



## A fuzzy expert system for automatic seismic signal classification



El Hassan Ait Laasri<sup>a,\*</sup>, Es-Saïd Akhouayri<sup>a</sup>, Dris Agliz<sup>a</sup>, Daniele Zonta<sup>b</sup>, Abderrahman Atmani<sup>a</sup>

<sup>a</sup>Electronic, Signal processing and Physical Modelling Laboratory, Department of Physics, Faculty of Sciences, Ibn Zohr University, B.P. 8106 Agadir, Morocco

<sup>b</sup>Department of Civil, Environmental and Mechanical Engineering, University of Trento, via Mesiano 77, 38123 Trento, Italy

### ARTICLE INFO

#### Article history:

Available online 27 August 2014

#### Keywords:

Seismic signal classification  
Seismic signal feature extraction  
Fuzzy rule based expert system  
Fuzzy reasoning  
Fuzzy set

### ABSTRACT

Automatic classification of seismic events is of great importance due to the large amount of data received continuously. Seismic analysts classify events by visual inspection and calculation of event signal characteristics. This process is subjective and demands hard work as well as a significant amount of time and considerable experience. A reliable automatic classification task considerably reduces the effort required and makes classification faster and more objective. The aim of this study is to develop a fuzzy rule based expert classification system that is able to imitate human reasoning and incorporate the analyst's knowledge of seismic event classification. The fundamental idea behind using this approach was motivated by the way in which human analysts classify seismic events based on a set of experiential rules. Additionally, this approach was chosen due to its interpretability and adjustability, as well as its ability to manage the complexity of real data. Relevant discriminant features are extracted from event signal. Using these features, the classification system was built based on the vote by multiple rule fuzzy reasoning method with three types of rules. Comparison of this method with the single winner classical fuzzy reasoning model was carried out. Classification results on real seismic data showed the robustness of the classifier and its capability to operate in on-line classification.

© 2014 Elsevier Ltd. All rights reserved.

### 1. Introduction

The ease with which a trained human brain can classify objects, recognize faces or voices, understand spoken languages, read handwritten characters, etc., has inspired many scientists to seek to design and build machines that can mimic the human recognition system in recognizing patterns. Nowadays, with the rapid development in computer technology and digital systems, pattern recognition has gained more and more interest because of its practical importance in nearly all branches of applied science. In this study, we are particularly interested in signal classification, and more precisely seismic signal classification. In a signal classification problem, the aim is to design a minimum-error system for labeling an input signal with one of a given set of classes.

Seismic monitoring networks detect and record a huge number of seismic events continually. Such events can be produced from a wide variety of sources. In fact, seismic waves can be generated by natural sources such as earthquakes and ocean waves, or by man-made sources such as explosions and cultural activities (industry, traffic, etc.). Classification of seismic events is of great importance

due to several reasons. Besides the need for recognizing earthquake signals to launch an early alarm, classification of seismic signals on a routine basis provides an organized database that could be easily exploited in seismic research. Location and investigation of active tectonics as well as analysis of seismic hazards in a region of interest are the main focuses of seismic studies. In these studies, identification of earthquake signals is the critical first step. Recognition of explosion signals is also a practical need in a wide range of applications. For example, detection and identification of nuclear explosion signals is of considerable interest in the context of nuclear test ban treaty verification (CTBT) (Hoffmann, Kebeasy, & Firbas, 1999).

Seismic signal classification is traditionally performed through manual analysis based on visual inspection and calculation of signal features such as spectral characteristics (Bormann et al., 2009; Bormann, Klinge, & Wendt, 2009). This process is subjective and demands hard work as well as considerable experience and a significant amount of time. Moreover, in view of the very high volume of seismic data received continuously, the considerable daily processing conducted by analysts is stressful and arduous. Therefore, constructing a reliable automatic classification system is crucial to considerably reduce the effort required as well as to make classification faster and more objective.

