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Implementation of JMA B-Δ Method for Earthquake Early Warning

During the last decade Earthquake Early Warning (EEW) has received increasing attention form the Seismological community. As a result a number of interesting approaches such as Elarms, TauCPd, or B-Δ algorithms have been developed.

As B-Δ is among the best algorithms with respect to scalability and performance, we have adopted the methodology for our GMSplus instrument.

Main properties of our implementation are rapid magnitude and epicentre estimation based on the amplitude increasing rate of the initial P-wave and the maximum amplitude, small network footprint for information dissemination, local warning and alert notification by using the instruments capabilities.

A number of instruments are currently undergoing a field test in a seismic active region outside of Europe.

Methodology Outline and Implementation

As shown in Figure 1 the software provides five types of results to characterize an event based on B-Δ method:

- Magnitude estimate
- Distance estimate
- Azimuth calculation based on first observed move
- Event declaration based on characteristic function ratio
- Noise judgment based on configurable criteria

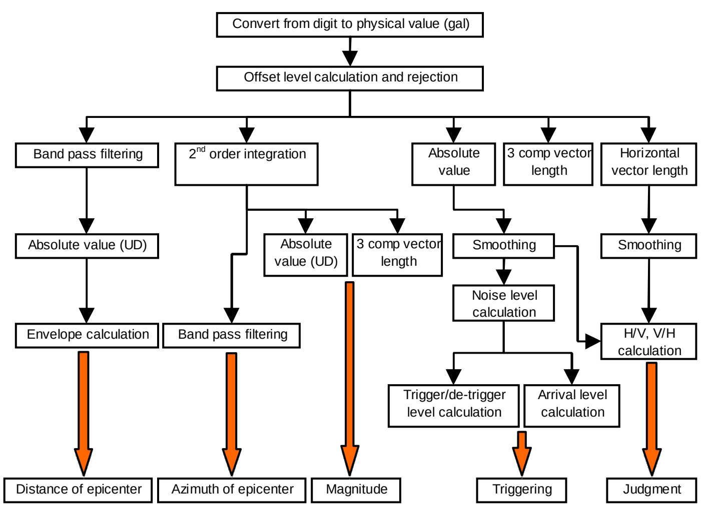

Figure 1. Basic waveform processing and parameter calculation of earthquake early warning system.

Magnitude Estimate

For magnitude and distance, Odaka's method has been used for characterisation of an earthquake (Toshikazu Odaka, 2003). Figure 2 shows the envelope curve for the displacement during initial phase of arriving earthquake waves. For a first magnitude estimate at least two seconds of waveforms (P-phase) are required.

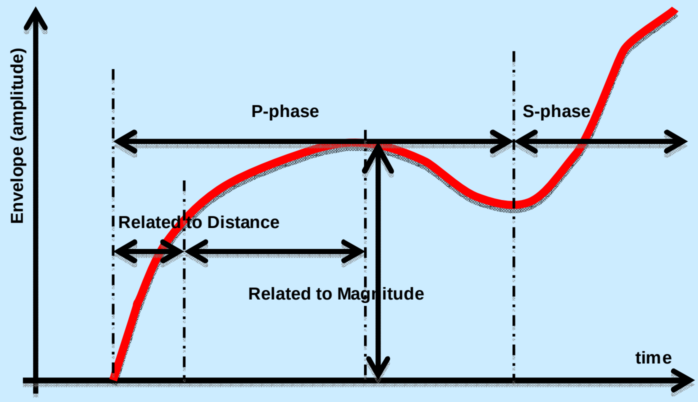

Figure 2. Schematic illustration of the B-Δ method to predict seismic source parameters.

$$y(t) = B \cdot t \cdot e^{-A \cdot t} \tag{1}$$

Equation (1) describes this relationship between envelope and time for an event. B characterises the onset of the P-wave and is larger for larger earthquakes, A accounts for the end of the two second time window and is smaller for large earthquakes as P-wave amplitudes tend to be constant in this case. Parameter t is the time in seconds.

Finding a solution for A and B of equation (1) is equivalent to minimizing the difference between $LN(env)$, which is the logarithm of the observed bandpass filtered vertical acceleration, and $LN(fit) = \ln(B) + \ln(t) - A \cdot t$.

Having a solution for A and B, P-wave magnitude can be computed using the following equation:

$$M_p = \gamma_p \cdot \log\left(D\left(\max\left(ud\right)\right)\right) + \delta_p \cdot \log\left(B\right) + \varepsilon_p \tag{2}$$

Similar for S-wave magnitude with adapted constant values for γ_s, δ_s and ε_s instead of γ_c, δ_c and ε_c.

