Volcano-Independent Seismic Recognition: detecting and classifying events of a given volcano using data from others

Guillermo Cortés Moreno[1], Roberto Carniel[1], Philippe Lesage[2], Maria Angeles Mendoza Perez[3], and Ivo Della Lucia[1]

[1]Università degli Studi di Udine
[2]Université Grenoble Alpes, Université Savoie Mont Blanc, CNRS,IRD, IFSTTAR, ISTerre,
[3]Universidad de Granada

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Abstract

Modern seismic networks provide a huge amount of data received in real-time, being impossible the manual identification of relevant events useful to monitor the activity of the volcano. Thus, many volcano observatories are interested in tools to perform an online, automatic analysis of the seismic activity. Machine Learning area provides various of Volcano-Seismic Recognition (VSR) systems designed to classify seismic events in real-time. However, only a few approaches can also detect them in a continuous data streams. Most of those VSR systems are based on the 2-step supervised paradigm: 1. A training database (X-DB) of a given volcano 'X' is prepared with hundreds of events manually detected and classified according to their physical origin. 2. Statistical models are built analysing this DB, and are later used to automatically identify events in new data recorded at the volcano X. This supervised procedure is the major drawback to achieve a fast deployment of a VSR system for another volcano Y, as the preparation of its own Y-DB takes considerable time, and requires qualified operators and previous recordings, which is difficult for volcanoes without recent activity or which haven't been monitored. In order to overcome these limitations, the EU-funded project 'VULCAN.ears' focused on real-time, Volcano-Independent VSR (VI.VSR) approaches. It proposes alternative solutions based on state-of-the-art technologies as universal DBs and models, waveform standardisation and parallel architectures. Recent results obtained by mixing DBs from Popocatépetl, Colima, Deception and Arenal active volcanoes will be presented. We apply VULCAN.ears technologies to evaluate VSR systems on joint DBs built with data of several volcanoes. We also use volcano-independent models to automatically classify events of another volcano, analysing how the recognition accuracy varies as the training DB becomes more complex. All tests are carried out by an easy to use, user-friendly graphical application (geoStudio). All these achievements produce new insights useful to redesign the next-generation, portable and robust VSR systems.

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Guillermo Cortés[(1)], Roberto Carniel[(1)], Philippe Lesage[(2)], M. Ángeles Mendoza[(3)] and Ivo Della Lucia[(1)]

(1) Dipartimento Politecnico di Ingegneria e Architettura — DPIA, Università degli studi di Udine, Friuli, Italy [*guillermo.cortes@uniud.it*] [*roberto.carniel@uniud.it*] [*ivodielle90@gmail.com*]

(2) Université Grenoble Alpes, Université Savoie Mont Blanc, CNRS, IRD, IFSTTAR, ISTerre, Grenoble, France - [*lesage@univ-smb.fr*]

(3) Visual Information Processing Group, Universidad de Granada, Spain - [*ninesmp75@gmail.com*]

0. Aims & Proposals

➢ Volcano-Seismic Recognition (VSR) at Volcano Observatories (VOs)

- ✔ Volcano-Seismic *(VS) activity* is the most used indicator to evaluate volcanic hazard and forecast eruptions[(1)]
- ✗ VOs require expert staff to *manually label* VS events: *detect* (time delimitation) + *classify* (assign them to their physical type or *VS class*)
- ✗ Manual VSR is slow and not always reliable
- ✗ C*urrently, automatic VSR* is only deployed in few VOs

➢ Aims: automatic Volcano-Independent Volcano-Seismic Recognition (VI.VSR)

i. automatic Volcano-Seismic Recognition (VSR): statistical modelling of *previously labelled* VS classes to achieve:

- ✔ *Real-time VSR* to detect and classify events *on continuous data streams*
- ✔ *easy VO integration* into most popular data acquisition systems (Earthworm & WebObs)

ii. Volcano-Independent VSR aims to *recognise events from any volcano* without any prior knowledge of its VS classes by means of *universal VSR,* allowing*:*

