EAGER IMPRESS-U: Exploratory Research on Generative Compression for Compressive Lidar

The project covers issues covering theoretical aspects of machine learning, remote sensing and signal and image processing. Its main goal is to develop new ideas and methods of generative compression enabling the transmission and storage of large amounts of measurement data from satellite lidars. Such devices are an important element of remote sensing systems enabling the acquisition of measurement data regarding the topological structure of the Earth's surface (including forests, rivers and water reservoirs, desert, grassy and urbanized areas). The analysis carried out on such data allows us to deepen our understanding of many phenomena taking place on Earth, in particular the processes occurring in the ecosystem that determine the circulation of nutrients, water and carbon on Earth. However, such an analysis is not possible without providing an appropriate amount of reliable measurement data.

Unlike aerial measurements, the current measurement capabilities of satellite lidars are limited both in terms of spatial resolution and range. This is due to the fact that the reflections of the laser beam emitted from the satellite are measured only along a one-dimensional path. This results in the omission of large areas of terrain between adjacent tracks, the location of which results from the satellite's motion relative to the Earth. One of the latest achievements developed by NASA to minimize these limitations is the idea of a two-dimensional lidar, thanks to which it is possible to cover a larger area with emitted laser beams more evenly. However, this solution, called compressive satellite lidar, means that despite a wide field of observation, we are dealing with the so-called sparse sampling of the area, which means that measurements are made at points much further apart than in the case of the so-called "dense" measurements performed using aerial remote sensing. Therefore, the phenomenon of missing data also occurs in this situation, although it is of a different nature than in the case of 1D lidars.

The aim of the project is to investigate the possibility of using machine learning methods, in particular for deep neural networks, to reconstruct a three-dimensional image of the terrain based on data from a compression satellite lidar obtained from an altitude of several hundred kilometers with a quality comparable to the results obtained from an altitude of several hundred meters. Although currently no compression of measurement data is used in NASA satellite lidars, in the case of compression lidars this possibility arises naturally, so an additional goal of the project is to investigate the possibility of using generative compression methods for this type of measurement data, enabling much higher levels of compression than previously available methods.

Due to the fact that the results of training deep neural networks are strongly dependent on the loss function used, an important element of the project is to examine the impact and select the best possible model that will allow for the best possible reconstruction of the image of the terrain subjected to generative compression. Currently, only the simplest image quality and similarity metrics are used for this purpose, such as mean square error (MSE) and others based on pixel comparison, or structural similarity (SSIM) based metrics, applied mainly for natural images. However, in recent years there has been significant progress in the field of image quality assessment, including metrics based on image similarity, which allows the use of other metrics, including those adapted to the specificity of images acquired using remote sensing techniques, also as a loss function during the neural network’s training process.

The role of the Polish team, in close cooperation with the team from the National Aviation University "Kharkiv Aviation Institute" in Kharkiv (KhAI), is to develop appropriate loss functions, in particular based on the adaptation and modification of the previously proposed combined image quality metrics for various types of images, as well as their verification for satellite and aerial measurement data provided by the team from the University of Delaware. Such metrics, after optimization for their application to various types of images, including satellite and aerial ones, are characterized by high correlation with subjective assessments, which has been documented in numerous publications of both the PI and the team from the Faculty of Electrical Engineering of the West Pomeranian University of Technology in Szczecin (WPUT), as well as those developed in as part of previous cooperation with the team from KhAI.

The project involves strengthening cooperation between scientists from the University of Delaware, West Pomeranian University of Technology in Szczecin and National Aviation University in Kharkiv, including: monthly internships of team members from WPUT and KhAI in Delaware, as well as study visits and ongoing remote cooperation during the implementation of the project.