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Opponent's report

on the doctoral dissertation

3D MAPPING FROM SPARSE LIDAR DATA

submitted by

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The choice of research topic

The theme of this thesis is very current. Mobile laser mapping has been increasingly used in many in-door and out-door applications and it is a field of research with a very rapid innovation and development. The contribution of this doctoral thesis is mostly in the field of 3D data registration and data collection and processing using own mobile backpack system. This is a very interesting and up-to-date research goal resonating in many studies worldwide. In that sense the selection of the research topic is reasonable and fully justified.

Research methods

This work is dominated by various research methods mostly concentrated in the area of LiDAR data processing using various mathematical, computer science and geospatial methods. Specifically, Collar Line Segmentation and Convolutional Neural Network methods were used in the LiDAR data registration and further processing of sparse Lidar data collected by the Velodyne sensor.

Scientific results

The thesis is written as a compilation of author's previously published four papers supplemented with introduction and summary chapters such as motivation and existing solutions and conclusions. In each of these papers, Mr. Veľas is a first author, so we can assume his substantial contribution to scientific results of the research presented in this thesis.

The contribution of these papers and thesis can be summarized as follows:

Martin Velas, Michal Spanel, and Adam Herout. Collar line segments for fast odometry estimation from velodyne point clouds. In 2016 IEEE International Conference on Robotics and Automation (ICRA), pages 4486–4495, May 2016. ISBN 978-1-4673-8026-3. doi: 10.1109/ICRA.2016.7487648.

This paper introduces a novel way of Velodyne point cloud representation using the Collar Line Segments (CLS), the algorithm of "line clouds" registration, and its further improvement by processing multiple preceding scans. These algorithms were used for Velodyne LiDAR scans registration of the KITTI dataset and compared to the state-of-the-art technique Generalized ICP. The new method achieves better results in terms of registration accuracy, especially for challenging situations like natural scenes or lack of relevant landmarks. Considering the time consumption, the presented approach is approximately 10× faster. Using further proposed improvements, the registration reaches 6 cm weighted average registration error on the KITTI evaluation data sequences.

Martin Velas, Michal Spanel, Michal Hradis, and Adam Herout. CNN for IMU assisted odometry estimation using velodyne LiDAR. In 2018 IEEE International Conference on Autonomous Robot Systems and Competitions (ICARSC), pages 71–77, April 2018. doi: 10.1109/ICARSC.2018.8374163.

This paper presents a novel method of odometry estimation using convolutional neural networks. As the most significant contribution, networks for very fast realtime and precise estimation of translation parameters, beyond the performance of other state of the art methods, were proposed. The precision of proposed CNNs was evaluated using the standard KITTI odometry dataset. Theproposed solution can replace less accurate methods like odometry estimated from wheel platform encoders or GPS based solutions, when GNSS signal is not sufficient or corrections are missing (indoor, forests, etc.). Moreover, with the rotation parameters obtained from the IMU sensor, results of the mapping can be shown in a preview for online verification of the mapping procedure when the data are being collect. Also two alternative network topologies and training strategies for prediction of orientation angles were introduced enabling complete visual odometry estimation using CNNs in a real time.

Martin Velas, Michal Spanel, Tomas Sleziak, Jiri Habrovec, and Adam Herout. Indoor and outdoor backpack mapping with calibrated pair of velodyne lidars. Sensors, 2019(1):1–34, 2019. ISSN 1424-8220. doi: 10.3390/s19183944.

This paper presents a human-carried mapping backpack based on a pair of Velodyne LiDAR scanners. The mobile mapping system is a universal solution for both large scale outdoor and smaller indoor environments. It benefits from a combination of two LiDAR scanners, which makes the odometry estimation more precise. The scanners are mounted under different angles, thus a larger space around the backpack is scanned. By fusion with GNSS/INS sub-system, the mapping of featureless environments and the georeferencing of resulting point cloud is possible. By deploying SoA methods for registration and the loop closure optimization, it provides sufficient precision for many applications in BIM (Building

Information Modeling), inventory check, construction planning, etc. In indoor experiments, the proposed backpack was evaluated against ZEB-1 solution, using FARO terrestrial scanner as the reference, yielding similar results in terms of precision, while this system provides higher data density, laser intensity readings, and scalability for large environments.