- ✔ *Fast VSR deploy for awakening volcanoes* and for *new appearing classes* in active volcanoes

➢ Proposal: portable & universal VSR systems

i. portable VSR solutions, relying on:

- ✔ *Easy-to-use* (Python-based) user interfaces to facilitate the VSR integration at VOs
- ✔ Structured *Hidden Markov models* (HMMs) to perform real-time, continuous VSR[(2)]

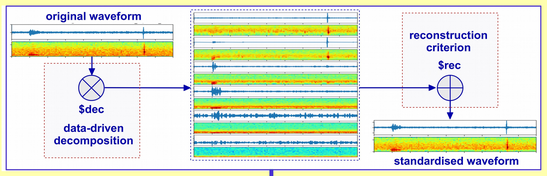
ii. universal VSR, based on ***VULCAN.ears*** project[(3)] approaches:

- ✔ *Universal DBs* collected from more than 15 volcanoes to build *universal* VSR models
- ✔ *Efficient waveform description* will enhance the volcano-independence of models
- ✔ *Parallel VSR channels* focused on each VS class, increasing reliability and precision

I. Methodology: *Efficient* waveform description to build *universal, Volcano-Independent* VSR systems

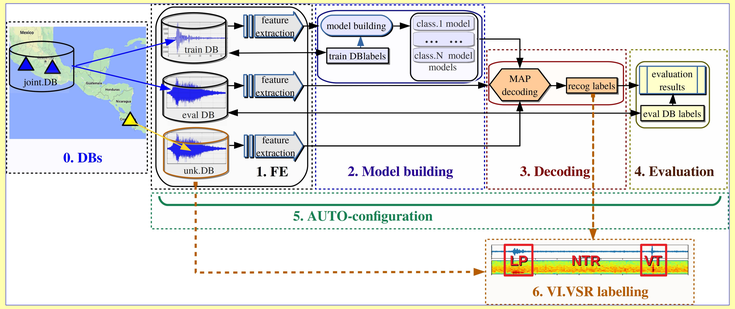
1. *Efficient* waveform description as *a sequence of feature vectors*

(1.1) standardisation (STAND)[(4)] via decomposition + reconstruction ($dec:$rec)
(1.2) parameterisation (param.#feats) of overlapped waveform segments as *feature vectors*
(1.3) feature selection (DFS)[(5)] in the given (param.#feats) parameterisation scheme



2. *Universal*-VI.VSR system setup & recognition of unknown data

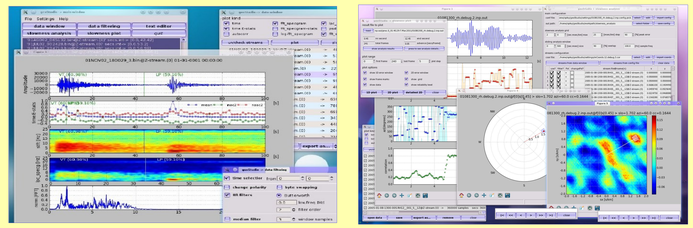
(0) DBs: a universal, *joint.DB* is used to build *universal VSR models*
(1) Feature Extraction (FE): *efficient waveform description* by a stream of feature vectors[(6)]
(2) Model building: of each VS class in the *train DB* using its *labels*
(3) Decoding: automatic detection & classification of *eval DB* events
(4) Evaluation of results comparing *recog labels* vs. *eval DB labels* via VSR precision (*cPrec)*
(5) AUTO-configuration by (re)evaluation **(4)** of the **(1+2+3)** stages
(6) Volcano-independent labelling of VS events of an *unk.DB* acquired at *another volcano*



3. *Easy* VSR integration at VOs via *easy-to-use* interfaces linking VSR & VOs

i. *geoStudio*[(3)] multi-platform**, graphical user interface** for seismic analysis:

