三维点云处理综述合集

三维点云是最重要的三维数据表达方式之一。

从技术角度看，在三维重建、SLAM、机器人感知等多个领域，三维点云都是最简单最普遍的表达方式，因为三维点云直接提供了三维空间数据，而图像则需要通过透视几何来反推三维数据。应用角度上，从无人驾驶中的激光雷达到微软 Kinect、iPhone FaceID 及 AR/VR 应用，都需要基于点云的数据处理。

以下收集了 17 篇点云处理的综述文章，方便大家全面了解三维点云处理的技术发展、了解其发展路线，便于咱们自己的学习规划及学术方向研究。

微信扫码，备注**点云论文**，可直接领取论文集

01 Comprehensive Review of Deep Learning-Based 3D Point Cloud Completion Processing and Analysis

作者： Ben Fei, Weidong Yang, Wenming Chen, Zhijun Li, Yikang Li, Tao Ma, Xing Hu, Lipeng Ma

摘要： Point cloud completion is a generation and estimation issue derived from the partial point clouds, which plays a vital role in the applications in 3D computer vision. The progress of deep learning (DL) has impressively improved the capability and robustness of point cloud completion. However, the quality of completed point clouds is still needed to be further enhanced to meet the practical utilization. Therefore, this work aims to conduct a

comprehensive survey on various methods, including point-based, convolution-based, graph-based, and generative model-based approaches, etc. And this survey summarizes the comparisons among these methods to provoke further research insights. Besides, this review sums up the commonly used datasets and illustrates the applications of point cloud completion. Eventually, we also discussed possible research trends in this promptly expanding field.

02 A Quick Review on Recent Trends in 3D Point Cloud Data Compression Techniques and the Challenges of Direct Processing in 3D Compressed Domain

作者： Mohammed Javed, MD Meraz, Pavan Chakraborty

摘要： Automatic processing of 3D Point Cloud data for object detection, tracking and segmentation is the latest trending research in the field of AI and Data Science, which is specifically aimed at solving different challenges of autonomous driving cars and getting real time performance. However, the amount of data that is being produced in the form of 3D point cloud (with LiDAR) is very huge, due to which the researchers are now on the way inventing new data compression algorithms to handle huge volumes of data thus generated. However, compression on one hand has an advantage in overcoming space requirements, but on the other hand, its processing gets expensive due to the decompression, which indents additional computing resources. Therefore, it would be novel to think of developing algorithms that can operate/analyse directly with the compressed data without involving the stages of decompression and recompression (required as many times, the compressed data needs to be operated or analyzed). This research field is termed as Compressed Domain Processing. In this paper, we will quickly review few of the recent state-of-the-art developments in the area of LiDAR generated 3D point cloud data compression, and highlight the future challenges of compressed domain processing of 3D point cloud data.

03 Deep Learning for LiDAR Point Clouds in Autonomous Driving:

A Review

作者： Ying Li, Lingfei Ma, Zilong Zhong, Fei Liu, Dongpu Cao, Jonathan Li, Michael A. Chapman

摘要： Recently, the advancement of deep learning in discriminative feature learning from 3D LiDAR data has led to rapid development in the field of autonomous driving. However, automated processing uneven, unstructured, noisy, and massive 3D point clouds is a challenging and tedious task. In this paper, we provide a systematic review of existing compelling deep learning architectures applied in LiDAR point clouds, detailing for specific tasks in autonomous driving such as segmentation, detection, and classification. Although several published research papers focus on specific topics in computer vision for autonomous vehicles, to date, no general survey on deep learning applied in LiDAR point clouds for autonomous vehicles exists. Thus, the goal of this paper is to narrow the gap in this topic. More than 140 key contributions in the recent five years are summarized in this survey, including the milestone 3D deep architectures, the remarkable deep learning applications in 3D semantic segmentation, object detection, and classification; specific datasets, evaluation metrics, and the state of the art performance. Finally, we conclude the remaining challenges and future researches.

04 Deep Learning for Image and Point Cloud Fusion in Autonomous Driving: A Review

作者： Yaodong Cui, Ren Chen, Wenbo Chu, Long Chen, Daxin Tian, Ying Li, Dongpu Cao

摘要： Autonomous vehicles were experiencing rapid development in the past few years. However, achieving full autonomy is not a trivial task, due to the nature of the complex and dynamic driving environment. Therefore, autonomous vehicles are equipped with a suite of different sensors to ensure robust, accurate environmental perception. In particular, the camera-LiDAR fusion is becoming an emerging research theme. However, so far there has been no critical review that focuses on deep-learning-based camera-LiDAR fusion methods.

