Activity Regimes Inferred from Automatic Classification of Volcanic Tremor at Mt. Etna, Italy

M. Masotti\textsuperscript{1}, S. Falsaperla\textsuperscript{2}, H. Langer\textsuperscript{2}, S. Spampinato\textsuperscript{2}, R. Campanini\textsuperscript{1}

\textsuperscript{1}Medical Imaging Group, Department of Physics, University of Bologna
\textsuperscript{2}Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Catania
Mt. Etna

Mount Etna is the largest active volcano in Europe:

- **Type:** Basaltic stratovolcano
- **Location:** Sicily, Italy (3350 m a.s.l.)
- **Latest eruptions:** 01, 02-03, 04-05, 06

Mount Etna’s volcanic monitoring is a key issue.
Volcanic Tremor

For basaltic volcanoes (e.g., Mount Etna)...

- Volcanic tremor is a persistent seismic signal marking different states of the volcano’s activity:
  - Pre-eruptive
  - Lava fountain
  - Eruptive
  - Post-eruptive

- Volcanic tremor provides reliable information for alerting governmental authorities during a crisis and permits surveillance even when direct access to the eruptive theatre is not possible.
In [Masotti, Geo. Res. Lett., 33 (20) (2006)], a system able to automatically classify different states of the volcano’s activity from the analysis of its volcanic tremor was proposed:

Data: Volcanic tremor  \[\rightarrow\]  Features: Spectrogram-based  \[\rightarrow\]  Classification: Support Vector Machine

Here, what if:

- Support Vector Machine is optimized (e.g., using Genetic Algorithm)?
- A different (optimized) classifier is used (e.g., Artificial Neural Networks or Cluster Analysis)?
- A different eruption is considered (e.g., 2006)?
Data

Seismograms are labeled according to their recording date…

<table>
<thead>
<tr>
<th>Date</th>
<th>Lava fountain (FON)</th>
<th>Pre-eruptive (PRE)</th>
<th>Eruptive (ERU)</th>
<th>Post-eruptive (POS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>01 Jul 01</td>
<td>153</td>
<td>55</td>
<td>180</td>
<td>37</td>
</tr>
<tr>
<td>06 Jul 01</td>
<td>84</td>
<td>0</td>
<td>168</td>
<td>84</td>
</tr>
<tr>
<td>01 Aug 15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Feature Extraction

Features are computed by…

1. Calculating the spectrogram of each seismogram (10 min., 0-15 Hz)
2. Averaging the rows of each spectrogram (62-dimensional feature vector)
Classification

A comparison is performed among:

- Supervised classification based on Support Vector Machine (SVM) + Genetic Algorithm (GA)

  VS

- Supervised classification based on Artificial Neural Network (ANN) + GA

- Unsupervised classification based on Cluster Analysis (CA)
Classification :: SVM

Supervised classification

Maximum margin

$$w \cdot x + b = 0$$

Maximal margin hyperplane
Supervised classification
Unsupervised classification
Some of the SVM and ANN parameters are tuned using GA:
Results :: SVM + GA

Overall classification error:
22/425 = 5% patterns

2001

Overall classification error:
22/336 = 7% patterns

2006
Results :: SVM + GA

Overall classification error:

\[ \frac{68}{761} = 9\% \text{ patterns} \]
Results :: ANN + GA

Overall classification error:
2001 patterns
124/425 = 29%

2006 patterns
64/336 = 19%
Results :: ANN + GA

Overall classification error:
196/761 = 26% patterns
Results :: CA

2001
Number of clusters: 5

2006
Number of clusters: 2
Results :: CA

Number of clusters: 4
Conclusions

- The improvement achieved using SVM+GA rather than SVM is not significant, i.e., < 1%

- SVM+GA performs significantly better than ANN+GA, i.e., overall classification error is equal to 5% on 2001 and 7% on 2006, versus 29% on 2001 and 19% on 2006, respectively

- Individually, SVM+GA and ANN+GA achieve quite similar classification results regardless of the data considered, i.e., 2001, 2006, or 2001+2006

- CA: separation of data is quite close to what expected
The translation of the SVM-based system (TREMOrEC) from Matlab to Visual C++, to make it available to our collaboration and scientific community for validation, is completed.

For more information, and to see a demo of TREMOrEC, join us today at poster A-05120!
Thank you