ISPRS Journal of Photogrammetry and Remote Sensing 119 (2016) 90–107

Contents lists available at ScienceDirect

ISPRS Journal of Photogrammetry and Remote Sensing

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

Dynamic occlusion detection and inpainting of in situ captured terrestrial laser scanning point clouds sequence

Chen Chi [a], Yang Bisheng [a,b,*]

[a] State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing, Wuhan University, Wuhan 430079, China
[b] Beijing Advanced Innovation Center for Imaging Technology, Beijng 430079, China

ARTICLE INFO

Article history:
Received 9 November 2015
Received in revised form 15 May 2016
Accepted 17 May 2016

Keywords:
Terrestrial laser scanning
LiDAR data
Dynamic occlusion detection
Point clouds inpainting
Point clouds preprocessing

ABSTRACT

Laser point clouds captured using terrestrial laser scanning (TLS) in an uncontrollable urban outdoor or indoor scene suffer from irregular shaped data blanks caused by dynamic occlusion that temporarily exists, i.e., moving objects, such as pedestrians or cars, resulting in integrality and quality losses of the scene data. This paper proposes a novel automatic dynamic occlusion detection and inpainting method for sequential TLS point clouds captured from one scan position. In situ collected laser point clouds sequences are indexed by establishing a novel panoramic space partition that assigns a three dimensional voxel to each laser point according to the scanning setups. Then two stationary background models are constructed at the ray voxel level using the laser reflectance intensity and geometrical attributes of the point set inside each voxel across the TLS sequence. Finally, the background models are combined to detect the points on the dynamic object, and the ray voxels of the detected dynamic points are tracked for further inpainting by replacing the ray voxels with the corresponding background voxels from another scan. The resulting scene is free of dynamic occlusions. Experiments validated the effectiveness of the proposed method for indoor and outdoor TLS point clouds captured by a commercial terrestrial scanner. The proposed method achieves high precision and recall rate for dynamic occlusion detection and produces clean inpainted point clouds for further processing.

© 2016 International Society for Photogrammetry and Remote Sensing, Inc. (ISPRS). Published by Elsevier B.V. All rights reserved.

1. Introduction

Terrestrial light detection and ranging (LiDAR) scanners capture highly accurate and dense three dimensional (3D) measurements of real world scenes in the form of 3D scattered points. LiDAR point clouds and derivatives (e.g. 3D models) have been used for numerous applications, such as civil engineering (Lichti et al., 2002), archaeology documentation (Lerma et al., 2010), landscape simulations (Starek et al., 2011), biomass estimation (Kankare et al., 2013), high-resolution topography (Pirotti et al., 2013), and augmented reality (Portalés et al., 2010). Nevertheless, the point clouds often suffer from data blanks, which appear as holes in the scene, from poor laser pulse return from highly specular surfaces, out of scanner field of view, and, most of all, occlusions.

Terrestrial LiDAR scanners produce low energy laser pulses and cannot penetrate opaque objects. The range measures used to calculate the 3D point cloud are produced by the reflected ray of the closest surface in the scene along the emission angle. Thus, the data points from further surfaces along this ray are missing and appear as shadowed. Completeness of the raw TLS points is required for a variety of applications involving scene modeling (Murphy et al., 2013) or segmentation (Barnea and Filin, 2013). However, collecting TLS point clouds with no missing data is not technical feasible, and missing data caused by foreground surface occlusions has been a major problem in terrestrial laser scanning (Becker et al., 2009; Doria and Radke, 2012; Friedman and Stamos, 2012). Filling the missing data in TLS point clouds is required for preprocessing in a variety of applications.

Many studies have explored 2D image inpainting, i.e., filling image data blanks (Arias et al., 2011; Buyssens et al., 2015). Image inpainting involves filling the data blanks caused by damaged image data or occlusion left by removing foreground objects with optimal texture and color under the criteria of introducing minimum visible artifacts. Commercial or open source image editing software (e.g. Adobe Photoshop and GNU Image Manipulation Program (GIMP), respectively) provide image inpainting functions for single or multiple images. Although TLS data suffers from the same occlusion problems, few studies and software packages are available addressing data inpainting for 3D TLS imaging.

---

* Corresponding author.
E-mail addresses: chenchi_liesmars@foxmail.com (C. Chen), bshyang@whu.edu.cn (B. Yang).

http://dx.doi.org/10.1016/j.isprsjprs.2016.05.007
0924-2716/© 2016 International Society for Photogrammetry and Remote Sensing, Inc. (ISPRS). Published by Elsevier B.V. All rights reserved.

In an uncontrolled indoor or outdoor urban environment, in addition to stationary foreground objects occluding further surfaces (static occlusions), the scene is filled with moving foreground objects (e.g. pedestrians and/or vehicles) that cause temporary occlusions (dynamic occlusions). The static occlusions can be solved by changing the scan positions to acquire new scans and later registering the multi-station scans. Nevertheless, adopting this method to detect and fill the dynamic occlusions that temporarily exists in every scan is problematic: firstly, there is no guarantee that new scans at different scan positions covers the occluded regions, since the occluding objects are always changing, for instance, collecting scans in a hot spot filled with large amount of fast moving pedestrians; secondly, the occluding points (points on the moving objects) exist after merging multi-scan data. Those undesirable points will contaminate the scene data in applications such as scene modeling and may not be classified correctly by shape based point clouds classification algorithms, because of their irregular geometrical distribution; thirdly, change scan position and register multi-scan data requires a certain amount of human labor.