Due to the importance of an automatic classification task, many research efforts have been devoted to designing seismic

\* Corresponding author. Tel.: +212 528 220 957; fax: +212 528 220 100.

E-mail addresses: [hassan.or@hotmail.com](mailto:hassan.or@hotmail.com) (E.H. Ait Laasri), [e.akhouayri@uiz.ac.ma](mailto:e.akhouayri@uiz.ac.ma) (E.-S. Akhouayri), [d.agliz@uiz.ac.ma](mailto:d.agliz@uiz.ac.ma) (D. Agliz), [daniele.zonta@unitn.it](mailto:daniele.zonta@unitn.it) (D. Zonta), [atmani\\_abderrahman@hotmail.com](mailto:atmani_abderrahman@hotmail.com) (A. Atmani).

classification systems. Several methods have been developed and tested in many countries. The shape of recorded signals, the feature extraction method and the classifier are often different. This is mostly due to the fact that characteristics of seismic signals are closely related to properties of the medium, which vary significantly from area to area (Jenkins & Sereno, 2001; Zeiler & Velasco, 2009). The simple classifier that has been mostly used in regions where repeating sources occur is based on the cross-correlation function (Harris, 1991; Joswig, 1990, 1995). In these regions, a set of signals are collected from previously occurred seismic events to represent the prototypes of classes. Cross-correlation function can then be used to recognize subsequent signals of each class. The drawback of this method is that it is very sensible to the form of the signal, which is mostly distorted by the environment. Spectral ratios of seismic waves are commonly presented as good discriminants between earthquakes and mining blasts (Allmann, Shearer, & Hauksson, 2008; Kim, Park, & Kim, 1998; Walter, Mayeda, & Patton, 1995). Nevertheless, such information is not available all the time because of the fact that not all seismic signals present clear and separable seismic waves. In this case, the spectral ratio does not appear to be sufficient to discriminate these two classes of events. Limitation of these techniques has led to more sophisticated methods. Methods based on the Hidden Markov modelling were applied to volcanic event classification (Benitez et al., 2007). The capability of an unsupervised clustering technique based on the maximum likelihood estimation was tested on the seismic database of Iran (Ansari, Noorzad, & Zafarani, 2009). Various types of neural networks have been applied to seismic event discrimination between earthquakes and explosions (Ait Laasri, Akhouayri, Agliz, & Atmani, 2011; Curilem, Vergara, Fuentealba, Acuña, & Chacón, 2009; Dysart & Pulli, 1990; Kuyuk, Yildirim, Dogan, & Horasan, 2011; Musil & Plesinger, 1996; Shimshoni & Intrator, 1998; Yildirim, Gulbag, Horasana, & Dogan, 2010; Zadeh and Nassery, 1999), as well as classification of volcanic events (Langer, Falsaperla, Powell, & Thompson, 2006; Scarpetta et al., 2005). A genetic algorithm-based boosting approach has been used to discriminate between earthquake and explosion signals (Orlic & Loncaric, 2010).

In this study, we propose a Fuzzy Rule Based Expert System (FRBES) for automatic classification of seismic events. The fundamental idea behind this approach arises from the fact that seismic signal analysts are able, based on their experience of looking at many seismograms, to classify seismic events by visual inspection and calculation of signal characteristics. We are interested in transforming the analyst's knowledge of seismic signal classification into a FRBES which can imitate the reasoning process of the analyst in solving the classification problem. The use of FRBES as a classifier for seismic signals is motivated by several reasons:

- FRBES can be built based on the training data as well as the heuristic knowledge and experience of people who have already mastered the classification procedure, in direct contrast to many other methods such as artificial neural networks which are entirely based on the training data. Due to years of experience and potential of human brain, it is clear that seismic signal analysts construct solid knowledge and ability to classify seismic events. These analysts usually employ experiential rules, which can be cast into a FRBES. In addition, the possibility of mixing different information such as that coming from expert knowledge and information coming from training data may significantly improve the generalization ability of the classifier and so its performance.
- FRBES has proved to be a powerful framework to incorporate imprecise knowledge using the concept of linguistic variables instead of precise quantitative values used in conventional

mathematical tools. Such linguistic variables are more suitable for processing real world data and particularly seismic data, which are mostly imprecise, noisy and distorted.

