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# Discriminant models of blasts and seismic events in mine seismology

Long-Jun Dong [a,b,*], Johan Wesseloo [b], Yves Potvin [b], Xi-Bing Li [a]

[a] School of Resources and Safety Engineering, Central South University, Changsha, China
[b] Australian Centre for Geomechanics, University of Western Australia, Crawley, WA, Australia

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## 1. Introduction

Microseismic monitoring gives mining engineers information about the local state and stress conditions of the rock mass. By receiving real-time information on the location of seismic events, engineers and operators can identify where these events are occurring relative to mine openings and active workplaces and visualize how these conditions are changing over time.[1–6] By understanding how the rock mass is behaving, operators can infer which mining activities are affecting the overall structure, and by how much.

A challenge in microseismic monitoring is to correctly identify seismic events from blasts, as blasts contaminating the database have an adverse effect on any analysis. Presence of blasts in the event catalogue may result in the wrong interpretation, e. g. the fictitious region of high seismic stress. The currently widely used method, the manually discriminant method, discriminates blasts and seismic events according to the blast time of day, repetition of the waveforms, etc. This method's disadvantages are: (1) there is a delay for classified results; (2) operator sensitivity; (3) blasting may sometimes occur outside of general blasting times and large seismic events occur during blast times; and (4) the professional knowledge and practical experience are needed to analyse large amounts of data. Mine seismicity databases often contain periods with different levels of blast contamination with high levels of that often correlate with personnel shortages and personnel changes.

A similar problem of classifying seismic events exists in crustal seismology.[7] Identification and classification of different seismic events with similar characteristics in a region of interest is one of the most important subjects in seismic hazard studies. Techniques using various models to discriminate earthquakes and man-made explosions such as quarry blasts, nuclear tests, underwater explosions etc., have been derived worldwide, each one appropriate to a particular region. The widely used methods for discriminators are summarized as follows: (1) the waveform spectrum analysis[8–11]; (2) multivariate statistical methods, such as the multivariate maximum-likelihood Gaussian classifier technique,[12,13] linear discriminant method,[13–15] the ridge discrimination techniques[16]; and (3) soft computing techniques such as artificial neural networks, self organizing map, adaptive neuro-fuzzy inference system etc., have been employed more recently.[8,12,17–24] The classifying category, components of discriminators, and used methods are listed in Table 1.

The waveform spectrum analysis is a good method to analyse the different characteristics between the waveform and spectrum for seismic events and blasts, but it is very difficult to use for mine site workers because of the large amount of data from each sensor and the need for comprehensive professional knowledge of signal processing. Multivariate statistical methods and soft computing techniques could be good methods if the reasonable discriminant parameters are extracted. Vallejos and Mckinnon[24] applied the logistic regression and the neural network to classify events and blasts. The location error and 13 seismic parameters provided by

* Corresponding author at: School of Resources and Safety Engineering, Central South University, Changsha 410083, China.
*E-mail addresses:* lj.dong@csu.edu.cn, csudlj@163.com (L.-J. Dong).

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**Table 1**
Summary of discriminators used to identify explosions or noise.