To search for alternatives that automatically solve occlusions, research communities have been consistently studying on the TLS 3D data occlusion inpainting methods. Existing literatures utilize single 2.5D or 3D observation of the scene with or without auxiliary data to solve the occlusion from foreground objects, filling the shadow area with synthesized data (Becker et al., 2009; Cai et al., 2015; Doria and Radke, 2012; Friedman and Stamos, 2012; Lozes et al., 2014). The industry also provides a preliminary solution to solve the dynamic occlusions temporarily exist (ZF-laser, 2016). However, the differences between dynamic occlusions caused by moving objects and static occlusions caused by stationary objects have been overlooked in most of the previous studies.

Dynamic occlusions exhibit no consistency across multiple observations, and can be detected and inpainted with real scan points using redundant data automatically. Occlusion inpainting in single data frame without categorizing static or dynamic occlusion leads to three major flaws: (1) all occlusions are filled with synthesized data rather than real observations, considerably increasing the complexity of recovering 3D structure; (2) all occlusions must be manually predefined by a mask, with no capability to automate identifying occlusions; (3) the undesirable occluding points on the moving objects aren't automatically eliminated and will harden further point clouds processing procedures. In the meantime, many TLS applications such as multi-scans registration (Theiler et al., 2015), 3D modeling (Pu and Vosselman, 2009), archaeology documentation (Lerma et al., 2010), indoor mapping (Oesau et al., 2014) and point clouds segmentation (Barnea and Filin, 2013) benefits and requires occlusion free points clouds. Hence, automatic detection of dynamic occlusion points, and subsequent locating and filling of dynamic occlusions is essential for improving point cloud quality and integrity before commencing the TLS point cloud processing pipeline.

This paper proposes a TLS point clouds inpainting method to detect dynamic occluding points, and to locate and fill dynamic occlusions with authentic 3D points using in situ captured TLS point cloud sequences.

1. A terrain laser scanner captures sequential scans from the same scan position.
2. A panoramic space partition is executed on the point clouds in the scan sequence to divide the scene into 3D ray voxels.
3. Two stationary background models are constructed for each ray voxel using the laser reflectance intensity and geometrical attributes of the point set inside each voxel across the TLS sequence.
4. The models are combined through an adaptive logistic function weight selection method to classify the points as dynamic foreground points or static background points.

Dynamic occlusions are detected by tracking the ray voxel index of the dynamic points and are filled with points from the corresponding ray voxels where the point set is classified as background throughout the scan sequence, achieving dynamic occlusion detection and inpainting of TLS point clouds.

Collecting point clouds in public space is a typical scenario of TLS applications. The proposed method achieves background point clouds without disturbing of people's social activities. So that contributes to the public morality with no compromising of the data quality and completeness. The potential applications of the proposed method are mainly three-fold: (1) Pre-processing for tradition TLS pipeline. For example, eliminate the moving occluding points and fill the occlusion for better environment modeling in public space. (2) Preprocessing for urban change detection. Temporary moving objects such as pedestrians and cars add uncertainties to the urban environment change detection results (Xiao et al., 2015). Utilizing the proposed method, the short term changes (e.g. pedestrians) are detected and eliminated generating a solid background point clouds that can be further used in multi-temporal analysis. (3) Surveillance and intrusion detection. The proposed method generates accurate background point clouds with high geometric details, thus can be using in detecting intrusions for surveillance purposes. Although surveillance and intrusion detection can be done with cheap cameras, the proposed method proves an alternative to detect foreground objects without the sunlight.

The main contributions of the proposed method are that it proposed a novel 3D background modeling method which adaptively combine geometric and intensity features through logistic function for dynamic occlusions detection and inpainting, thus overcomes the shortcomings of ubiquitous and temporary existing dynamic occlusions and occluding points in TLS, resulting in accurate and robust TLS point clouds inpainting.

Related work on 3D data inpainting is reviewed in Section 2. Section 3 introduces the key components of the proposed dynamic occlusion detection and inpainting method. Experimental studies applying the proposed method to real scenes are presented in Section 4, and the final conclusions are presented in Section 5.

2. Literature review

Defining the occlusion area is the first step toward reconstruction or recognition (Friedman and Stamos, 2012). Occlusion detection and inpainting of 3D points cloud data can be performed upon either raw 3D points or 2.5D formation depth maps derived from stereo vision or RGB-D cameras.

Depth map is a type of 3D data stored in two dimensional (2D) formations. Filling holes in depth maps can be treated as image inpainting to some degree. Major depth map inpainting studies have been inspired by image inpainting techniques which focused on repairing small to medium sized holes in single depth or disparity images by exploring local geometry for interpolation, and global texture similarity for patch copying. Exploring local geometry for interpolation is a preliminary choice for small size defects. Stavrou et al. (2006) applied 2D image inpainting algorithms involving Haar wavelet and image decomposition methods to 3D data by treating the acquired 3D data as images. Oishi et al. (2011) proposed belief propagation to restore missing data in deteriorated range images using adjacent ranges and intensity values. Global texture similarity, such as the well-established exemplar based imaging inpainting technique, has also been utilized to recover relatively large missing data areas. Doria and Radke (2012) proposed a depth map inpainting algorithm in the gradients domain combining gradient domain image editing and patch based image inpainting. Kulkarni and Rajagopalan (2013) proposed inpainting by uniting geometry in neighboring areas and self-similar training patches through a tensor

Download English Version:

https://daneshyari.com/en/article/6949290

Download Persian Version:

https://daneshyari.com/article/6949290

Daneshyari.com