To bridge this gap and motivate future research, this paper devotes to review recent deep-learning-based data fusion approaches that leverage both image and point cloud. This review gives a brief overview of deep learning on image and point cloud data processing. Followed by in-depth reviews of camera-LiDAR fusion methods in depth completion, object detection, semantic segmentation, tracking and online cross-sensor calibration, which are organized based on their respective fusion levels. Furthermore, we compare these methods on publicly available datasets. Finally, we identified gaps and over-looked challenges between current academic researches and real-world applications. Based on these observations, we provide our insights and point out promising research directions.

05 Review: deep learning on 3D point clouds

作者： Saifullahi Aminu Bello, Shangshu Yu, Cheng Wang

摘要： Point cloud is point sets defined in 3D metric space. Point cloud has become one of the most significant data format for 3D representation. Its gaining increased popularity as a result of increased availability of acquisition devices, such as LiDAR, as well as increased application in areas such as robotics, autonomous driving, augmented and virtual reality. Deep learning is now the most powerful tool for data processing in computer vision, becoming the most preferred technique for tasks such as classification, segmentation, and detection. While deep learning techniques are mainly applied to data with a structured grid, point cloud, on the other hand, is unstructured. The unstructuredness of point clouds makes use of deep learning for its processing directly very challenging. Earlier approaches overcome this challenge by preprocessing the point cloud into a structured grid format at the cost of increased computational cost or lost of depth information. Recently, however, many state-of-the-arts deep learning techniques that directly operate on point cloud are being developed. This paper contains a survey of the recent state-of-the-art deep learning techniques that mainly focused on point cloud data. We first briefly discussed the major challenges faced when using deep learning directly on point cloud, we also briefly discussed earlier approaches which overcome the challenges by preprocessing the point cloud into a structured grid. We then give the review of the various state-of-the-art deep learning approaches that directly process point

cloud in its unstructured form. We introduced the popular 3D point cloud benchmark datasets. And we also further discussed the application of deep learning in popular 3D vision tasks including classification, segmentation and detection.

06 Target-less registration of point clouds: A review

作者： Yue Pan

摘要： Point cloud registration has been one of the basic steps of point cloud processing, which has a lot of applications in remote sensing and robotics. In this report, we summarized the basic workflow of target-less point cloud registration,namely correspondence determination and transformation estimation. Then we reviewed three commonly used groups of registration approaches, namely the feature matching based methods, the iterative closest points algorithm and the randomly hypothesis and verify based methods. Besides, we analyzed the advantage and disadvantage of these methods are introduced their common application scenarios. At last, we discussed the challenges of current point cloud registration methods and proposed several open questions for the future development of automatic registration approaches.

07 Linking Points With Labels in 3D: A Review of Point Cloud Semantic Segmentation

作者： Yuxing Xie, Jiaojiao Tian, Xiao Xiang Zhu

摘要： 3D Point Cloud Semantic Segmentation (PCSS) is attracting increasing interest, due to its applicability in remote sensing, computer vision and robotics, and due to the new possibilities offered by deep learning techniques. In order to provide a needed up-to-date review of recent developments in PCSS, this article summarizes existing studies on this topic. Firstly, we outline the acquisition and evolution of the 3D point cloud from the perspective of remote sensing and computer vision, as well as the published benchmarks for PCSS studies. Then, traditional and advanced techniques used for Point Cloud Segmentation (PCS) and PCSS are reviewed and compared. Finally, important issues and open questions in PCSS

studies are discussed.

08 Transformers in 3D Point Clouds: A Survey

作者： Dening Lu, Qian Xie, Mingqiang Wei, Linlin Xu, Jonathan Li

摘要： In recent years, Transformer models have been proven to have the remarkable ability of long-range dependencies modeling. They have achieved satisfactory results both in Natural Language Processing (NLP) and image processing. This significant achievement sparks great interest among researchers in 3D point cloud processing to apply them to various 3D tasks. Due to the inherent permutation invariance and strong global feature learning ability, 3D Transformers are well suited for point cloud processing and analysis. They have achieved competitive or even better performance compared to the state-of-the-art non-Transformer algorithms. This survey aims to provide a comprehensive overview of 3D Transformers designed for various tasks (e.g. point cloud classification, segmentation, object detection, and so on). We start by introducing the fundamental components of the general Transformer and providing a brief description of its application in 2D and 3D fields. Then, we present three different taxonomies (i.e., Transformer implementation-based taxonomy, data representation-based taxonomy, and task-based taxonomy) for method classification, which allows us to analyze involved methods from multiple perspectives. Furthermore, we also conduct an investigation of 3D self-attention mechanism variants designed for performance improvement. To demonstrate the superiority of 3D Transformers, we compare the performance of Transformer-based algorithms in terms of point cloud classification, segmentation, and object detection. Finally, we point out three potential future research directions, expecting to provide some benefit references for the development of 3D Transformers.