$D\left(\max\left(ud\right)\right)$ from above is the maximum of the bandpass filtered vertical displacement. For distance calculation the following equation (α and β are site specific constants) is used:

$$\log\left(\Delta\right) = \alpha \cdot \log\left(B\right) + \beta \tag{3}$$

Case Study

For performance evaluation the 5.5 Mw Chino Hills event from 2008-07-29 18:41:15.710 was used, which occurred at 33.9530N 117.7613W. The waveforms are original 100Hz gain corrected velocity waveforms from Southern California Earthquake Data Center (SCEDC) and were converted to acceleration to fit the requirements of the algorithm.

Performance evaluation was done on a standard x86 based Linux system. Table 1 below shows the result from selected stations. M_p is the first magnitude estimate based on two seconds of data after event declaration. All magnitude estimates are within an acceptable range (+/-1 magnitude units as for testing the California Early Warning System).

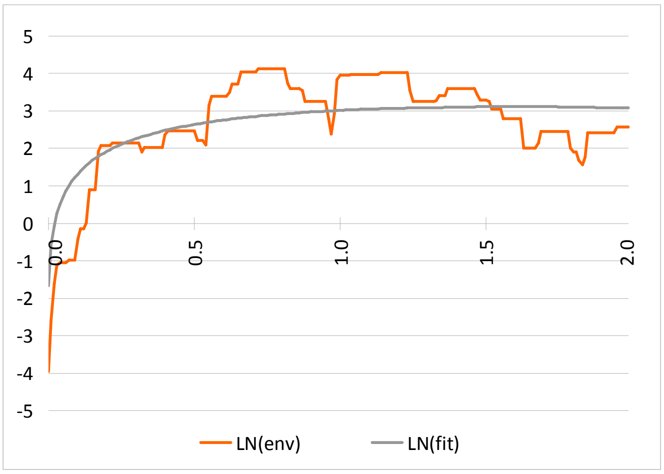

Figure 3. A and B value fitting for Station CHN based on first two seconds of P-wave data after trigger.

Figure 3 shows 200 samples of envelope values for the Chino Hills (CHN) station and the resulting function with best-fit. To find the best-fit solution, a simple search function which minimizes the root mean square (RMS) value between observed envelope values LN(env) and output denoted as LN(fit) was used. As a result of this search we obtained for A = 0.622961 and B = 37.888. According to Equations (2) and (3) this gives as estimate for the magnitude M_p 5.2 [Ml] and for the distance 15.2 [km].

Information Dissemination

For EEW two output types are supported:

- physical output via relay on an integrated alarm card with configurable magnitude threshold
- network messages with small network bandwidth requirements.

An event message is 170 Bytes in size and provides a complete set of health status information, e.g., environmental and electrical conditions, occurrence of critical errors, and earthquake parameter information such as arrival times, magnitude estimates, etc.

Current implementation uses UDP messages to transmit the information to a central server where the minimum bandwidth requirement is 9600 Baud. As messages are sent constantly and sent information is redundant, any packet losses can be detected immediately and lost packets are compensated with the next, subsequent message.

Conclusions & Future Work

Based on information from the application of the B-Δ implementation by JMA in Japan for several years and based on our own experience from the field test, the algorithm is one of the best realizations for Earthquake Early Warning on the market today. Field tests have shown that reliable operation under narrow bandwidth conditions is possible and the algorithm provides reliable warning in difficult environmental conditions.

As future work we are evaluating the application of small clusters of instruments for protection of critical infrastructure such as power plants or factories. Furthermore, we are realizing a software component for the GMSplus which supports monitoring of early warning status of neighbouring instruments to provide more accurate alerts based on information from multiple instrument sources.

References

Toshikazu Odaka, K. A. (2003). A New Method of Quickly Estimating Epicentral Distance and Magnitude from a Single Seismic Record. *Seismological Society of America*.

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Table 1. Source solution and estimated earthquake parameters for 5.5 Mw Chino Hills earthquake in 2008

Station Information					JMA Results					
Station	Dist	BackAzi	Lat	Lon	M_p	Time	M_s	Time	Dist	BackAzi
CHN	9.02	235.70	34.00	117.68	5.2	18:42:20.59	4.9	18:42:21.80	15	239
WLT	18.55	109.72	34.01	117.95	5.6	18:42:21.76	5.9	18:42:24.97	40	67
PLS	22.46	321.32	33.80	117.61	5.5	18:42:22.18	6.0	18:42:25.33	54	297
RIO	26.23	129.93	34.10	117.98	5.9	18:42:22.83	6.1	18:42:27.09	53	129
LLS	34.23	29.29	33.68	117.94	5.7	18:42:24.35	6.1	18:42:30.50	48	38
PER	52.27	281.35	33.86	117.21	5.3	18:42:26.47	4.8	18:42:28.62	42	284