# Improving Terrestrial Laser Scanning Accuracy: Modeling Distance Uncertainties with Machine Learning Techniques

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## SUMMARY

Laser scanning is a widely used method for obtaining 3D point clouds, particularly for applications that require high accuracy such as deformation analysis. To achieve this, uncertainties associated with terrestrial laser scanners (TLS) must be modeled as accurately as possible. Our research focuses on the influences that affect TLS distance measurement, in a controlled environment with stable temperature and air pressure. We used a laser tracker (Leica ATR960) and a handheld laser scanner (Leica LAS XL) to record objects with high accuracy, which were used as reference points for TLS (Z+F Imager 5016) scans.

A total of 50 scans were performed from various positions, providing a wide range of distances and incidence angles for each object. We developed a cloud-to-mesh comparison to ensure that the residuals are reflected in the distance measurement. To model and predict distance uncertainties as a function of various influences, we applied different machine learning (ML) approaches to the resulting dataset, including outlier removal and feature engineering. The machine learning models were trained on a large dataset consisting of more than 100,000,000 data points, ensuring robustness and generalizability of the results.

Our validation method involved randomly splitting the dataset into training and validation subsets, with the latter being completely independent from the former. Conventional ML approaches such as multiple linear regression were found to be inferior to neural networks and decision tree-based models. Moreover, we investigated the possibility of stacking the investigated ML models by combining them. Stacking refers to the process of using multiple models to make a prediction, rather than relying on a single model. By combining the strengths of different ML models, we expected to see an improvement in the accuracy of the predictions. Our results showed that stacking did in fact improve the accuracy of the predictions, indicating that it is a promising approach for

future studies.

The results of the study suggest that the accuracy of TLS measurements can be improved by up to 75% using the ML models developed in the study. The study also demonstrates the importance of properly modeling and accounting for distance uncertainties in TLS measurements, particularly when high accuracy is required. Furthermore, we found that the distance measurement can be calibrated using the ML-models, resulting in an improvement of the TLS-measurement. The ML models developed in the study are expected to have wide-ranging applications in various fields such as civil engineering, surveying, and architecture.