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TU Graz

Application of Data Science and Artificial Intelligence to Geoengineering

Ongoing Research on Data Science/Machine Learning/AI Application at the Institute of Rock Mechanics and Tunnelling

Analysis and Interpretation of TBM Data

Tunnel Boring Machines (TBMs) are well established in tunnel construction, with monitoring and predicting TBM performance being crucial for project timelines and risk mitigation. Machine Learning (ML), offers promising avenues for analysing TBM operational data. One of these avenues is depicted by the concept of generative modelling that can generate new data samples resembling given datasets[1]. In construction engineering, the application of generative models like Generative Adversarial Networks (GANs) and Variational Autoencoders (VAEs) gained momentum.

1. GANs for synthetic TBM data generation

ML models are extremely data hungry, while geotechnical datasets are limited in quantity and fall short in fulfilling all requirements for certain empirical, constitutive, or analytical geotechnical tasks. Additionally, confidentiality issue limits the use or real datasets. Synthetically generated data can provide a remedy in situations where the use of real data is restricted. By applying a tailored GAN trained on real observations it is possible to generate realistic synthetic TBM operational data. Data generated by GANs has similar properties to the original data but consists of unique patterns without the possibility of tracing the technical content of the original data[2]. Figure 1 shows GAN's input (first row) and pairs of the original vs GANs generated data in next rows. The GANs produced data exhibits same patterns and distribution as the original data, thus can be used in analysis as real data.

Seventeen partners from Italy, Germany, Romania and Austria are working together in a transdisciplinary consortium (see figure below). Existing underground structures are being studied at selected pilot sites, in collaboration with the following universities: *Politecnico di Torino (Italy), Technische Universität Darmstadt (Germany), Technische Universität Graz (Austria), and Technische Universität Cluj-Napoca (Romania).* The different climatic, geological, and infrastructural conditions at each site allow for a robust analysis of the transferability of the developed solutions to other European cities and regions. On the Austrian side, the project partners include Wiener Linien, the Innsbrucker Kommunalbetriebe (IKB), and the City of Bregenz.

