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Extraction of cylinders and estimation of their parameters from point clouds

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A B S T R A C T

In this paper, a novel algorithm is proposed for extracting cylinders and estimating their parameters from 3D point cloud data. First, normal vectors and curvature information are computed for each data point as a preprocessing step. Then potential points that could belong to cylindrical surfaces are extracted by using curvature information. For each potential cylinder point, its neighborhood is considered as inlier points and a robust cylinder fitting algorithm is applied on these inlier points. Inlier points are updated and the fitting process is applied iteratively to propagate to all remaining points belonging to a cylinder. A validation method is proposed to assess whether the detected cylinder is reliable or not. Finally, by applying mean shift clustering, final descriptive parameters of cylinders are estimated accurately. To demonstrate its robustness, the method is tested on both synthetic and complex point clouds with different levels of noise and outliers.

1. Introduction

Due to the rapid development of scanning technologies, very large sets of accurate 3D points can be collected easily and quickly. Therefore, more and more computer vision and graphics applications have used such scanners, especially in industrial manufacturing. Cylinder extraction and cylinder fitting are the problems that have been investigated recently, but which are still open.

Most manufactured objects are composed of basic primitives such as planes, spheres, cylinders, toruses and cones [1,2]. Cylinders are the most frequently used primitive in these objects such as pipes, sleeves, connectors. Moreover, cylinder detection could be used in various applications: reverse engineering [3], 3D registration [4], pipeline plant modeling [5], etc. Currently, there are many methods [5–8] that have investigated how to detect cylinders and estimate their descriptive parameters from point cloud data. A cylinder is frequently described by 3 parameters: axis orientation $\vec{a}$, a point on the axis p^* and radius r [1]. However, few methods can determine these descriptive parameters accurately. Most methods [2,5–7] require the user to choose some threshold values—a difficult task for complex models. Moreover, the problem of detecting multiple cylinders is non-trivial, since it is easily affected by noise/outliers or depends on prior segmentation results.

Therefore, our goal is to propose a robust method for estimating cylinder parameters accurately and extracting multiple cylinders simultaneously from a given point cloud. Some examples of cylinder extraction detected by our method are shown in Fig. 1. The contributions of the proposed method are summarized as follows: (i) estimating the descriptive parameters of cylinders accurately; (ii) extracting multiple cylinders at the same time; (iii) proposing a novel method for validating the detected cylinders; (iv) detection and estimation robust to acquisition of noise and outliers.

The rest of this paper is organized as follows. Previous work is summarized in Section 2. Single cylinder fitting is presented in Section 3. The procedure of multiple cylinder extraction is described in Section 4. Results and discussion are presented in Section 5, and Section 6 draws some conclusions on the proposed method.

2. Related work

Many methods have investigated the problem of cylinder extraction. In this section, we briefly review some methods related to the one presented in this paper. Existing methods are generally classified into two categories: those requiring prior segmentation and those working directly on point clouds.

The methods belonging to the first group fit a cylinder model to a set of segmented points. They often use non-linear optimization to minimize the sum of orthogonal distances to the cylinder surface [9,10]. These methods depend on the quality of the initial segmentation [11] that needs to assign the correct type of

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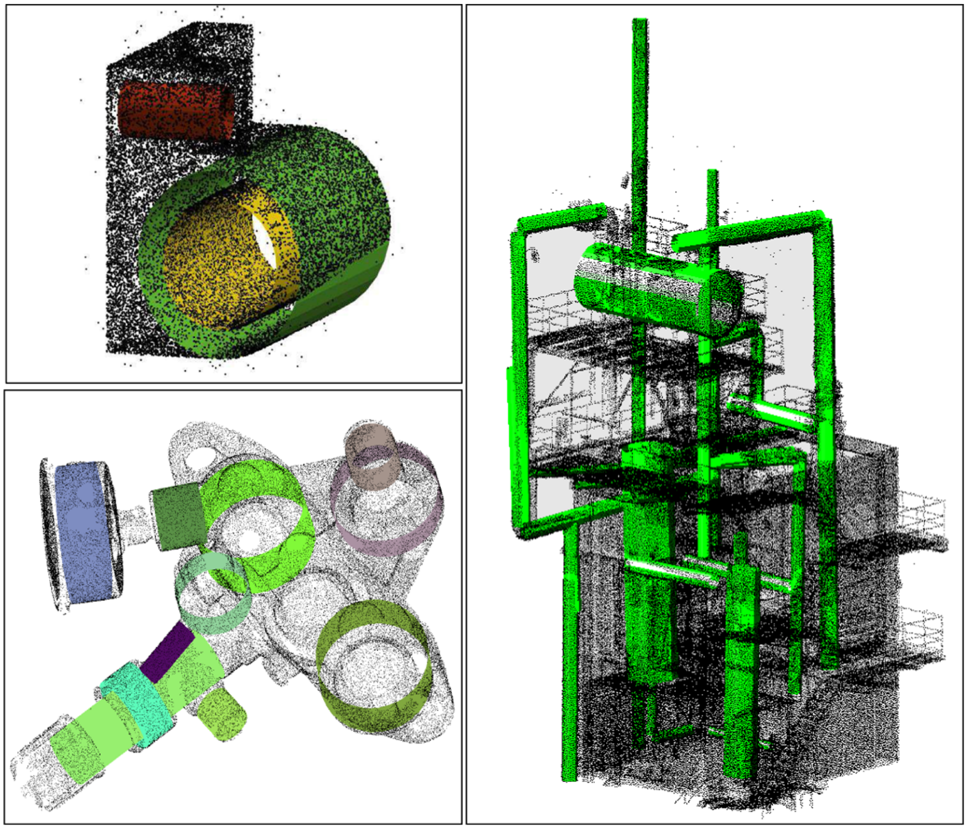

Fig. 1. Detected cylinders from noisy data with outliers. Zoom in to view noisy data and outliers.

primitive to each data point. However, this requirement is difficult to meet for real data with noise and outliers. Moreover, non-linear least-squares fitting is an iterative process that requires good initial parameters to avoid local minima.

Hierarchical clustering [12,1], which often requires that the number of segments be pre-selected by the user, is a good method for primitive extraction. However, this method is computationally intensive in time complexity and memory even if the model contains just a few thousand points, because the method investigates all types of primitives at the same time to create a global list of priorities by using algebraic fitting [13]. Moreover, primitive fitting is not accurate, especially when the number of points is small. This affects the priority list leading to poor results. In addition, cylinder fitting in [12,1] cannot identify cylinder parameters accurately and reliably in a single step. Fig. 3(a) shows an example of this method after one iteration step, the detected cylinder does not fit the data points very well. Our method improves this technique to estimate cylinder parameters accurately through an iterative fitting process.

The second group attempts to process data points directly using RANSAC [14,2] or Hough-based methods [7,6] which are popular techniques for parametric model extraction. RANSAC [15,16] fits a model by using random sampling with minimum number of data points. For cylinders, two data points with their surface normals are enough for fitting [2]. However, the user must set several thresholds that may vary for different models, especially with noisy data and outliers. The results of the algorithm depend on the initial selection of points. In the worst case, RANSAC does not converge to a valid solution even when cylinders are present.

Hough transform [17] is popular for detecting simple shapes such as lines, circles and planes. But it is also known as a voting method with high computational requirements, and for which choosing the resolution of the accumulator cell is critical. In addition, 5 parameters need to be used for cylinder detection [7]. As reported in [7,18], some authors have attempted to speed up the procedure by splitting and pruning the parametric space.

A significant research study focuses on the use of the Gaussian sphere [19] to extract primitives [5–7]. Liu et al. [5] detect cylinders in large-scale point clouds of a pipeline plant. However, the limitation of the method is that it only supports the extraction of pipes either perpendicular or parallel to the ground. Chaperon et al. [6] combine the Gaussian sphere with a random sampling method (RANSAC) to extract cylinders and estimate their parameters. However, based on our experiments, these methods do not achieve accurate results for complex models containing other types of primitives. For example, in Fig. 2(a), the joint model is made of 3 cylinders and several planes leading to red and green circles, where two parallel cylinders correspond to the same red circle. However, the red circle results not only from points belonging to cylinders but also outliers and other points on a plane having coincident normals (Fig. 2(b)). The blue circle is not created by the points belonging to the cylinder surface but rather by points distributed all over the model (Fig. 2(c)).

The proposed method belongs to the second group, which extracts cylinders directly from point cloud data. The problem addressed in this paper is to estimate cylinder parameters accurately. The algorithm is an iterative process of distance-based and normal-based fitting starting at different initial points. Furthermore, we propose a novel two-step validation method exploiting geometric consistency to improve cylinder detection. By using mean shift clustering, multiple cylinders are extracted simultaneously.

3. Iterative cylinder fitting

In this section, we assume that points are sampled on the surface of a cylinder, which includes noise and outliers. The case of