M. Velas, M. Spanel, M. Hradis, and A. Herout. CNN for very fast ground segmentation in velodyne LiDAR data. In 2018 IEEE International Conference on Autonomous Robot Systems and Competitions (ICARSC), pages 97–103, April 2018. doi: 10.1109/ICARSC.2018.8374167.

In this paper, a real time and robust ground segmentation method of Velodyne LiDAR data is presented. The results show that the sparse LiDAR data can be encoded into its dense 2D representation and effectively processed by CNN. The method improved the precision and significantly improved speed of the ground segmentation process from minutes to 140 ms using CPU and 7 ms with GPU acceleration. It was demonstrated that CNN approach is suitable for simpler task of ground segmentation where the results are near ideal. Also the dataset with ground annotated was created and made it publicly available along with the annotation tool. Such data can be used to design, train, and evaluate other ground segmentation approaches.

All these articles were subject to a peer-review process that approved the scientific content and contribution to respective scientific fields. In that sense I accept the fact that Mr. Vel'as substantially contributed to these studies as a first author and leader of the research team thus showing his ability to perform research activities and cooperative scientific works. It should be noted, however, that 3 papers are conference papers and only 1 paper was published in a scientific journal (Sensors). Also it should be noted that from the thesis it is not clear the contribution of the other co-authors and thus it is not clear the extent of Mr. Vel'as own contribution. In my opinion, when the doctoral thesis is submitted in the form of a set of published papers, it should be clearly and explicitly stated the contribution of the thesis author in the presented articles. Therefore I recommend to explain explicitly his personal contribution in each of these papers during the defense of the thesis.

I have a few comments and questions regarding the presented solutions:

- page 51, Table 5.1, p. 53, Figure 5.10, and others – units of error are missing (meters?)
- p. 75, please explain the following statement „Although, for many applications listed above, there is no need for such precision, our goal is the difference between the reality and the resulting 3D model below 5 cm. This value was requested by the experts in the field of geodesy with whom we consulted."

- p. 102 please comment in these statements. “For outdoor environments, there are also constraints for absolute error ea in global geodetic frame. The average of this absolute error is required to be below 14 cm for position in horizontal plane and 12 cm for height estimation. However, the constraints for maximal error are set to double of these values—up to 28 cm for horizontal and 24 cm vertical error. These values were obtained through consultation with experts in the field of geodesy and follow the requirements for creating the building models, outdoor vector maps, inventory check, etc.” The 3rd class mean geodetic error in Slovakia/Czechia is/was 0.06 m (acceptable for topographic/city maps 1:1,000). Please note that these erros are absolute errors within the national reference systems.
- The presented backpack laser mapping solution consists of a pair Velodyne laser scanners. In many outdoor solutions, the RGB camera greatly improves the interpretability/classification of points clouds. Is it possible to include a RGB camera to colorize the point clouds? Can you describe a possible solution?

Contribution to the science field

This dissertation brings a few results benefiting several scientific fields such as computers science, GIScience, or geodesy. These results are concentrated mainly in the area of point cloud from mobile laser scanners and mobile indoor and outdoor mapping using backpack solution. The presented solutions achieved excellent results in terms of mapping accuracy and versatility thus greatly contributing to ongoing research efforts in this area at the international level.

Meeting the objectives and overall evaluation

All research objectives defined in the thesis have been met and the scientific results are adequate for this level of academic degree. The publication activity of the PhD candidate is adequate and contributes to the overall favourable evaluation of his research results. Considering all aspects of the thesis, the presented results and my previous comments I recommend Ing. Martin Veľas to be awarded a PhD. degree after a successful defence of his thesis.

In Košice, August 31, 2020

prof. Mgr. Jaroslav Hofierka, PhD.