Signal, Image and Video Processing (2023) 17:2617–2625
https://doi.org/10.1007/s11760-022-02478-8

ORIGINAL PAPER

3D Reconstruction of deformable linear objects based on cylindrical fitting

Yiman Zhu[1] · Xiao Xiao[2] · Wei Wu[1] · Yu Guo[1]

Received: 29 September 2022 / Revised: 18 December 2022 / Accepted: 29 December 2022 / Published online: 10 January 2023

Abstract

The manipulation of deformable linear objects (DLOs) is an important task in many fields, which raises demands for the perception of DLOs in real situation. In this paper, we propose a cylindrical fitting reconstruction method for DLOs with only one frame of point clouds captured by a depth camera. The point clouds are first processed by operation space filtering and outlier removal to eliminate the interference. To accurately segment the specific object from the complex background, the PointSIFT module is inserted into PointNet++ architecture and fine-tuned on our dataset. To reconstruct the flexible DLOs in 3D space, an improved adaptive K-means algorithm which accommodates to the unknown length and curvature is designed. The adaptive K-means algorithm distributes the point clouds into appropriate number of cylindrical clusters. To achieve the main axis of the cylinders, we construct the point clouds covariance matrix. By applying principal component analysis (PCA), three orthogonal dimensions and the PCA bounding box are obtained. Afterward, an octree-based directional constraints is designed to sort the center points of DLOs with arbitrary curvature. The proposed framework achieves an average error of less than 1 mm during a manipulation experiment in a simulation live-line maintenance site.

Keywords Point cloud · Deformable linear objects · Semantic segmentation · 3D Reconstruction

1 Introduction

Nowadays, intelligent robots have shown their talents in many fields and undertake more and more repetitive operation tasks for human beings. The in-depth application of robot techniques requires the robot to manipulate not only rigid but also non-rigid objects, which are also defined as deformable linear object (DLOs). The reconstruction of DLOs has a wide range of applications in manufacturing, health care and power system such as industrial manufacturing, robotic surgery or live-line maintenance. Especially, in the field of live-line maintenance, the flexible shape of cable should be reconstructed to assist the robot with cable grasping and manipulation to finish installation and removal. The cable, which is composed of metal conductor and rubber, is a classic type of DLOs [17]. Different types of DLOs have different physical properties. The rigidity of cable is between that of the rope and the elastic rod. It means that it has both characteristics of elastic and plastic deformation in 3D space. Borum et al. [2] estimated the shape of a elastic rod by treating configuration of the problem as solutions of a geometric optimal control problem. Yan et al. [21] applied a model-based self-supervised learning method to estimate the 2D shape of a rope. But these methods only fit for planar situation. Some researchers have also explored the contact measurement method. Bretl and McCarthy [3] proposed an analytic formulation to estimate the shape of a flexible tube with constant length and available pose of both ends hold by robotic arms. Caldwell et al. [4] identified the parameters of a flexible loop by measuring forces and displacement during interaction with a manipulating arm. To sum up, existing researches mainly focus on the shape estimation of DLOs on planar or

✉ Yu Guo
guoyu@njust.edu.cn

Yiman Zhu
yiman@njust.edu.cn

Xiao Xiao
19852852891@163.com

Wei Wu
wuwei11705@njust.edu.cn

[1] School of Automation, Nanjing University of Science and Technology, Xiaolingwei Street, Nanjing 210094, Jiangsu, China

[2] The fiftieth Research Institute of China Electronic Technology Group Corporation, Changhe Street, Shanghai 200000, China