| No. | Category | Components of Discriminators | Method | Ref. |
|---|---|---|---|---|
| 1 | Blast and seismology | Time of occurrence, ratio of high- frequency and low-frequency radiation, and radiation pattern | A multivariate maximum-likelihood Gaussian classifier technique | 7 |
| 2 | Explosions from earthquakes | $M_m$, mainshock magnitude; $M_{min}$, minimum magnitude in sequence; $M_c$, magnitude of completeness for sequence. | Statistical method | 8 |
| 3 | Explosions and earthquakes | Rayleigh-wave spectral ratio magnitude | Analysis and comparison | 9 |
| 4 | Earthquake seismograms and explosion seismograms | Distance held constant and event magnitude varied, distance the variable and magnitude | Explore the ability of the human ear and the auditory analysis method | 10 |
| 5 | Earthquakes and underground nuclear explosions | Surface wave spectrums, Rayleigh velocity rupture velocity, wave length, etc. | Theoretical inferences about spectrums from small events | 11 |
| 6 | Explosions and earthquakes | $P_g/L_g$, $m_b/M_s$, and Love-wave energy | Maximum-likelihood Gaussian classifiers and a back propagation neural network | 12 |
| 7 | Explosions and earthquake | Energy contained within predetermined $P_1$, $S_1$, $P_2$, $S_2$, $P_g$, $B$, $L_{g1}$, $R_{gl}$, $R$ and vertical-component $P_g/L_g$ spectral ratio | Linear discriminator | 13–15 |
| 8 | Explosions and earthquake | Amplitudes: $P_g$ versus $L_g$, $P_n$ versus $L_g$, $P_n$ versus $L_g$, and $P_n$ versus $L_g$ | The ridge discrimination Techniques | 16 |
| 9 | Earthquakes and underwater explosions | The appearance of a slow and relatively low-frequency signal superimposed on the coda of the high frequency $P$ wave, and the absence of $S$ waves. | Artificial neural network | 17 |
| 10 | Quarry blasts and earthquakes | The peak amplitude ratio (S/P ratio) and the complexity value | Feedforward neural networks, adaptive neural fuzzy inference systems, and probabilistic neural networks | 18 |
| 11 | Quarry blasts and Seismic events | Frequency and time domain data (complexity, spectral ratio, S/P wave amplitude peak ratio and origin time of events) | Unsupervised learning (neural network) approach comprising a self organizing map | 19 |
| 12 | Microearthquakes and quarry blasts | Spectral and amplitude parameters, automatically extracted from local three component digital broadband velocigrams | Multi-layer perceptrons and Kohonen maps | 20 |
| 13 | Tectonic earthquakes and quarry blasts | Inspection of waveforms, spectral analysis, the daytime of quarry blasts | Artificial neural networks | 21 |
| 14 | Natural earthquakes and underground nuclear explosions | Distance corrected spectral data of regional seismic phases. $P_n$, $P_g$, $L_g$ spectra, spectral ratio and third moment of frequency | Artificial neural networks | 22 |
| 15 | Blast and seismic event in Mine | Seismic parameters provided on-line by the full-waveform systems | Multivariate classifiers | 23,24 |
| 16 | Seismic signals and noise | Frequency, amplitude, and constant relative bandwidth (RBW) over the whole frequency range | Frequency and spectral analysis | 25 |
| 17 | Explosions and earthquake | Seismic phases $P_n$, $P_g$, $S_n$, $L_g$, and distance | Comparison analysis, and relation curve of different factors | 26 |
| 18 | Explosions and earthquakes | $P_g$ versus $L_g$, $P_n$ versus $L_g$, $P_n$ versus $L_g$, and $P_n$ versus $L_g$. | The ridge discrimination techniques | 27 |
| 19 | Explosions and earthquakes | Rayleigh-wave magnitude $M_s$ to the bodywave magnitude $m_b$ ($M_s$:$m_b$) | The time-domain magnitude technique and a Rayleigh-wave formula | 28 |
| 20 | Explosions and earthquakes | Distance, relative $S$-wave energy , relative $S$-wave energy, $S/P$ ratio of the integral over amplitude, rpectrum $S/P$ ratio | Multivariate statistical analysis | 29 |
| 21 | Explosions and earthquakes | $L_g/P_g$ and $L_g/R_g$ maximum amplitude ratios, spectral peaks and slopes extracted, and the search for time-independent frequency structures in sonograms | A linear discrimination function | 30 |
| 22 | Explosions and earthquakes | Narrowband regional amplitude envelopes, source models, regional wave propagation, and the relationship between direct amplitudes and their respective codas | The coda-wave method, and formulating the problem through the construction of synthetic template envelopes | 31 |
| 23 | Explosions and earthquakes | Lg waveform and distance | Time-transformation methods | 32 |