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Jury Member Report – Doctor of Philosophy thesis.

Name of Candidate: Emre Ozdemir

PhD Program: Engineering Systems

Title of Thesis: Geospatial point cloud classification

Supervisor: Associate Professor Alessandro Golkar

Co-supervisor: Dr. Fabio Remondino, Bruno Kessler Foundation

Name of the Reviewer: Prof. Dr. Norbert Haala

I confirm the absence of any conflict of interest 	**Date: 02-11-2021**

The purpose of this report is to obtain an independent review from the members of PhD defense Jury before the thesis defense. The members of PhD defense Jury are asked to submit signed copy of the report at least 30 days prior the thesis defense. The Reviewers are asked to bring a copy of the completed report to the thesis defense and to discuss the contents of each report with each other before the thesis defense.

If the reviewers have any queries about the thesis which they wish to raise in advance, please contact the Chair of the Jury.

Reviewer's Report

Reviewers report should contain the following items:

- Brief evaluation of the thesis quality and overall structure of the dissertation.
- The relevance of the topic of dissertation work to its actual content
- The relevance of the methods used in the dissertation
- The scientific significance of the results obtained and their compliance with the international level and current state of the art
- The relevance of the obtained results to applications (if applicable)
- The quality of publications

The summary of issues to be addressed before/during the thesis defense

The generation of dense 3D point clouds from airborne sensors has become commonplace. While geometric aspects like the further development of algorithms for Multi-View-Stereo or the improvement of LiDAR sensors originally dominated the research in that domain, meanwhile semantic aspects like the classification of such point clouds getting more and more important. In this context, the thesis on Geospatial Point Cloud Classification delivered by M.Sc. Emre Özdemir aims on semantic information extraction from such point clouds while making use of tools recently developed in the domain of Deep Learning. Chapter 1 of the thesis gives a rather general and brief introduction into the state-of the-art in data collection of airborne point clouds by Multi-View-Stereo or airborne LiDAR. The chapter also briefly motivates the classification of point clouds and presents the structure of the thesis. Chapter 2 reviews classic Machine Learning as well as Deep Learning techniques in view of point classification. This motivates Mr. Ozdemir's own development, which is a mix of both. In his proposed framework, described in chapter 3, Mr. Ozdemir first extracts "handcrafted" features for the respective points, which are based on the spatial distribution of neighboring points. Such neighborhood analyses are frequently aggravated by irregular point densities, which are typical for airborne point clouds. To avoid that issue, he applies a downsampling to regularize point densities in a pre-processing step. The handcrafted features are then extracted at multiple scales based on the analysis of covariance matrix, which represent the respective local point distribution.

The core advantage of applying CNN for image analyses is the availability of a regular grid structure. This is very well suited for convolutions as well as downsampling and upsampling operations as "learned" during the training step. In contrast, point clouds are irregularly structured, which aggravates such operations considerably. The core idea of Mr. Ozdemir's approach is to generate a regular matrix structure for each point by rasterizing the extracted feature representation as well as the distribution of neighboring points. These "pseudo images" can then be fed into a 2D CNN for image object classification. Thus, standard combinations of Convolutional Layers as well as MaxPooling layers are available. This enables the determination of class probabilities for the respective 3D points using a rather simple 2D CNN. As an alternative to this 2D raster structure, Mr. Ozdemir additionally proposes a re-structuring of the matrices to implement a 3D CNN. After the computation of class probabilities by his approach, Mr. Ozdemir then clusters the classified point cloud to separate different building instances in the final step. To discuss the results of his approach in Chapter 4, Mr. Ozdemir performs test on five different benchmark data sets featuring different point density, resolution, sensor data, and number of classes. These investigations are followed by the validation of his framework in chapter 5, which includes generalization experiment and a comparison to state-of-the-art frameworks like for 3D point classification like KPConv and PointNet++. These investigations demonstrate, that the accuracy performance is comparable to such state-of-the-art approaches, while computational performance is superior, both due to regularization step and the grid type structure to represent local point distribution and features.

Classification of aerial 3D point clouds is one of the most active research topics in the geospatial community. As a matter of such, Mr. Ozdemir is working in a rather competitive research environment. In view of this, the quality of his results compared to other approaches is quite remarkable. His key idea to "rasterize" point distribution and features to enable processing in a 2D CNN is strikingly simple, but innovative and original. His research has been presented in 4 journal and 5 conference publications, which demonstrates the interest of the research community in his and the great relevance of work. Some parts of his thesis, e.g. the presentation of approaches for point cloud generation are a bit general, however, the thesis is clearly structured and very convincing. From my point of view the candidate should defend the thesis by means of a formal thesis defense.

Provisional Recommendation
☒ *I recommend that the candidate should defend the thesis by means of a formal thesis defense*
☐ *I recommend that the candidate should defend the thesis by means of a formal thesis defense only after appropriate changes would be introduced in candidate's thesis according to the recommendations of the present report*
☐ *The thesis is not acceptable and I recommend that the candidate be exempt from the formal thesis defense*