Editorial

Big data and machine learning in geoscience and geoengineering: Introduction

In recent years, we have entered the so-called Fourth Paradigm with the regular production of huge amount of observational data. Big data is often characterized by the three 'V's: Volume of data, Variety and Velocity. The concept of big data can potentially address some existing issues in areas of geoscience and geoengineering. Large-scale, comprehensive, multidirectional and multifield geotechnical monitoring is becoming a reality in the very near future. The in-depth analysis capabilities such as correction analysis, casual analysis, and decision support can become the core works for monitoring projects in the era of big data. Furthermore, site monitoring may be promoted to similar or even more important roles than the experimentation, theoretical analysis and numerical simulation. On the other hand, the nature of scientific geoscience and geoengineering data, and the processes used to retrieve and analyze them, may differ substantially from those in other fields. It is therefore timely that geoscience and geoengineering professionals pay increased attention to big data research, create the environment to utilize data to add value to our fields and promote collaboration with data analysts from other disciplines.

Machine learning (ML) is the scientific study of algorithms and statistical models that allows computers to learn from existing data, in order to improve their performance on specific tasks without being explicitly programmed. In recent years, the application of ML in a wide range of industries has grown rapidly. ML can be very useful in solving problems where deterministic solutions are not available or are excessively expensive in terms of computational cost but for which there are ample observations and data available. Due to the nature of geological materials, geoscience and geo-engineering face more significant uncertainties than other fields of civil and mechanical engineering. In addition, there is considerable monitoring and site investigation data in geotechnical engineering which can be taken advantage of by using data analytic methods. Therefore, ML can be a suitable and effective alternative to solve geotechnical engineering problems. The combination of big data and machine learning may create unexpected solutions to the conventional geotechnical problems.

Accordingly, in this Thematic Section of *Geoscience Frontiers*, we assemble 14 invited papers which provide insights into the latest developments and challenges in applying big data and machine learning to geoscience and geoengineering.

Predicting the performance of a tunneling boring machine is of vital importance to avoid any possible accidents during tunneling boring. Li et al. (2020) develop a long short-term memory neural network model to predict the TBM performances including the total thrust and the cutterhead torque in a real-time manner, based on the big data obtained from the 72.1 km long tunnel in the Yin-Song diversion project in China. The study also indicated that the ommision of a key parameter can significantly reduce the accuracy of the model, while the supplement of a parameter that highly-correlated with the missing one can improve the prediction.

Successful application of classic geostatistical models requires prior characterization of spatial auto-correlation structures, which poses a great challenge for unexperienced engineers, particularly when only limited measurements are available. Shi and Wang (2020) propose an ensemble radial basis function network (RBFN) method that not only to allows geotechnical anisotropy to be properly incorporated, but also quantifies uncertainty in spatial interpolation. The proposed method is illustrated using numerical examples of cone penetration test (CPT) data. Furthermore, a comparative study is performed to benchmark the proposed RBFN with two other non-parametric data-driven approaches. The results reveal that the proposed ensemble RBFN provides better estimation of spatial patterns and associated prediction uncertainty at unsampled locations when a reasonable amount of data is available as input.

Making use of a large volume of landslide data compiled in Hong Kong over the past few decades, Wang et al. (2020) introduce a novel machine-learning and deep-learning method to identify natural terrain landslides. Different types of landslide-related data were compiled, including topographic data, geological data and rainfall-related data. Three integrated geodatabases were also established, represented by Recent Landslide Database, Relict Landslide Database and Joint Landslide Database (JLD). Promising results were achieved by the machine learning and deep learning methods, in particular the convolutional neural networks (CNN) method, owing to its strengths in feature extraction and multi-layer two-dimensional data processing, which are important for landslide identification problems.

Zhang et al. (2020c) formulate surrogate models for prediction of braced excavation response, via ensemble learning methods including the extreme Gradient Boost and Random Forest Regression methods. The surrogate model takes into account parameters such as excavation width, wall stiffness, wall penetration, and soil properties represented by ratio of passive to active strength and stiffness to strength ratios, etc. The surrogate model is trained by finite element models adopting the elastoplastic constitutive model NGI-ADP, leading to an efficient alternative tool for prediction of horizontal wall displacements. The proposed method also allows sensitivity analyses to be performed efficiently, where the soil properties show more significant influences on the excavation response than wall width, wall penetration depth and excavation width.

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In the paper by Ray et al. (2020), the reliability analysis of shallow foundations on a clayey soil is assessed based on settlement criteria using three soft computing techniques: Minimax Probability Machine Regression (MPMR), Particle Swarm Optimisation-Artificial Neural Network (PSO-ANN) and Particle Swarm Optimisation-Adaptive Neuro-Fuzzy Inference System (PSO-ANFIS). The MPMR, PSO-ANN and PSO-ANFIS models were compared on the basis of various fitness parameters. All the three models were found to give good predictions of shallow foundation settlement on a clayey soil.

Precipitation-induced shallow landslides are common geological hazards in mountainous regions. In the paper by Liu et al. (2020), three machine learning algorithms, the Random Forest (RF), Boasted Regression Tree (BRT) and MultiLayer Perceptron neural network (MLP) are applied to model shallow landslides in Norway. A total of 8 landslide conditioning factors and 3 time-dependent triggering factors such as the slope angle, profile curvature and flow direction were selected as inputs. The results indicated that all three algorithms were capable of predicting the spatial distribution of landslides over a large area.

An important aspect in the geological risk assessment of tunnel face stability is the interpretation of the rock structure. The paper by Chen et al. (2020) present a framework for automated classification of rock mass structure based on the geological images of the tunnel face using CNN. Experimental results revealed that the proposed method is optimal and efficient for automated classification of rock structure using the geological images of the tunnel face.

The paper by Pan et al. (2020) propose a probabilistic analysis approach to assess seismic slope performance using a new metamodel that makes use of relevance vector machine and polynomial chaos expansion methodologies. In this work, a novel method was proposed to incorporate uncertainties associated with earthquake ground motions and soil shear strength.

Based on a large database of 4315 observations for 479 different anchors from 7 different projects, Shen et al. (2020) present a novel hybrid data-driven machine learning FastICA-MARS (Independent Component Analysis-multivariate adaptive regression splines) model for prediction of the load-displacement relationship of grouted anchors in weathered granite.

With sparse multivariate data obtained from geotechnical site investigation, it is impossible to identify outliers with certainty due to the distortion of statistics of geotechnical parameters caused by outliers and their associated statistical uncertainty resulted from data sparsity. Zheng et al. (2020) propose an approach quantifying the outlying probability of each data instance based on Mahalanobis distance and determining outliers as those data instances with outlying probabilities greater than 0.5. The proposed method tackled the distortion issue of statistics estimated from the dataset with outliers by a re-sampling technique and accounts, rationally, for the statistical uncertainty by Bayesian machine learning.

Compression index (C_c) is an essential parameter in geotechnical serviceability design. In the paper by Zhang et al. (2020a), a database with 311 clay cases with knowledge of C_c and three index properties was collected to train five commonly used machine learning (ML) models, including back-propagation neural network (BPNN), extreme learning machine (ELM), support vector machine (SVM), random forest (RF), and evolutionary polynomial regression (EPR). The results indicated that ML models outperform empirical prediction formulations and that RF performs the best in terms of prediction accuracy for C_c, followed by BPNN, ELM, EPR and SVM.

Knowledge of pore-water pressure (PWP) variation is fundamental for slope stability. To explore the applicability and advantages of recurrent neural networks (RNNs) on PWP prediction, Wei et al. (2020) proposed three types of RNNs, i.e., standard RNN, long short-term memory (LSTM) and gated recurrent unit (GRU) to compare the predictive performances with a traditional static artificial neural network. The results indicated that the GRU and LSTM models produced the most precise and robust prediction among the four models.

Zhang et al. (2020b) address the estimation of the undrained shear strength (USS) for soft sensitive clays. Based on the soil data sets from the TC304 database, this study constructed multivariate regression models to predict USS based on preconsolidation stress (PS), vertical effective stress (VES), liquid limit (LL), plastic limit (PL), and natural water content (W). Two relatively recent machine learning (ML) methods, XGBoost & Random Forest (RF), were investigated. These two methods were special in the way that they did not make predictions based on a single model but based on multiple models to combine their prediction powers. It was found that these two methods outperform some other ML approaches. Compared with RF, XGBoost further provided feature importance ranks, which can enhance the interpretability of model.

Traditional approaches to develop 3D geological models employ a mix of quantitative and qualitative scientific techniques, which do not fully provide quantification of uncertainty in the constructed models and fail to optimally weight geological field observations against constraints from geophysical data. Olierook et al. (2020) develop a methodology to fuse lithostratigraphic field observations with aeromagnetic and gravity data to build a 3D model in a small region of the Gascoyne Province, Western Australia. The results revealed that surface geological observations fused with geophysical survey data can yield reasonable 3D geological models with narrow uncertainty regions at the surface and shallow subsurface.

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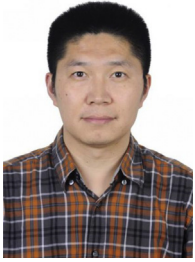
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