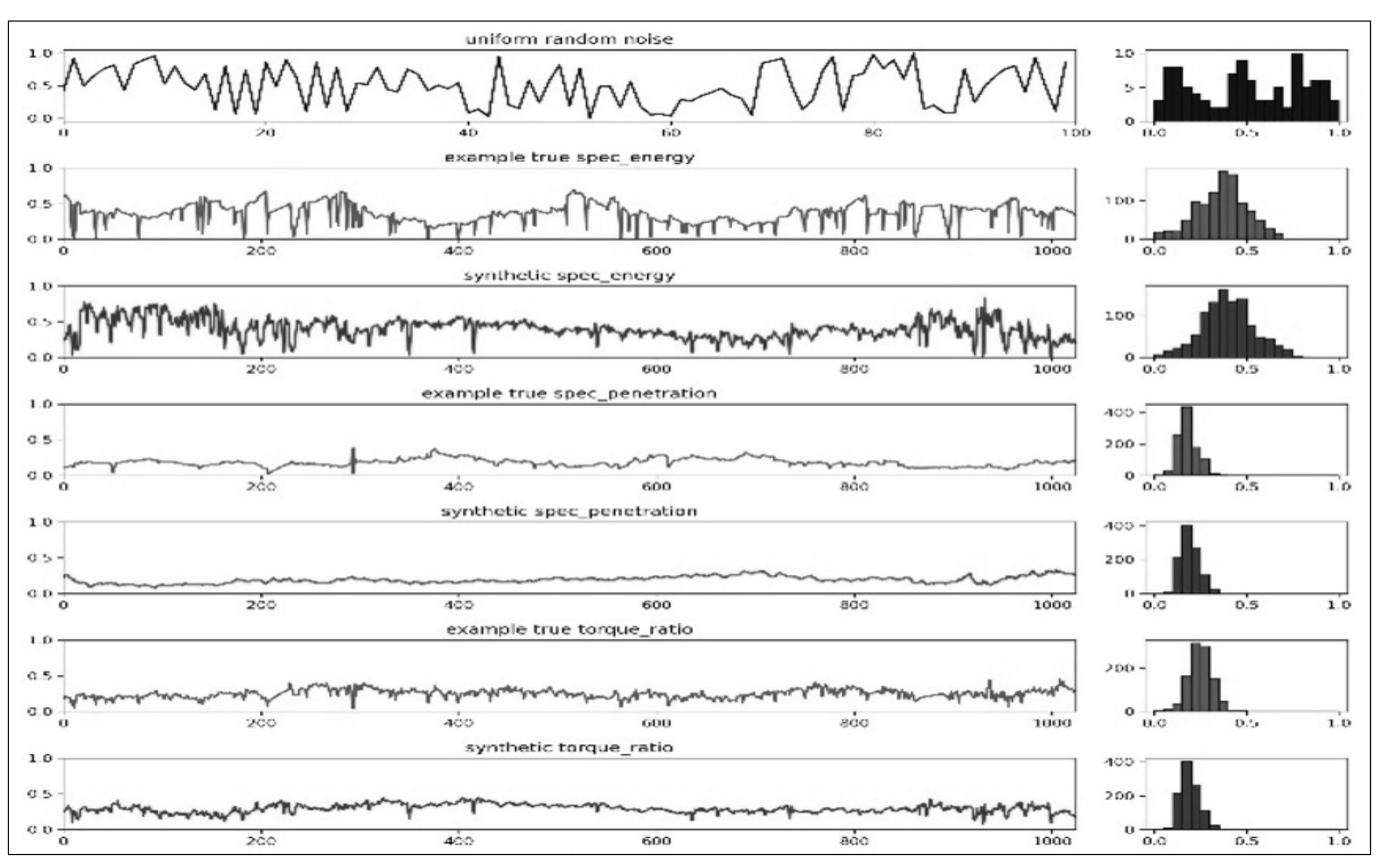

Fig 1: Results of the GAN for the generation of synthetic TBM data

2. VAEs for anomaly detection in TBM data

For anomaly detection in TBM operational data, VAE - an ML model consisting of an encoder and a decoder networks - can be used.[3] VAE encoder performs a dimensionality reduction to a latent space, from which the decoder learns to reconstruct the input with minimum error. If VAE, trained on clean data, exposed to anomalous data, the reconstruction error will increase. By setting a threshold for error the anomaly can be detected. In dataset, used for VAE training[4], key sections were selected for model testing, and remaining data was used for training. Sections classified as fault zones removed from the training. Adjusted boxplot for skewed distributions used to set a threshold.

Figures 2a and 2b show the reconstruction errors on the three test sections in combination with the skewness adjusted threshold.

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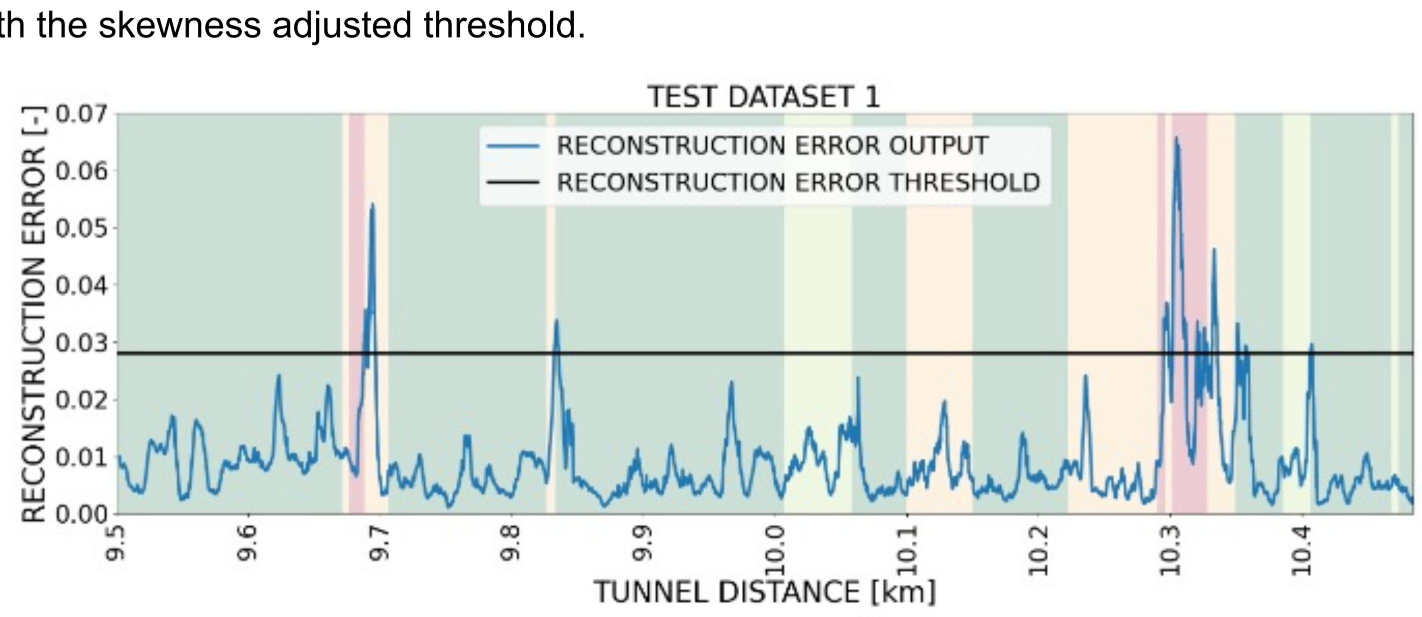

Fig. 2a: Anomaly detection with VAE: test dataset #1 with two fault zones.
Background colours: GI1 - dark green, GI2 - light green, GI3 - orange, GI4 - red.