- ✔ *Built-in VSR models* of standalone & joint DBs to perform VI.VSR
- ✔ Slowness maps by Zero-Lag correlation method
- ✔ I/O by *ObsPy*® builtin libs. Filtering and advancing plotting features



ii. *pyVSR* command-line interface as a Python wrapper for the VSR system:

- ✔ Ready-to-use scripts to *build* VSR models given a labelled DB
- ✔ Tools to run, define and evaluate whole VSR-tests
- ✔ *Online VSR* of data received from VO data servers

II. Station & volcano-independent VSR results

1. Robust & station-independent VSR at Deception Island

➢ **Station-independent VSR under *noisy* conditions VSR @ Deception Volcano**[(4)]**:** recognizing VT and LP events overlapped on noise/tremor signals in 2009 by models built with data acquired in 1995 at another location:

system	recog type	train.DB = dec.1995 events / classes @ duration	eval.DB = dec.2009 events / classes @ duration	param.#feats	*cPrec%*
SSA-VSR	continuous	288 / 3 @ 1,8 [h]	707 / 3 @ 12,2 [h]	mix.D.16	*66*
				mix.D.16[STAND]	*76*

✔ *VSR precision **increases 16%** using waveform standardisation (STAND)*

➢ **Parallel (PSA) vs. serial (SSA) VSR @ Deception**[(3)]**:** class-focused PSA.VSR channels allow a more efficient AUTO configuration than SSA.

system	recog type	train.DB = dec.1995 events / classes @ dur.	eval.DB = dec.1998 events / classes @ dur.	param.#feats	*cPrec%*
SSA	continuous	288 / 3 @ 1,8 [h]	445 / 3 @ 4,2 [h]	AUTO(mix.D.30)	*52*
PSA.chans	continuous	288 / 3 @ 1,8 [h]	445 / 3 @ 4,2 [h]	AUTO(mix.D.30)	*72*
joint.PSA					*70*

✔ *An **improvement of 38%** achieved by dedicated VSR channels (PSA.chans)*

2. VI.VSR: recognising Popocatépetl events using Colima models

➢ **continuous VI.VSR @ Popocatépetl by Colima:** waveform standardisation (STAND) + efficient feature selection (DFS[(5)]) + system auto.configuration (AUTO) empowers volcano-independent VSR:

system	recog type	train.DB = col.2004 events / classes @ dur.	eval.DB = pop.2002 events / classes @ dur.	param.#feats	*cPrec%*
SSA-VSR	continuous	345 / 6 @ 17 [h]	814 / 6 @ 37 [h]	MFCC.D.A.33	*59*
				AUTO(MFCC.D.A.33)	*65*

✔ *An **enhancement of 10%** via system AUTO-configuration*

3. VI.VSR: recognising Arenal events by Colima and Popocatépetl

➢ **VI.VSR models built by a joint.DB:** complex Arenal events can be successfully classified using *universal* models of a *universal* (joint) training DB

system	recog type	train.DB = col.2004+pop.2002 events / classes @ duration	eval.DB = are.2007 events / classes @ duration	param.#feats	*cPrec%*
SSA-VSR	isolated	813 / 7 @ 41 [h]	552 / 7 @ 14 [h]	mix.D.30	*50*
				AUTO(mix.D.30)	*71*

✔ *A **71% of precision classifying complex events** thanks to universal DBs*

III. VI.VSR highlights

(!) Remarks:

➢ **Volcano-Independent VSR becomes operational!** thanks to state-of-the-art ***VULCAN.ears*** technologies

➢ **Complex volcanoes require joint.DBs in order to build efficient VI.VSR models** (as Arenal volcano with 7 classes and its 3 types of tremors)

(+) Pros:

✔ **Promising early results!:** good precision in both, isolated (>71%) and continuous VI.VSR (>65%)

✔ ***geoStudio* and *pyVSR* interfaces allow a *fast & easy deployment* of VI.VSR systems**

(-) Cons:

✗ **A *universal* waveform description doesn't yet exist**, as it still depends on the training DB

✗ **VSR precision highly depends on the manual labelling of the training DBs**

References & Acknowledgments

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