Automatic P-onset precise determination based on local maxima and minima

Presented by:

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Precise wave arrival time determination plays a crucial role in seismic signal processing, especially for source location and tomography.

Wave arrival picking could be carried out manually. However, the increasing volume of data collected by large seismic networks, led to the necessity of automatic schemes.

An automatic picker is mostly a quasi-real time process that scrutinizes sample by sample the detected signal, searching for the exact instant where the first change appears.
Automatic picking of impulsive seismic arrivals can be simple, however accurate and reliable automatic picking of very low and emergent seismic arrivals is still a major challenge in seismic signal processing.

The P-wave onset is characterized by a rapid change in frequency and/or amplitude of the seismic trace. Therefore, a reliable picker should be able to pick variations in amplitude and frequency features.
Many automatic methods have been investigated, ranging from simple to sophisticated procedures. Most popular automatic pickers for P-arrival are:

1. **ALLEN’s picker**
   - It uses STA/LTA of \( CF_i = x_i^2 + C_i \cdot \dot{x}_i^2 \)

2. **KRADOLFER’s picker**
   - It employs \( CF_i = \frac{E_i^4 - E_i^4}{\sigma_i^2} \)
   - where \( E_i^2 = x_i^2 + \dot{x}_i^2 \sum_{j=1}^{i} \frac{x_j^2}{\sum_{j=1}^{i} \dot{x}_j^2} \)

3. **PAI-k**
   - It is based on Skewness
   - \( S = \frac{E[(X - E[X])^3]}{E[(X - E[X])^2]^{3/2}} \)

4. **PAI-S**
   - It is based on Kurtosis
   - \( k = \frac{E[(X - E[X])^4]}{E[(X - E[X])^2]^2} \)

5. **LMD**
   - It is based on \( LM_W = \{ k \in W : Z(k) > \max \{ Z(k-1), Z(k+1) \} \} \)
Let’s $z(t)$ denotes the signal recorded by a vertical component seismometer

$t_1$ is the position of a local maximum if $z(t_1) > \max(z(t_1 - 1), z(t_1 + 1))$

$t_2$ is the position of a local minimum if $z(t_2) < \min(z(t_2 - 1), z(t_2 + 1))$
Our approach takes into account changes in both amplitude and frequency that occur when a P phase arrives.

Our approach:

1. **Z: Seismogram**
2. **L: Local maxima and minima**
   - Compute a characteristic function to enhance **change in amplitude**
   - Estimate frequency variation
3. **P-wave arrival time**
How is amplitude variation detected

\[ F_i = \left[ z_i^2 + (L_i - L_{i-1})^2 \right]^2 \]

\[ CF_i = \frac{F_i}{\sigma_i} \]

\[ t_A \] is the instant where \( CF_i \) exceeds a threshold

\( \sigma \) is the standard deviation of \( F_i \), taken from the beginning to the present sample \( i \). \( \sigma \) is not updated during detection.
How is frequency variation detected

\[ Z: \text{Seismogram} \]

\[ L: \text{Local maxima and minima} \]

\[ STA_i = \frac{N_{L_i \in STA}}{N_{STA}} \quad LTA_i = \frac{N_{L_i \in LTA}}{N_{LTA}} \]

\[ t_F = \max(STA/LTA) \]
How the two parameters are combined

Once the amplitude and frequency changes are picked, the algorithm proceeds to a second stage where subsequent analysis are performed to find the precise P-phase arrival time.

So far, the analysis consist in checking some predefined rules, like:

- If the $t_A$ and $t_F$ are coincided, then $t_P = t_A = t_F$.
- If the $t_A$ and $t_F$ are far then the algorithm picks most probably a short term increase of noise at $t_A$.
- If $t_A$ is picked before $t_F$ then the event should be investigated.
- If $t_F$ is picked nearly before $t_A$ then then $t_P = t_F$. 


Tests on real seismic signals
Topology of the local seismic network of Agadir

Red triangle shows the position of stations.
Green circles indicate the locations of events used for this study. 54 seismograms are used, ranging in magnitude from $M_L = 0.7$ to $3.6$. 
Example of seismograms
Histogram of differences between manually and automatically derived P-arrivals using our approach.
The SNR [dB] is measured according to the following equation: 

$$SNR = 20 \cdot \log \frac{A_s}{A_n}$$

$A_s$ ($A_n$) is RMS-value of 1 sec (2 sec) signal after (before) P-wave.
Comparison with other algorithms

Comparisons of the proposed algorithm with other very well known methods on the 54 seismograms.

The following table illustrates the distribution of P-arrival time estimations for the six algorithms with respect to the deviation from analysts picks.

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>0 - 0.11 s</th>
<th>0.12 – 0.25 s</th>
<th>≥ 0.26 s</th>
</tr>
</thead>
<tbody>
<tr>
<td>LMMP (%)</td>
<td>61.11</td>
<td>25.92</td>
<td>12.96</td>
</tr>
<tr>
<td>LMD (%)</td>
<td>40.74</td>
<td>03.70</td>
<td>55.55</td>
</tr>
<tr>
<td>KRADOLFER (%)</td>
<td>53.70</td>
<td>22.22</td>
<td>24.07</td>
</tr>
<tr>
<td>ALLEN (%)</td>
<td>31.48</td>
<td>14.81</td>
<td>53.7</td>
</tr>
<tr>
<td>PAI-k (%)</td>
<td>35.18</td>
<td>12.96</td>
<td>51.86</td>
</tr>
<tr>
<td>PAI-S (%)</td>
<td>24.07</td>
<td>11.11</td>
<td>64.81</td>
</tr>
</tbody>
</table>
Comparison with other algorithms

An example of emergent arrival

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Error (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LMMP (our approach)</td>
<td>0.08</td>
</tr>
<tr>
<td>LMD</td>
<td>1.02</td>
</tr>
<tr>
<td>KRADOLFER</td>
<td>1.31</td>
</tr>
<tr>
<td>ALLEN</td>
<td>1.46</td>
</tr>
<tr>
<td>PAI-k</td>
<td>20.88</td>
</tr>
<tr>
<td>PAI-S</td>
<td>20.88</td>
</tr>
</tbody>
</table>
The principal results obtained from this study are summarized as follows:

- The procedure of computation is simple and the precision is relatively high;
- It combines amplitude and frequency features, yielding the best performance under different SNR onset;
- Comparison with manually derived P-readings by seismic analyst shows that precise automatic P-onset determination is achievable, even for low SNR and emergent events;
- Comparative study with five other techniques employed mostly in practice demonstrates the best performance of the proposed method on different SNR seismograms.
Future development

- Develop a dynamic threshold based on the local maxima of noise
- Further examination of the frequency feature
- Further evaluation of the algorithm on a large data set
- Develop a quality assessment process
- Investigate picking of S-wave
Thank you for attention