammetry is one of the long established methods in 3D modelling (Veldhuis and Vosselman,1998). Photogrammetry is still being employed at present and is now being integrated with other techniques like Constructive Solid Geometry (CSG) and point clouds to improve accuracy in detection. Three different combinations exist for the fitting/detection using CSG, images and point clouds in the reconstruction of piping installations (Tangelder et al., 2000; Rabbani et al., 2004). Another method which is surface or curve fitting generally involves the fitting of geometric surfaces or curves to point sets (Pratt, 1987). As with any non-linear problem, good initial estimates of the parameters are needed. Estimating the parameters is a challenge because apart from the geometry, no other additional information is available in most cases (Mitra and Nguyen, 2003). In addition to the problems encountered by current algorithms, these algorithms do not detect deformations.

3. PROPOSED METHOD

Deformation detection involves a series of steps that are carried out from data acquisition to the final model namely registration, data structuring, segmentation and detection. Here it is assumed that the point cloud has been registered correctly and that the points are unstructured. The algorithm will therefore be explained from the segmentation stage. The segmentation results form the basis of the detection algorithm. Each step is elaborated on in the succeeding sections together with the proposed algorithms.

3.1 Segmentation concept

A surface can be approximated using a set of planar curves running in many different directions. These curves pass through the same points and terminate at discontinuities encountered at surface boundaries as illustrated in Figure 1. By recreating curves in a point set and intersecting the curves, a surface can be reconstructed.

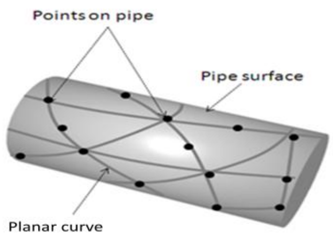

Figure 1. Surface representation using planar curves. The curves share common points even though they run in different direction.

To create curves such as in Figure 1, the point cloud is partitioned into a series of contiguous planar profiles aligned along a user defined direction in space. Together all profiles aligned along the same direction in space are called a stack. If the width, w of a profile is sufficiently small, then the points in a profile can be assumed to represent curve nodes. Multiple stacks are generated with different orientations in space. When the stacks are overlaid they yield intersecting profiles. If the curves within a profile are discontinuous, then the intersection of the profiles yields surface segments as illustrated in Figure 2.

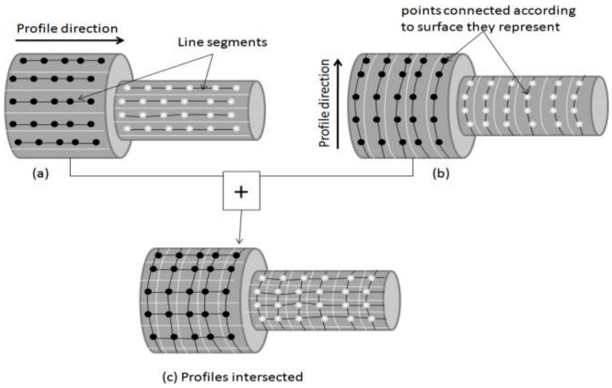

Figure 2. Segmentation by profile intersection: (a) and (b) show two different stacks on a pipe, (c) Profiles are intersected to obtain segments

In summary:

1. The segmentation can be represented by the graph $G(V, E)$ where V is the set of point cloud points and E is the edges connecting the points of the surface segments.
2. A stack is given by the graph $G_{\varphi}(V, E_{\varphi})$ where $E_{\varphi} \subset E$ is the edges connecting the points in the stack. Note that each stack contains all the points in the cloud.
3. Each profile in a stack is given by $G_{\varphi,pi}(V_{pi}, E_{\varphi,pi})$ where pi is the index of a profile in the stack, $V_{pi} \subset V$ is the set of profile points, and $E_{\varphi,pi} \subset E$ is the set of profile edges.
4. The intersection of profiles *pi* and *pj* in two different stacks m and n is a single point v, $G_{\varphi m,pi}(V_{pi}, E_{\varphi m,pi}) \cap G_{\varphi n,pj}(V_{pj}, E_{\varphi n,pj}) = v$

By means of a connected component analysis on the graph G the surface segments can then be extracted. The profile count in any given stack depends on the width w of each profile and extent of the points in the stack direction. At least three stacks are necessary for a good segmentation.

3.2 Profile segmentation

Profile segmentation is the process of creating the curves, or connecting the points within each profile. Here two methods are used, segmentation by proximity and segmentation by curve fitting.

1. Profile Segmentation by proximity: Typically nearby points belong to the same surface. Therefore, by connecting only those points that are within a maximum distance of each other we can obtain points on the same curve. This is similar to creating a Relative Neighbourhood Graph. The maximum distance is typically determined by the average spacing of points within a point cloud.