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Long-term prediction model of rockburst in underground openings using heuristic algorithms and support vector machines ☆

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ABSTRACT

Rockburst possibility prediction is an important activity in many underground openings design and construction as well as mining production. Due to the complex features of rockburst hazard assessment systems, such as multivariables, strong coupling and strong interference, this study employs support vector machines (SVMs) for the determination of classification of long-term rockburst for underground openings. SVMs is firmly based on the theory of statistical learning algorithms, uses classification technique by introducing radial basis function (RBF) kernel function. The inputs of models are buried depth H, rocks' maximum tangential stress σ_θ, rocks' uniaxial compressive strength σ_c, rocks' uniaxial tensile strength σ_t, stress coefficient σ_θ/σ_c, rock brittleness coefficient σ_c/σ_t and elastic energy index W_{et}. In order to improve predictive accuracy and generalization ability, the heuristic algorithms of genetic algorithm (GA) and particle swarm optimization algorithm (PSO) are adopted to automatically determine the optimal hyper-parameters for SVMs. The performance of hybrid models (GA + SVMs = GA-SVMs) and (PSO + SVMs = PSO-SVMs) have been compared with the grid search method of support vector machines (GSM-SVMs) model and the experimental values. It also gives variance of predicted data. A rockburst dataset, which consists of 132 samples, was employed to evaluate the current method for predicting rockburst grade, and the good results of overall success rate were obtained. The results indicated that the heuristic algorithms of GA and PSO can speed up SVMs parameter optimization search, the proposed method is robust model and might hold a high potential to become a useful tool in rockburst prediction research.

1. Introduction

A rockburst (Ortlepp, 1997) is a sudden and violent expulsion of rock from the surrounding rock mass. In China, with the increase of mining depth and conditions become more complex, as well as more and more large-scale underground projects are under construction in the deep zone of intense tectonic activities, such as water conservancy and hydropower, transportation, defense and basic physics experiments. These projects provide an important opportunity for the progress of geo-engineering. However, serious challenges also exist because of the complicated geological conditions and potential geological hazards (especially high-strength rockburst) during tunnel construction, causing great losses of life and property. Only from 2001 to 2007, China has deep engineering metal mine disaster as a result of accidents amounted to more than 13,000, the death people exceed 16,000 and resulted in substantial valuable resources can not mine; In recent years, in the field of water and traffic engineering, every year due to disaster-induced deep engineering projects have up to thousands of accidents, the number of casualties have nearly a thousand people, many engineering schedule delays more than six months or even 1 year, tens of millions or even billions of machinery and equipment obsolescence, huge economic losses (see http://www.whrsm.ac.cn/zt/emdct973/xmgk/). And with the increase of mining depth, in situ stress shows a linear or nonlinear increasing tendency, ground temperature increases, the osmotic pressure of groundwater will be further raised, rock become hard and brittle, deteriorating geological conditions, the risk of rock burst will be

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further increased. Therefore, there is a need for the development of suitable computational methods for the prediction and control of rockbursts particularly for a safe and economical underground excavation for construction or mining in burst-prone ground (Sun and Wang, 2000; Board and Fairhurst, 1983).

For this case, since the first record of rockburst appeared at a tin mine in Britain in 1738, numerous related research works, concerning about the mechanism, characteristics or type, formation condition and disaster control of rock burst have been conducted by many researchers (Deng et al., 2011; Ortlepp and Stacey, 1994). For example, Cook et al. (1966) provided a theoretical method of predicting rockburst based on the opinion that violent damage of rock occurs when an excess of energy becomes available during the postpeak deformation stage. Casten and Fajklewicz (1993) analyzed the rock-burst risk in the case of the Dickebank seam coal mines (Casten and Fajklewicz, 1993); Shivakumar et al. (1996) summarized the spatial distribution characteristics of rockburst at the Kolar Gold Mines. In order to understand the rockburst mechanism, Zubelewicz and Mroz (1983) simulated the dynamic instability of rock burst; Linkov (1996) studied the rockburst in an unstable rock mass and Jiang et al. (2010) presented the local energy release rate (LERR) to simulate the conditions causing rockburst. Kaiser et al. (1996) developed a handbook to guide rockburst support based on energy release approaches. As CRRP (1996) pointed out, rock burst is a violent failure phenomenon associated with (not caused by) a seismic event, which can be classified into three types: fault-slip burst, strainburst and conbination burst. Currently, based on the time and scope of rockburst prediction, the methods for predicting rockburst hazard degrees can be classified into two categories: long-term forecasts and short-term small-scale regional forecasts (Peng et al., 2010). Short-term prediction of rock burst is measured by means of some underground rock scene or the prediction of rock burst phenomena, determining the exact location of rock burst occurrence and the specific time, the current short-term forecast model is acquired some useful eigenvalue by the appropriate field measurement method, then established a mathematical model to analyze the amount of features, and then prediction the rockburst. Several on-site testing methods commonly used are: the photoelastic method, method of drilling bits, the resistance method, seismic parameters and rock mechanics methods, the microseismic monitoring system method, microgravity method, geophysical prospecting covers seismic, electromagnetic, geological radar and acoustic emission method (Jha and Chouhan, 1994; Mansurov, 2001; Frid, 1997; Alcott et al., 1998; Dowding and Andersson 1986). For example, Brady and Leighton recorded a seismicity phenomenon before a moderate rock burst (Brady and Leighton, 1977) while Tang et al. introduced the feasibility in principle of monitoring and prediction of rockbursts using microseismic monitoring techniques during tunnel construction of Jinping II hydropower station (Tang et al., 2010). Tang and Xia presented a seismological method for prediction of areal rockbursts in deep mine on the basis of the seismic source mechanism and unstable failure theory (Tang and Xia, 2010). Long-term prediction of rockburst refers to a preliminary prediction of rockburst trend and qualitative judgments in project regions during initial project, currently long-term prediction of rockburst is mainly used by:

