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Recognition of one class of quadrics from 3D point clouds

Zivana Jakovljevic*, Veljko Markovic, Radovan Puzovic, Vidosav Majstorovic

University of Belgrade, Faculty of Mechanical Engineering, Department for Production Engineering, Kraljice Marije 16, 11000 Belgrade, Serbia

* Corresponding author. Tel.: +381-11-3302-404; fax:+381-11-3370-364.*E-mail address:*zjakovljevic@mas.bg.ac.rs

Abstract

Within cyber physical production systems 3D vision as a source of information from real-world provides enormous possibilities. While the hardware of contemporary 3D scanners is characterized by high speed along with high resolution and accuracy, there is a lack of real-time on-line data processing algorithms that would give certain elements of intelligence to the sensory system. Critical elements of data processing software are efficient, real-time applicable methods for fully automatic recognition of high level geometric primitives from point cloud (surface segmentation and fitting). This paper presents a method for recognition of one class of quadrics from 3D point clouds, in particular for recognition of cylinders, elliptical cylinders and ellipsoids. The method is based on the properties of scatter matrix during direct least squares fitting of ellipsoids. Presented recognition procedure can be employed for segmentation of regions with G1 or higher continuity, and this is its comparative advantage to similar methods. The applicability of the method is illustrated and experimentally verified using two case studies. First case study refers to a synthesized, and the second to a real-world scanned point cloud.

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1. Introduction

Smart devices (sensors and actuators) with embedded computational and communication modules are nowadays widely implemented in manufacturing. These devices provide enormous possibilities for control of manufacturing processes through interconnection of physical systems and cyber world within Cyber Physical Systems (CPS) concept. CPS are the systems that integrate physical processes and computing elements through their real-time interaction [1]. They can be regarded as systems of systems [2] and can be implemented at various levels of manufacturing process control, starting from manufacturing resources' elements, their subsystems, machines, up to the manufacturing system as a whole. Cyber Physical Production Systems (CPPS) are foreseen as the highest level of CPS implementation in manufacturing. There are a number of R&D challenges related to CPPS [3], and one of them is the fusion of real world manufacturing systems and their virtual representation (Fig. 1.). CPPS require real-time interconnection between shop floor and its virtual representation through automatic data acquisition/information retrieval from real world and feedback from cyber system. Timely delivery of big data from real-world, as well as timely and effective extraction and interpretation of information are crucial for implementation of this concept.

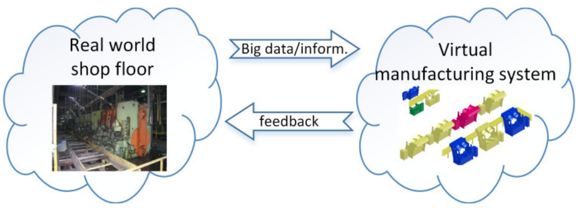

Fig. 1. Fusion of real world manufacturing systems and its virtual representation.

Retrieval (extraction and interpretation) of geometric information and its timely representation in virtual system is one of the most important issues within CPPS. Besides, this kind of feedback is significant element of virtualization module within cloud manufacturing concept in which virtual manufacturing resources should be available to all interested parties (consumers, providers, operators…) through virtual enterprise [4]. Contemporary three-dimensional (3D) scanning

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devices are characterized by high speed, resolution, and accuracy [5] and can be effectively employed for acquisition of big data in the form of 3D point clouds. These point clouds contain information about geometric features of objects from the real world. There exist a number of very efficient algorithms for point cloud registration, integration, and meshing [6], and automatic generation of aesthetically sound 3D model in the form of triangular mesh from point cloud is a standard feature of CAD systems. However, retrieval of high level information about geometric features of scanned object in the form of geometric primitives and generation of parametric 3D CAD model from point cloud are still carried out interactively by user and represent an open research area.

Geometric primitives that build objects along with their parameters can be regarded as the most important geometric features of objects. Extraction of information about these features from point cloud, i.e. recognition of geometric primitives from point cloud is carried out through the following steps: 1) segmentation of points that belong to specific geometric primitive, and 2) estimation of parameters of geometric primitive segmented in previous step. For the success of this process, the first step is crucial – once geometric primitive is adequately segmented, the estimation of its parameters (fitting) is straightforward. Implementation of 3D point clouds within CPPS requires effective, real-time applicable segmentation algorithms that are executed automatically.

Planes and rotational surfaces, in particular cylinders, are most frequently met geometric primitives in mechanical engineering. Recognition of planar surfaces from 3D point cloud has attracted most research efforts, and there is a number of techniques based on: 3D Hough transform [7], RANAC (Random Sample Consensus) algorithm [8,9], various region growing algorithms [10,11], wavelet transform [12], etc. Cylinders, on the other hand, belong to the class of natural second order surfaces (quadrics). Retrieval of quadrics' geometric parameters from point clouds has also been the subject of a number of research works. All, so far proposed strategies for segmentation of quadrics from 3D point clouds can be classified into the following two groups [13]: 1) strategies based on edge detection, and 2) strategies based on regions. Edge based strategies assume that there is an abrupt change between two adjacent geometric primitives in the point cloud and they are only applicable for G0 continuous surfaces. On the other hand, region based segmentation is carried out using split and merge approach or using region growing. In region growing techniques, algorithm starts from a chosen seed point (or a seed region) and grows a region around it using different criteria referring to differential geometry features of surfaces such as local surface normal [14], average curvature [15], principal curvatures [16], or bicubic Bézier surface properties [17]. In the most of these methods the seed point is selected manually, since automatic selection of seed point can be a complex task. An interesting approach for segmentation of quadrics from scanned lines that is based on numerically stable least squares fitting of ellipse is presented in [18].

This paper represents an extension of our previous research referring to recognition of elliptical segments from scanned lines [19] and to initial research referring to recognition of quadrics from point clouds [20]. We present a method for recognition of one class of quadrics from unstructured 3D point clouds, along with the guidelines for interpretation of recognized segments in the form suitable as input to CAD system. In particular, we consider second order surfaces that can be represented by ellipsoid equation, such as cylinders, elliptical cylinders, spheres, and ellipsoids. The method is region growing method that exploits properties of scatter matrix calculated during direct least squares fitting of ellipsoids as a region growing criterion. Opposite to edge based techniques, the proposed method is convenient for recognition of adjacent surface segments with G1 or higher continuity. An advantage of proposed method compared to region based techniques is that seed point is selected automatically thus providing fully automatic performance of the recognition process.

The rest of the paper is organized as follows. In Section 2 we present the method for recognition of considered class of quadrics, relevant theoretical background, and the role of the method within the system for retrieval of information about geometric features from 3D point cloud. Section 3 illustrates the applicability of the method using two case studies; first case study considers synthesized point cloud, and the second a point cloud obtained by scanning of a real world object. Finally in Section 4, we provide some concluding remarks and future work guidelines

2. Recognition of one class of quadrics from 3D point clouds

Proposed method for recognition of considered class of quadrics from 3D point clouds represents a part of the system (information machine) for retrieval of information about considered geometric primitives from point cloud. This system has the following two modules: 1) module for recognition (segmentation and fitting) of G1 continuous surface segments, and 2) module for interpretation of extracted information (Fig. 2.). Module for recognition of surfaces segments and estimates surfaces' parameters from 3D point cloud using algorithm that is presented in the sequel. From this module, estimated surfaces' parameters are output in the vector form which is not convenient for automatic input to CAD models within virtual manufacturing system. This information needs to be transformed into one of the suitable, preferably neutral, formats for model representation in virtual manufacturing environment, such as STEP, IGES, UPR [21]. Information interpreter (Fig. 2) carries out required transformation. In our research we have opted to use transformation into Initial Graphics Exchange Specification - IGES format.

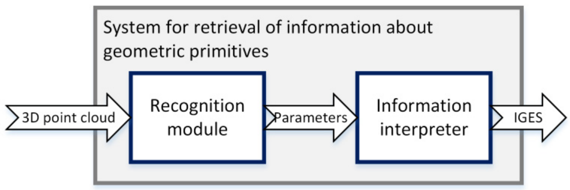

Fig. 2. System for retrieval of information about geometric primitives.