09 Surface Reconstruction from Point Clouds: A Survey and a Benchmark

作者： Zhangjin Huang, Yuxin Wen, Zihao Wang, Jinjuan Ren, Kui Jia

摘要： Reconstruction of a continuous surface of two-dimensional manifold from its raw, discrete point cloud observation is a long-standing problem. The problem is technically ill-posed, and becomes more difficult considering that various sensing imperfections would appear in the point clouds obtained by practical depth scanning. In literature, a rich set of methods has been proposed, and reviews of existing methods are also provided. However, existing reviews are short of thorough investigations on a common benchmark. The present paper aims to review and benchmark existing methods in the new era of deep learning surface reconstruction. To this end, we contribute a large-scale benchmarking dataset consisting of both synthetic and real-scanned data; the benchmark includes object- and scene-level surfaces and takes into account various sensing imperfections that are commonly encountered in practical depth scanning. We conduct thorough empirical studies by comparing existing methods on the constructed benchmark, and pay special attention on robustness of existing methods against various scanning imperfections; we also study how different methods generalize in terms of reconstructing complex surface shapes. Our studies help identify the best conditions under which different methods work, and suggest some empirical findings. For example, while deep learning methods are increasingly popular, our systematic studies suggest that, surprisingly, a few classical methods perform even better in terms of both robustness and generalization; our studies also suggest that the practical challenges of misalignment of point sets from multi-view scanning, missing of surface points, and point outliers remain unsolved by all the existing surface reconstruction methods. We expect that the benchmark and our studies would be valuable both for practitioners and as a guidance for new innovations in future research.

10 Sequential Point Clouds: A Survey

作者： Haiyan Wang, Yingli Tian

摘要： Point cloud has drawn more and more research attention as well as real-world applications. However, many of these applications (e.g. autonomous driving and robotic manipulation) are actually based on sequential point clouds (i.e. four dimensions) because the

information of the static point cloud data could provide is still limited. Recently, researchers put more and more effort into sequential point clouds. This paper presents an extensive review of the deep learning-based methods for sequential point cloud research including dynamic flow estimation, object detection \& tracking, point cloud segmentation, and point cloud forecasting. This paper further summarizes and compares the quantitative results of the reviewed methods over the public benchmark datasets. Finally, this paper is concluded by discussing the challenges in the current sequential point cloud research and pointing out insightful potential future research directions.

11. A Survey of Robust 3D Object Detection Methods in Point Clouds

作者： Walter Zimmer, Emec Ercelik, Xingcheng Zhou, Xavier Jair Diaz Ortiz, Alois Knoll

摘要： The purpose of this work is to review the state-of-the-art LiDAR-based 3D object detection methods, datasets, and challenges. We describe novel data augmentation methods, sampling strategies, activation functions, attention mechanisms, and regularization methods. Furthermore, we list recently introduced normalization methods, learning rate schedules and loss functions. Moreover, we also cover advantages and limitations of 10 novel autonomous driving datasets. We evaluate novel 3D object detectors on the KITTI, nuScenes, and Waymo dataset and show their accuracy, speed, and robustness. Finally, we mention the current challenges in 3D object detection in LiDAR point clouds and list some open issues.

12. Unsupervised Point Cloud Representation Learning with Deep Neural Networks: A Survey

作者： Aoran Xiao, Jiaxing Huang, Dayan Guan, Xiaoqin Zhang, Shijian Lu

GitHub： https://github.com/xiaoaoran/3d_url_survey

摘要： Point cloud data have been widely explored due to its superior accuracy and robustness under various adverse situations. Meanwhile, deep neural networks (DNNs) have achieved very impressive success in various applications such as surveillance and autonomous driving.

The convergence of point cloud and DNNs has led to many deep point cloud models, largely trained under the supervision of large-scale and densely-labelled point cloud data. Unsupervised point cloud representation learning, which aims to learn general and useful point cloud representations from unlabelled point cloud data, has recently attracted increasing attention due to the constraint in large-scale point cloud labelling. This paper provides a comprehensive review of unsupervised point cloud representation learning using DNNs. It first describes the motivation, general pipelines as well as terminologies of the recent studies. Relevant background including widely adopted point cloud datasets and DNN architectures is then briefly presented. This is followed by an extensive discussion of existing unsupervised point cloud representation learning methods according to their technical approaches. We also quantitatively benchmark and discuss the reviewed methods over multiple widely adopted point cloud datasets. Finally, we share our humble opinion about several challenges and problems that could be pursued in future research in unsupervised point cloud representation learning. A project associated with this survey has been built at this https URL.