- More importantly, FRBESs employ linguistic variables and fuzzy rules which are human-understandable. These rules increase the transparency and interpretability of fuzzy systems and enable them to be easily comprehensible for humans, contrary to many other approaches, especially the artificial neural networks, which are considered as black-boxes. Furthermore, owing to its transparency, modifiability, comprehensibility and coherence with previous knowledge, a FRBES can be tuned, updated and adapted if necessary, thus enhancing the degree of freedom of the classifier adjustability.

These capabilities inspired many researchers to apply fuzzy algorithms to a variety of classification problems, including hydro-meteor classification (Marzano, Scaranari, & Vulpiani, 2007), speech/music discrimination (Reyes, Candeas, Galan, & Munoz, 2010), vehicle classification (Kim, Kim, Lee, & Cho, 2001), chemical process classification (Dash, Rengaswamy, & Venkatasubramania, 2003), and image classification (Sharma, Gupta, Kumar, & Kapoor, 2011). Many other investigators have sought to improve the performance and accuracy of FRBES for classification (Ho, Chen, Ho, & Chen, 2004; Mansoori, Zolghadri, & Katebi 2007; Sanz, Fernández, Bustince, & Herrera, 2010, 2011).

The rest of this paper is organized as follows. First, we briefly discuss seismic data characteristics in Section 2. In Section 3, the first part is devoted to feature extraction, and the second part presents the proposed classification system. The experimental results and performance of the system are shown in Section 4. Finally, Section 5 outlines conclusions.

## 2. Seismic data and their characteristics

### 2.1. Data

The data used in this work to evaluate our classification system were recorded by the local seismic network of Agadir. The latter belongs to the national seismic network of Morocco and consists of vertical-component short-period seismometers with an output proportional to ground velocity. The seismometers are deployed around Agadir city and linked with the data center (located in Agadir) via a radio-frequency FM modulated network. Seismic data are continuously acquired and transmitted in real-time to the data center where they are digitized and analyzed. Each detected event is recorded with the pre-event and post-event data in order to assure complete recording of seismic events. The employed detector in the local seismic network of Agadir, as in many other seismic networks around the world, is the STA/LTA energy-based detector (Akhouayri, Agliz, Fadel, & Ait Ouahman, 2001; Trnkoczy, 2009). This detector triggers whenever a sufficiently data segment energy is encountered. In this manner, the recorded seismicity is continually contaminated by various kinds of events that can trigger the detection algorithm. Because of many quarries located surrounding Agadir city, numerous quarry blast seismograms are recorded on a daily basis. Besides earthquake and quarry blast events, many additional sources are responsible for several other detections. Such sources are considered in this study as seismic noise sources, which incorporate wind, ocean waves and cultural activities (e.g., machinery). Typical vertical-component seismograms of four seismic sources are plotted in Fig. 1.

Classification of these events has been performed manually by human analysts who are sufficiently familiar with the various kinds of waveforms. However, the significant daily processing conducted by analysts is stressful and time consuming. It thus

متن کامل مقاله

دریافت فوری ←

**ISI**Articles

مرجع مقالات تخصصی ایران

- ✓ امکان دانلود نسخه تمام متن مقالات انگلیسی
- ✓ امکان دانلود نسخه ترجمه شده مقالات
- ✓ پذیرش سفارش ترجمه تخصصی
- ✓ امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
- ✓ امکان دانلود رایگان ۲ صفحه اول هر مقاله
- ✓ امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
- ✓ دانلود فوری مقاله پس از پرداخت آنلاین
- ✓ پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات