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Monitor-While-Drilling-based estimation of rock mass rating with computational intelligence: The case of tunnel excavation front☆

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ABSTRACT

The construction of tunnels has serious geomechanical uncertainties involving matters of both safety and budget. Nowadays, modern machinery gathers very useful information about the drilling process: the so-called Monitor While Drilling (MWD) data. So, one challenge is to provide support for the tunnel construction based on this *on-site* data.

Here, an MWD based methodology to support tunnel construction is introduced: a Rock Mass Rating (RMR) estimation is provided by an MWD rocky based characterization of the excavation front and expert knowledge.

Well-known machine learning (ML) and computational intelligence (CI) techniques are used. In addition, a collectible and *"interpretable"* base of knowledge is obtained, linking MWD characterized excavation fronts and RMR.

The results from a real tunnel case show a good and serviceable performance: the accuracy of the RMR estimations is high, $Error_{test}$≅3%, using a generated knowledge base of 15 fuzzy rules, 3 linguistic variables and 3 linguistic terms.

This proposal is, however, is open to new algorithms to reinforce its performance.

1. Introduction

Nowadays, most operations and tasks in modern industrial activities are monitorized and, in general, the data and performance are logged for different reasons, such as maintenance and safety. Construction, mining, and the tunnelling industry involve activities, equipment and technologies that can match the current trend concerning the capture and logging of data to take advantage of the embedded information for a better performance and improvement of the processes. So, the challenge is how to evaluate all the available data, information and expert knowledge to improve these processes from all points of view: safety, management, quality, etc. which can all lead, of course, to a more profitable business.

The proposal of this work is focused on the tunnelling industry, to be precise the specific case of railway tunnels, but this can be applied to other similar cases such as road tunnels; underground mining and utilities. Tunnel excavation has used two main methods: *Drill & Blast* and *Tunnel Boring Machine (TBM)* [1]. The first is the most popular excavation method for conventional tunnelling, in particular for railtrack tunnels. In any case, both methodologies involve the use of computer and control based machinery to capture and log data of different natures concerning the process: this is the so-called *Monitor or Measurement While Drilling* (MWD) data [2].

Conventional tunnels can be defined as the construction of underground openings of any shape by a cyclic construction process [1]. This type of tunnels are usually made using the *Drill & Blast* excavation method. Here, the *"jumbos"* are the machinery for face drilling (see Fig. 1): drilling several holes in the rock wall face area, known as the excavation front, after which these holes are filled with explosives. The explosion causes the collapse of the rock and the lengthening of the tunnel. Then, a new excavation front appears ahead, and this cycle is repeated.

The result of each of these steps is an excavation front, and its performance is based on such measurements as the rock mass stability, or other tunnel design indexes that may be available. Here, the RMR system is a well-known geomechanical classification system for rocks [3] which is very popular for tunnel construction and is used, in its several versions, as a design tool to determine a tunnel support type. It is a vital element for this kind of business.

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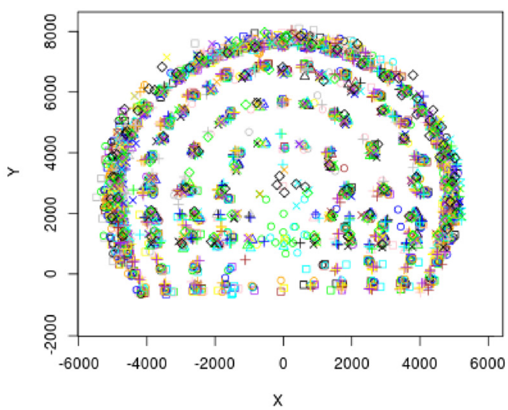
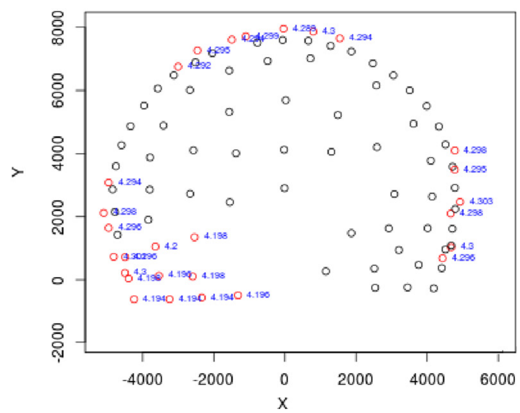
(a) Jumbo and excavation front

(b) Jumbo drilling holes on the excavation front



(c) Overlapped patterns of drillings of the excavation fronts



(d) Pattern of drilling holes for an excavation front

Fig. 1. Drill & Blast excavation method.

All of this is carried out by the technicians in charge of these operations. In this context, some extra support for the conditioning of the excavation front would be very interesting in order to deal with the uncertainties associated with the problem and its implications: safety, management, budget, etc. So far, one of the most usual MWD based applications has been the guiding, positioning and conditioning of the machines, but other valuable and serviceable support could be possible. How this data can be used to give support on-site to improve the efficiency of the tunnelling process is still an open and debatable issue.

Here, the proposed methodology gives *"on-site"* support to the usual work flow of this below-surface construction based on the MWD data recorded in real time and ML & CI techniques: *a priori* RMR estimation of the next excavation front to be discovered is provided using an unsupervised MWD based characterization of the drilling front and the available expert knowledge. This characterization is supported by a clustering of MWD based drillings into a few rocky categories. In order to deal with this latter task, an unsupervised selection of the most relevant MWD variables is made. Both previous steps also address the almost unavoidable issue of the reduction in complexity, or dimensionality, regarding the information managed so that it can be used by ML& CI techniques and the users. This dimensionality challenge is critical: every excavation front is characterized, and summarized, to estimate the RMR using its own hole drillings, which, due to the high number of them for each front, are summarized by a few MWD drilling based rocky clusters. On the other hand, all this is supported by MWD data containing a high number of variables, so an analysis and selection of these data variables is compulsory.

All these previous proposal steps are implemented by several different ML & CI algorithms for each one, in order to achieve a better performance. This means carrying out user-tuned decision making at each stage to get the stage output. Which is also made by fuzzy approaches for a better robustness and, as well as using linguistic terms during this decision making. Finally, the RMR estimation is made using linguistic and scatter genetic fuzzy rule based systems (FRBS). During this final task, the expert knowledge is supplemented by the unsupervised MWD knowledge from the previous steps. Additionally, this last stage allows a collectible knowledge base to be obtained through by fuzzy rules linking MWD rocky based excavation fronts with RMR estimations.

This entire methodology implies that data, expert knowledge and information must be available in sufficient quantity and quality to be implemented using these ML & CI approaches, so as to be able to reach a sufficiently good performance for the desired goals.

The rest of this paper is organized as follows: in Section 2, a brief review of related works is done. Section 3 summarizes the computational intelligence for this proposal. The proposed methodology is detailed in Section 4. Section 5 explains and discusses the experimental work and its results. Finally, the conclusions of this work are set out in Section 6.

2. Related works

Tunnelling, and all works involving geological mechanics, have a high level of uncertainties concerning the geomechanics and their evaluation. Some popular views to address these uncertainties are based on soft computing, artificial intelligence, computational intelligence, or machine learning, etc. All these well-known approaches can deal with this challenge: fuzzy logic permits fuzzy information to be dealt with; artificial neural networks allow us to learn from collected data; a genetic algorithm is able to optimize parameters, while fuzzy rule based systems describe the knowledge known or learnt by "if-then"