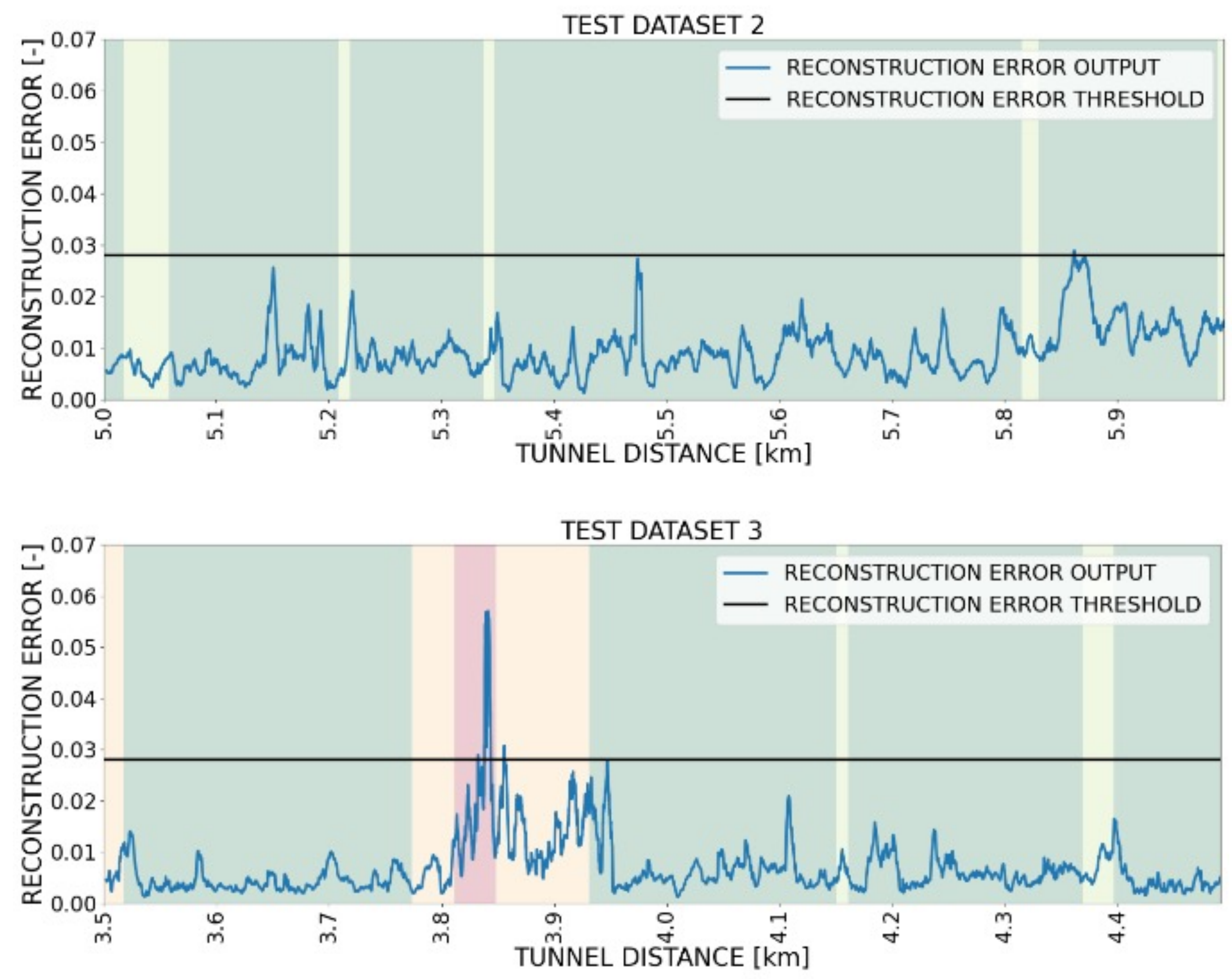

Fig. 2b: Anomaly detection with VAE: test datasets #2 with no fault zone and test datasets #3 with a mix of good and bad rock mass conditions.
Background colours: GI1 - dark green, GI2 - light green, GI3 - orange, GI4 - red.

The parts, where the reconstruction error's threshold is exceeded correlate with geologically relevant fault zones classified as GI 4.

Tunnelling: Sensor Data Analysis for Process Optimization

Measurement While Drilling (MWD) data provides insights into the tunnelling process, enabling identification of geological risks and optimization of operational performance. Applications of ensemble of machine learning models demonstrate considerable potential in extracting meaningful patterns from complex sensor data.

