## AY2018/2019 Semester 1 Conference (Week 11)

Wygolik, R. (2002). Determination of P phase arrival in low-amplitude seismic signals from coal-mines with wavelets. In Signal Processing Conference, 2002 11th European. IEEE.

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## Re-call: Typical Criteria for Manual Phase Picking

Primary Wave ( $\mathbf{P}$ Wave/Phase): This wave has an estimated velocity of around $v=6 \mathrm{~km} / \mathrm{s}$ and arrives first as it travels directly from the Earthquake focus point to the Seismic Station. It is a longitudinal wave, that is a wave that travels in a direction parallel to the direction of vibration, which creates regions of compression and rarefaction.

P Phase arrival detection: Detected by marking the time when the amplitude increases for the first time from zero, as the P Wave arrives first.

Secondary Wave (S Wave/Phase): This wave has an estimated velocity of $3.6 \mathrm{~km} / \mathrm{s}$ and arrives later, as it is much slower than both Primary (P) Wave. It is a traverse wave, that is a wave that travels in a direction perpendicular to the direction of vibration, such wave consists of crest and trough, in terms of an amplitude.

S Phase arrival detection: It arrives later with a very large amplitude.

## Introduction to the Research Paper by Wygolik, R. (2002)

## Motivation: To save human lives and prevent casualties

The mechanical stress, vibrations and uncontrollable shakings of the mining sites, may induce rock bursts. In other words, rock bursts means that in the mining tunnel site, several rock debris from the ceiling may fall down abruptly, which may cause severe injuries to the mining workers.

## Relevance

Predicting rock bursts is the main concern for protecting human lives and enforce safety. So the recording and localisation of the seismic events are necessary, and these will require some essential information about the seismic signals, especially P Phase and S Phase.


## Introduction to the Research Paper by Wygolik, R. (2002)

## Existing automatic P Phase picking method and its issues

Moving Average: $y[n]=\frac{1}{N} \sum_{k=0}^{N-1} x[n-k]=x[n] * h[n]$. Its impulse response: $h[n]=\frac{1}{N} \sum_{k=0}^{N-1} \delta[n-k]$. Here, the moving average is a low pass filter, $H\left(e^{i \omega}\right)=\frac{\sin (0.5 N \omega)}{N \sin (0.5 \omega)} e^{i(-0.5 \omega(N-1))}$, with cut-off frequency of approximately $\omega_{c}=2 \pi \frac{0.442947}{\sqrt{N^{2}-1}}$, to remove high frequency noises. However, it will not work well on signals with low amplitude and low signal to noise ratio (SNR) in general, which is the case for seismic signal in mining.

## Proposal of automatic P Phase picking method by Wygolik, R. (2002)

The author proposed to use Discrete Wavelet Transform (DWT) to do automatic P Phase picking and detection with better accuracy, which make use of the Multiresolution Analysis (MRA). In the next few slides, it will explain the proposed method in more details.

## Introduction to the Research Paper by Wygolik, R. (2002)

The existing method in the previous slide will encounter issues, such as ambiguous P Phase arrival picking. Examples of seismic signals with low amplitude and low signal to noise ratio (SNR) to illustrate the issue:


## Multiresolution Analysis (MRA)



$$
f[n]=A_{1}+D_{1}=A_{2}+D_{2}+D_{1}=A_{3}+D_{3}+D_{2}+D_{1}=A_{m}+\sum_{k=1}^{m} D_{k}
$$

Here, $D_{k}$ and $A_{k}$ are the details (high frequency components) and approximations (low frequency components), respectively, at level $k$.

## Discrete Wavelet Transform (DWT)



Here, high-pass filter $G\left(e^{i \omega}\right)$ and low-pass filter $H\left(e^{i \omega}\right)$ are decomposition filters, while $G^{*}\left(e^{i \omega}\right)$ and $H^{*}\left(e^{i \omega}\right)$ are reconstruction filters for $G\left(e^{i \omega}\right)$ and $H\left(e^{i \omega}\right)$ respectively. $I\left(e^{i \omega}\right) \approx 1$ is an identity filter. Must satisfy:

$$
\begin{gathered}
h[n] * g^{*}[n]=g[n] * h^{*}[n]=0, h^{*}[n] * h[n]+g^{*}[n] * g[n]=\text { identity }[n] \\
D T F T: H\left(e^{i \omega}\right) G^{*}\left(e^{i \omega}\right)=G\left(e^{i \omega}\right) H^{*}\left(e^{i \omega}\right)=0 \\
D T F T: H^{*}\left(e^{i \omega}\right) H\left(e^{i \omega}\right)+G^{*}\left(e^{i \omega}\right) G\left(e^{i \omega}\right)=I\left(e^{i \omega}\right) \approx 1
\end{gathered}
$$

## Results

## Multiresolution Analysis (MRA)

Using MRA on seismic signals with low amplitude and low signal to noise ratio (SNR), initial level decomposition still contains much noise, however, after many levels of decomposition, the noise reduces greatly and the jump of details at P Phase arrival are more obvious.

## Jump of details

Jump of details is implemented by rejecting details at first few levels, multiplying absolute values of details at subsequent levels, that is:

$$
\prod_{k=k_{0}}^{n}\left|D_{k}\right|
$$

Remember that the details, $D_{k}$, represents high-frequency components.

## Results



## Denoising: Wavelet based noise reduction

## Hard Thresholding

$$
\hat{D}_{k}[n]= \begin{cases}D_{k}[n] & ,\left|D_{k}[n]\right|>n_{s} \\ 0 & ,\left|D_{k}[n]\right| \leq n_{s}\end{cases}
$$

Soft Thresholding

$$
\hat{D}_{k}[n]= \begin{cases}\operatorname{sign}\left(D_{k}[n]\right)\left(\left|D_{k}[n]\right|-n_{s}\right) & ,\left|D_{k}[n]\right|>n_{s} \\ 0 & ,\left|D_{k}[n]\right| \leq n_{s}\end{cases}
$$

Threshold $n_{s}$

$$
\begin{gathered}
n_{s}=\sigma \sqrt{2 \ln (L)} \\
\sigma=\frac{\operatorname{median}\left(\left|\mathbf{D}_{\mathbf{1}}[\mathbf{n}]\right|\right)}{0.6745}
\end{gathered}
$$

$L$ is the length of the threshold coefficients, and $\sigma$ denotes noise level.

## Wavelet noise reduction and Haar Wavelet for P Phase Det



## Overall Big Picture



## Conclusion

Discrete Wavelet Transform (DWT) and Multiresolution Analysis (MRA) indeed helps to pick P Phase more accurately, especially the mining signals, the one with low amplitude and low signal to noise ratio (SNR). However, due to nonstationary nature of these signals, there are no general method for always accurate $P$ Phase picking.

