J. Vis. Commun. Image R. 46 (2017) 95–106

Contents lists available at ScienceDirect

J. Vis. Commun. Image R.

journal homepage: www.elsevier.com/locate/jvci

Review

Recent developments and trends in point set registration methods ☆

Baraka Maiseli [a,b,*], Yanfeng Gu [a], Huijun Gao [c]

[a] School of Electronics & Information Engineering, Harbin Institute of Technology, Harbin 150001, PR China
[b] Department of Electronics & Telecommunication Engineering, College of Information & Communication Technologies, University of Dar es Salaam, P.O. Box 33335, Dar es Salaam, Tanzania
[c] Research Institute of Intelligent Control and Systems, Harbin Institute of Technology, Harbin 150001, PR China

ARTICLE INFO

Article history:
Received 31 January 2017
Revised 25 February 2017
Accepted 12 March 2017
Available online 15 March 2017

Keywords:
Point matching
Registration
Performance
Optimization
Point set

ABSTRACT

Point set registration (PSR) is the process of computing a spatial transformation that optimally aligns pairs of point sets. The method helps to amalgamate multiple datasets into a common coordinate system. Because of their immense practical applications, several studies have attempted to address challenges inherent in the PSR problem. However, limited works exist to discuss recent developments, failures, and trends of the PSR methods. To date, a classical work of Tam et al., published in 2013, can be regarded as a comprehensive review paper for registration methods. Nevertheless, this work has inadequately revealed a range of possible knowledge gaps of the previous studies. Additionally, since the publication year of their work, more superior and state-of-the-art methods have been proposed. The present study surveys PSR approaches until 2017, and our primary focus is to expose central ideas and limitations of the methods to facilitate experts and practitioners advance the field.

Contents

☆ This paper has been recommended for acceptance by Zicheng Liu.

* Corresponding author at: Department of Electronics & Telecommunication Engineering, College of Information & Communication Technologies, University of Dar es Salaam, P.O. Box 33335, Dar es Salaam, Tanzania.

E-mail address: barakamaiseli@yahoo.com (B. Maiseli).

http://dx.doi.org/10.1016/j.jvcir.2017.03.012
1047-3203/

1. Introduction

1.1. Definitions of key terms

A point set, commonly known as a point cloud, refers to a set of points contained in a particular coordinate system. Usually, a point set is generated by 3D (three-dimensional) scanners to represent an outer surface of an object in a 3D space. This technology is an indispensable tool to collect, interpret, and analyze geological and geotechnical data. Also, the technology is useful to create 3D CAD (computer aided design) models for manufactured parts, and to visualize, animate, and render objects.

Point set registration or PSR (point matching), as used in computer vision and pattern recognition, is a process of determining a spatial transformation that aligns two point sets. The method serves as an important step to merge multiple datasets into a more accurate (reference) model. Also, point matching is used in optical character recognition [1–3], pose estimation [4], medical image analysis [5–7], shape modeling [8], and feature detection. In medicine, point matching helps to align data from magnetic resonance and computed tomography images [9,10].

Transformation, a primary task in PSR, is the process of changing the physical geometric properties of an object or a point (location, size, and/or orientation) in a coordinate system. Transformation can either be rigid, which preserves distances between every corresponding pairs of points, or non-rigid (affine), which involves scaling and shear mapping. Rigid and non-rigid registrations of point sets produce rigid transformation (translation and rotation) and non-rigid transformation (scaling and shear mapping), respectively.

The PSR system requires two critical inputs: a (static) *target* point set E, which represents a globally consistent model, and a (moving) *source* point set S, which includes measured data points to be registered. During the registration process, corresponding pairs of points between E and S are identified, then S is transformed to another point set, which is compared with E using a suitable similarity index. The purpose of the comparison is to minimize discrepancies such that the two point sets, E and the transformed S, have the best possible alignment.

1.2. Motivations and aims

Point set registration offers a wide range of applications in computer vision and pattern recognition, as noted earlier in this section. Despite the merits, matching point sets is rather a non-trivial problem. The long-standing challenges of the classical registration algorithms are (1) computational speed, (2) dimensionality of datasets, (3) outliers and missing data, and (4) alignment accuracy. These challenges have captured the attention of several scholars, whose pivotal objective is to devise methods and algorithms that can effectively address the four aspects.

Our analysis discovered that most available point matching approaches have inadequately addressed challenges in the PSR problem. For instance, some algorithms are relatively computationally efficient, but their accuracies are affected by outliers, and vice versa [11–16]. Also, other algorithms produce more accurate results even under noisy environments, but are complex and computationally inefficient [17,18]. Additionally, we noted inadequacy of recent self-contained works that summarize point matching algorithms. Probably a notable review article is that of Tam et al., published in 2013 [19]. Since publication of Tam's work, there has been tremendous developments in point matching algorithms.

Motivated by the aforementioned research gaps, the current work surveys the most recent point matching algorithms. In a classical work by Tam et al., the authors reviewed the algorithms prior to 2013 [19], and we extend their work to cover methods and algorithms until 2017. Our study may allow scholars to discover new research avenues, understand trends and challenges in the field, and decide wisely when selecting the algorithms for practical applications.

1.3. Contributions

This work reviews state-of-the-art point matching algorithms. We expose challenges that limit the algorithms and make them less useful in practical applications. Additionally, the work discusses performance indicators that can be used to evaluate the algorithms. Of these indicators, we have introduced a simple approach to compare the computational speed of the PSR algorithms without considering hardware limitations. Note that previous review articles have inadequately exposed and discussed performance attributes of the algorithms. Also, the current study proposes a general framework for evaluating point set registration algorithms. With the performance indices integrated into the framework, scholars may understand how to conduct experiments, evaluate their algorithms, and perform comparisons. Moreover, we have discussed critical issues that impact the evaluation process of the PSR methods. Lastly, the work has highlighted some foreseeable trends in registration of point sets. This contribution may provide useful insights to understand a possible direction in which the field is steering.

2. Point set registration (PSR) algorithms

2.1. Problem formulation

In [20], Bing et al. summarize the point matching problem as follows: consider a finite-dimensional real vector space $\mathbb{R}^n$ that