1. Predicting over-excavation in drill-and-blast tunnelling using MWD data

Drill-and-blast tunnelling operations encounter variations in excavation geometry, resulting in additional cost and reduced structural stability. ML model can find correlation between MWD data and over-excavation. Accuracy of a single Random Forest Regression (RFR) model for predicting an over-excavation was compared against cascade ML model comprised of RFR and Autoencoder models. The cascade model combines several predictive steps aiming to enhance accuracy by using a hierarchical learning structures.

Figure 3 shows the predicted over- and under-excavation length at the tunnel face for contour boreholes. The actual measured values are shown alongside predictions. The cascade models matches original measurements closer and outperform the single model. The deep cascade model shows higher prediction accuracy in challenging regions.

Factors, influencing the model prediction accuracy, also include input feature selection and data quality.

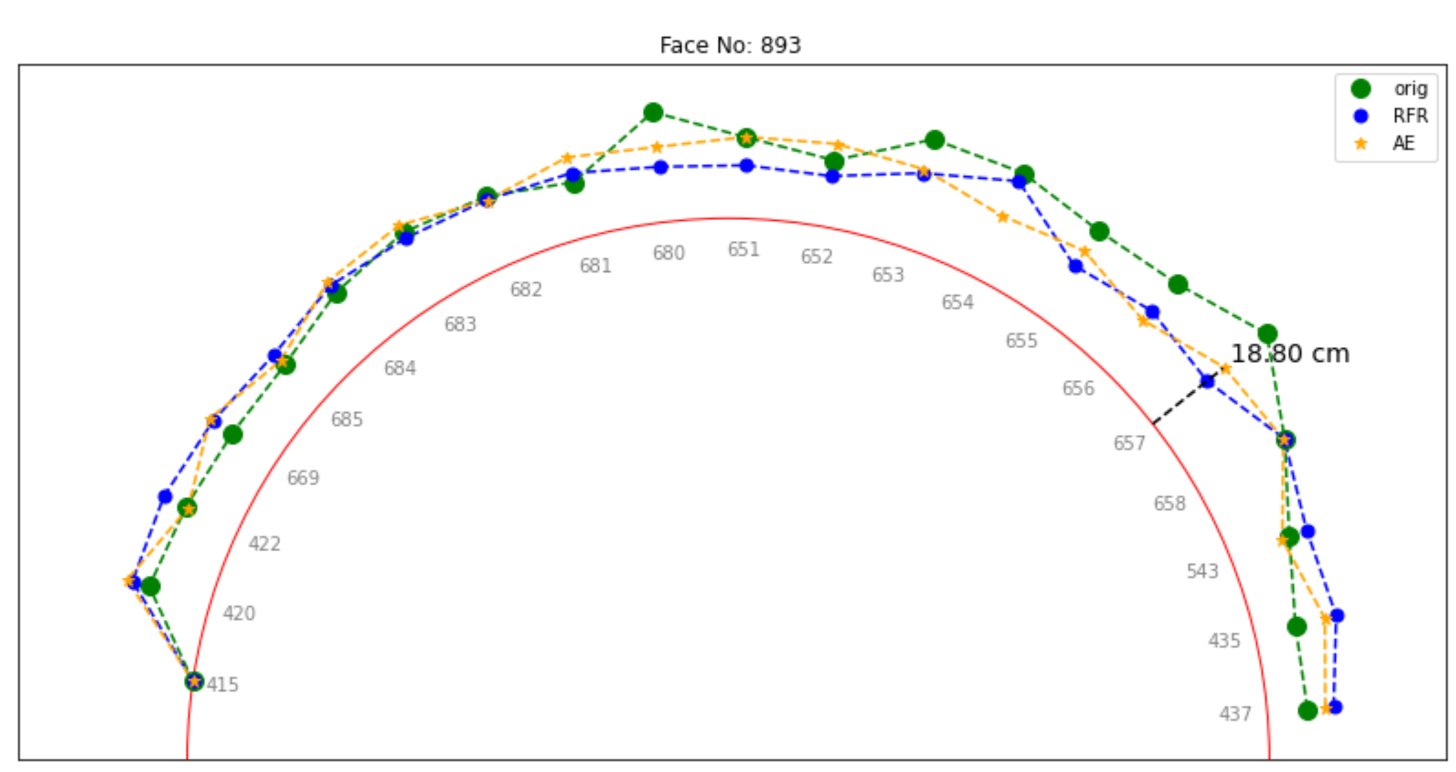

Fig. 3: Predicted over-excavation length for boreholes: actual value (green) vs values predicted by single RFR (blue) and ensemble models (yellow).

References

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