A New Automatic Pattern Recognition Approach for the Classification of Volcanic Tremor at Mount Etna, Italy

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Outline

1. Introduction
2. Data and Methods
3. Results
4. Discussion
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Mount Etna is the largest active volcano in Europe:

- **Type**: Basaltic stratovolcano
- **Location**: Sicily, Italy (3350 m a.s.l.)

Mount Etna’s volcanic monitoring represents 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
Automatic Pattern Recognition Approach

How to develop an automatic classifier able to recognize different states of the volcano’s activity from the analysis of its volcanic tremor?

Data Collection & Labeling

Training of the Classifier

Feature Extraction

Test of the Classifier
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The 17 July–08 August, 2001 eruption is considered...

Analysis is performed over 01 July–15 August, 2001

Seismograms are recorded at the 3–component station ESPD:
- 142 seismograms for the East–West (EW) component
- 142 seismograms for the North–South (NS) component
- 142 seismograms for the Vertical (Z) component
Seismograms are labeled according to their recording date...

By considering the three components of each seismogram as different patterns...

<table>
<thead>
<tr>
<th>N. of patterns for each class</th>
<th>PRE</th>
<th>FON</th>
<th>ERU</th>
<th>POS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full set</td>
<td>154</td>
<td>55</td>
<td>180</td>
<td>37</td>
</tr>
</tbody>
</table>
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

For classification, a **Support Vector Machine (SVM)** classifier is chosen...

1. SVM finds the hyperplane \( \mathbf{w} \cdot \mathbf{x} + b = 0 \) maximizing the margin between the two classes in the training set.

2. If feature vectors are not linearly separable, the problem is mapped into a higher feature space by means of a kernel function \( \Phi(\mathbf{x}) \).
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Cross–Validation :: Data Partitioning

First, performances are studied using cross-validation + random subsampling...

By considering the three components of each seismogram as different patterns, for one fold...

<table>
<thead>
<tr>
<th>Class</th>
<th>N. of patterns for each class</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PRE</td>
</tr>
<tr>
<td>Full set</td>
<td>154</td>
</tr>
<tr>
<td>Train set</td>
<td>124</td>
</tr>
<tr>
<td>Test set</td>
<td>30</td>
</tr>
</tbody>
</table>
Cross–Validation :: Performances

By repeating 100 times train and test...

1. Global average classification performances: \((94.7 \pm 2.4)\%\)

2. Single–class average classification performances: (%)

<table>
<thead>
<tr>
<th>Actual Class</th>
<th>Predicted Class</th>
<th>PRE</th>
<th>FON</th>
<th>ERU</th>
<th>POS</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRE</td>
<td>PRE</td>
<td>94.2 (\pm) 5.2</td>
<td>5.4 (\pm) 4.8</td>
<td>0.4 (\pm) 1.3</td>
<td>0.0 (\pm) 0.0</td>
</tr>
<tr>
<td>FON</td>
<td>FON</td>
<td>20.2 (\pm) 12.6</td>
<td><strong>76.4 (\pm) 13.7</strong></td>
<td>3.4 (\pm) 5.1</td>
<td>0.0 (\pm) 0.0</td>
</tr>
<tr>
<td>ERU</td>
<td>ERU</td>
<td>0.0 (\pm) 0.3</td>
<td>0.3 (\pm) 1.3</td>
<td><strong>99.6 (\pm) 0.4</strong></td>
<td>0.1 (\pm) 0.6</td>
</tr>
<tr>
<td>POS</td>
<td>POS</td>
<td>0.0 (\pm) 0.0</td>
<td>0.0 (\pm) 0.0</td>
<td>0.0 (\pm) 0.0</td>
<td><strong>100.0 (\pm) 0.0</strong></td>
</tr>
</tbody>
</table>

3. Similar results when EW, NS, and Z are taken into account separately
Second, performances are studied using leave-one-out...

By considering the three components of each seismogram as different patterns, for one (example) fold...

<table>
<thead>
<tr>
<th></th>
<th>N. of patterns for each class</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PRE</td>
</tr>
<tr>
<td>Full set</td>
<td>154</td>
</tr>
<tr>
<td>Train set</td>
<td>153</td>
</tr>
<tr>
<td>Test set</td>
<td>1</td>
</tr>
</tbody>
</table>
Leave–One–Out :: Performances

By repeating 142 times (on each single component) train and test...
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Focusing on the Z component for brevity... (but analogous considerations can be drawn for EW and NS)

- Misclassifications are mostly concentrated near class transitions
- Reasonably because of:
  1. **Intrinsic fuzziness** in the transition from one volcanic state (i.e. class) to the other
  2. Human **imprecisions in labeling**
Intra–Class Variability :: PRE and FON

Focusing on the Z component for brevity...
(but analogous considerations can be drawn for EW and NS)

PRE variability: quite high
some PRE events are similar to FON events

FON variability: high
many FON events are similar to PRE or ERU events
Intra–Class Variability :: ERU and POS

Focusing on the Z component for brevity…
(but analogous considerations can be drawn for EW and NS)

**ERU variability: quite low**
- few ERU events are similar to FON events

**POS variability: low**
- very few POS events are similar to PRE events
Summary and Conclusions

Summarizing...
- **Volcanic tremor** recorded at Mount Etna is automatically classified
- Data: 01 July–15 August, 2001
- Features: Spectrogram–based
- Classifier: Support Vector Machine (SVM)
- Classification error: < 6%

Concluding...
- Practical utility: on–line classification
- Practical/Scientific utility: off–line classification of huge (past) databases
- Practical/Scientific utility: the SVM classifier is a mathematical tool linking volcanic tremor to different states of the volcano’s activity in a reproducible way