13. Sequential Point Cloud Prediction in Interactive Scenarios: A Survey

作者： Haowen Wang, Zirui Li, Jianwei Gong

摘要： Point cloud has been widely used in the field of autonomous driving since it can provide a more comprehensive three-dimensional representation of the environment than 2D images. Point-wise prediction based on point cloud sequence (PCS) is an essential part of environment understanding, which can assist in the decision-making and motion-planning of autonomous vehicles. However, PCS prediction has not been deeply researched in the literature. This paper proposes a brief review of the sequential point cloud prediction methods, focusing on interactive scenarios. Firstly, we define the PCS prediction problem and introduce commonly-used frameworks. Secondly, by reviewing non-predictive problems, we analyze and summarize the spatio-temporal feature extraction methods based on PCS. On this basis, we review two types of PCS prediction tasks, scene flow estimation (SFE) and point cloud

location prediction (PCLP), highlighting their connections and differences. Finally, we discuss some opening issues and point out some potential research directions.

14. A Technical Survey and Evaluation of Traditional Point Cloud Clustering Methods for LiDAR Panoptic Segmentation

作者： Yiming Zhao, Xiao Zhang, Xinming Huang

GitHub：

https://github.com/placeforyiming/iccvw21-lidar-panoptic-segmentation-tradicv-survey-of-point-cloud-cluster

摘要： LiDAR panoptic segmentation is a newly proposed technical task for autonomous driving. In contrast to popular end-to-end deep learning solutions, we propose a hybrid method with an existing semantic segmentation network to extract semantic information and a traditional LiDAR point cloud cluster algorithm to split each instance object. We argue geometry-based traditional clustering algorithms are worth being considered by showing a state-of-the-art performance among all published end-to-end deep learning solutions on the panoptic segmentation leaderboard of the SemanticKITTI dataset. To our best knowledge, we are the first to attempt the point cloud panoptic segmentation with clustering algorithms. Therefore, instead of working on new models, we give a comprehensive technical survey in this paper by implementing four typical cluster methods and report their performances on the benchmark. Those four cluster methods are the most representative ones with real-time running speed. They are implemented with C++ in this paper and then wrapped as a python function for seamless integration with the existing deep learning frameworks. We release our code for peer researchers who might be interested in this problem.

15. A comprehensive survey on point cloud registration

作者： Xiaoshui Huang, Guofeng Mei, Jian Zhang, Rana Abbas

摘要： Registration is a transformation estimation problem between two point clouds, which

has a unique and critical role in numerous computer vision applications. The developments of optimization-based methods and deep learning methods have improved registration robustness and efficiency. Recently, the combinations of optimization-based and deep learning methods have further improved performance. However, the connections between optimization-based and deep learning methods are still unclear. Moreover, with the recent development of 3D sensors and 3D reconstruction techniques, a new research direction emerges to align cross-source point clouds. This survey conducts a comprehensive survey, including both same-source and cross-source registration methods, and summarize the connections between optimization-based and deep learning methods, to provide further research insight. This survey also builds a new benchmark to evaluate the state-of-the-art registration algorithms in solving cross-source challenges. Besides, this survey summarizes the benchmark data sets and discusses point cloud registration applications across various domains. Finally, this survey proposes potential research directions in this rapidly growing field.

16. Attention Models for Point Clouds in Deep Learning: A Survey

作者： Xu Wang, Yi Jin, Yigang Cen, Tao Wang, Yidong Li

摘要： Recently, the advancement of 3D point clouds in deep learning has attracted intensive research in different application domains such as computer vision and robotic tasks. However, creating feature representation of robust, discriminative from unordered and irregular point clouds is challenging. In this paper, our ultimate goal is to provide a comprehensive overview of the point clouds feature representation which uses attention models. More than 75+ key contributions in the recent three years are summarized in this survey, including the 3D objective detection, 3D semantic segmentation, 3D pose estimation, point clouds completion etc. We provide a detailed characterization (1) the role of attention mechanisms, (2) the usability of attention models into different tasks, (3) the development trend of key technology.

17. Deep Learning for 3D Point Cloud Understanding: A Survey

作者： Haoming Lu, Humphrey Shi

GitHub： https://github.com/SHI-Labs/3D-Point-Cloud-Learning

摘要： The development of practical applications, such as autonomous driving and robotics, has brought increasing attention to 3D point cloud understanding. While deep learning has achieved remarkable success on image-based tasks, there are many unique challenges faced by deep neural networks in processing massive, unstructured and noisy 3D points. To demonstrate the latest progress of deep learning for 3D point cloud understanding, this paper summarizes recent remarkable research contributions in this area from several different directions (classification, segmentation, detection, tracking, flow estimation, registration, augmentation and completion), together with commonly used datasets, metrics and state-of-the-art performances. More information regarding this survey can be found at: this https URL.