Department of Aerospace and Geodesy
TUM School of Engineering and Design
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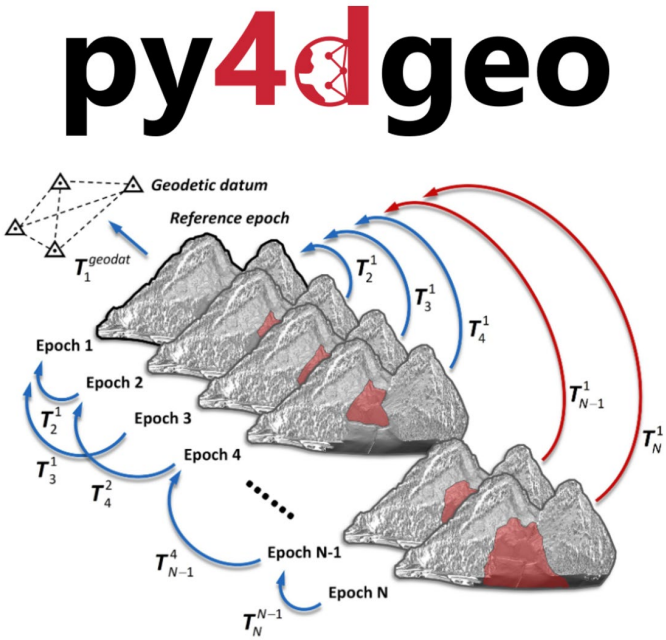
Interdisciplinary Project in an Application Subject (IDP)

Integration of a State-of-the-art 4D Point Cloud Registration Algorithm into the Open Python Library *py4dgeo*

Description of Project

Dense time series of 3D/4D point clouds acquired by modern laser scanning technology are widely used in geosciences, environmental monitoring, infrastructure assessment, and related fields. Automatic spatio-temporal change analysis depends critically on accurate and efficient registration/alignment of these point clouds.



This project engages students in extending an existing open-source Python library, *py4dgeo*, by integrating a state-of-the-art 4D point cloud registration algorithm called Piecewise-ICP (code provided in C++). *py4dgeo* is a comprehensive Python library designed for change analysis of multitemporal point clouds, bundling methods such as distance computation, statistical change detection, and existing registration tools, and supporting integration into broader Python-based geospatial workflows.

In this project, students will first study the theoretical foundations and implementation details of the Piecewise-ICP algorithm and its C++ code. They will then develop an integration strategy that best fits the software infrastructure of *py4dgeo* (C++ core with Python bindings) and finally translate the standalone C++ implementation into the registration module of *py4dgeo*, following the library's coding style and design principles. Existing data structures, workflows, library's functions and APIs in *py4dgeo* shall be used during integration. Finally, they will perform systematic evaluation of registration performance on representative datasets provided by the supervisors.

Relationship between Project and Application Area

This IDP sits at the intersection of software engineering, computer science, and geospatial data analysis. Accurate registration of 4D point clouds is fundamental for reliable change analysis and deformation monitoring across domains including engineering geodesy, remote sensing, and environmental science. Integrating a research-grade registration algorithm into a widely used library directly supports advanced workflows in these application areas for a broad community in geoscientific and environmental monitoring applications.

Milestones

M1: Review literature on 4D point cloud registration and understand key concepts.

M2: Study and document the existing Piecewise-ICP C++ implementation.

M3: Design and implement integration into *py4dgeo*.

M4: Test functionality and resolve build/runtime issues.

M5: Evaluate performance and accuracy on benchmark data.

M6: Prepare documentation and final project report.

Timetable

The total duration of the project is 12 months (recommended to span two semesters), but a shorter duration is also possible depending on the time capacity of the student:

- Months 1–2: Algorithm study and codebase familiarization.
- Months 3–9: Integration into py4dgeo (design, implementation, iterative testing).
- Months 10–12: Evaluation, benchmarking, and documentation.

Regular meetings with the supervisor are expected throughout the project.

Requirements

- Strong programming ability in C++ and Python.
- Comfortable reading and understanding existing codebases.
- Proficient use of GitHub and principles of code versioning, documentation, etc.
- Self-directed work style and ability to regularly report progress.
- Interest in point cloud processing and open-source software.

Contact:

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References:

1. Yang, Y. and Holst, C., 2025. Piecewise-ICP: Efficient and robust registration for 4D point clouds in permanent laser scanning. *ISPRS Journal of Photogrammetry and Remote Sensing*, *227*, pp.481-500.
2. Piecewise-ICP: Efficient and robust registration for 4D point clouds. https://github.com/yihui4d/Piecewise-ICP
3. py4dgeo: Library for change analysis in 4D point clouds. https://github.com/3dgeo-heidelberg/py4dgeo