- Theoretical prediction method from various perspectives (Tang et al., 2010; Shi et al., 2010), such as the strength theory, the rigidity theory, the burst liability theory, the energy theory, the instability theory, the catastrophe theory, the bifurcation theory, the theory of dissipative structures and the theory of chaos have been proposed to study of deformation localization and stability of the mechanical system in rock.
- Nonlinear science method, such as Pan et al. (2006) proposed a catastrophe theory to analysis of circular tunnel rockburst, Xie and Pariseau (1993) investigated the rockburst mechanism and prediction methods based on fractal geometry, and bifurcation and chaos theory, etc.
- Criterion values method (Tang et al., 2010, Chen et al., 2009), such as the energy criterion method, impact orientation criterion method, depth prediction critical, and to a variety of rock burst of factors considered in comprehensive evaluation. Lately, Zhang and Fu (2008) tried to establish five factors comprehensive criterion for strain-mode rockburst and its classification.
- Prediction rockburst method based on the priori knowledge, which can be extracted features samples and accessed knowledge from the case base, achieving to predict future requirements according to prior knowledge (Peng et al., 2010). Therefore, many theoretical and numerical models and technical means were developed to analyze the occurrence of rockbursts, it will have a better scientific and practical results to predict the future of rockburst using examples which has already the occurrence of rock burst in rock engineering.

To this end, Feng and Wang (1994) described a novel approach to predict probable rock bursts in underground openings based on learning and adaptive recognition of neural networks. Subsequently developed a new artificial intelligence methods and theories have been successfully introduced into the prediction of rock burst. To achieve good results, Wang et al. (1998) proposed a fuzzy comprehensive evaluation method for rockburst prediction based on fuzzy mathematics. Recently, in terms of rockburst prediction, Chen et al. (2009) and Zhang et al. (2010) proposed an extenics evaluation method for rockburst prediction; Zhao (2005) presented a rockburst classification method based on support vector machines; Gong and Li (2007) applied the discriminant analysis method to rockburst prediction. Shi et al. (2010) established an unascertained measurement classifying model to predict the possibility and classification of rockburst. A efficacy coefficient method for predicting the classification of rockburst was proposed by Wang et al. (2010). A fisher discriminant analysis (FDA) model for the prediction of classification of rockburst in deep-buried long tunnel was established by J. Zhou et al. (2010). Yang et al. (2010) presented a model of predicting the possibility and classification of rock burst based on the combination of rough set and fuzzy set theory. These studies offered new ideas and approaches for rockburst prediction. As an important means, numerical methods and laboratory rock burst test have been adopted by many researchers gradually in recent years. A finite element model is proposed by Sharan (2004) to predict the potential occurrence of rockburst in underground openings. Single-face dynamic unloading tests under true-triaxial condition were carried out by He et al. (2010) for Paleozonic marine sedimentation limestone samples produced by blocks cored from 1140 m depth in Jiahe coal mine of China. Zhu et al. (2010) proposed a numerical model to simulate on rockburst of underground opening triggered by dynamic disturbance using the rock failure process analysis (RFPA). However, due to the complexity of rock mass and the variety of influencing factors, it is very difficult to predict space–time distribution of rockburst exactly. The results of various prediction methods should be analyzed comprehensively. Moreover, each method has its own advantages and disadvantages, and understanding, predicting and controlling the rockbursts still pose a considerable challenge for underground engineering.

The Support vector machines (SVMs) is an efficient machine learning (ML) technique derived from statistical learning theory by Vapnik (1995), and has demonstrated its good performance in classification, regression, and time series forecasting and predition (Zhao and Yin, 2009; Kovačević et al., 2010; Khandelwal, 2010; Jiang et al., 2011) in geotechnical practice and mining science,