Development and Application of Earthquake Early Warning System in NCREE

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Introduction of earthquake wave

- **P Wave (primary wave)**: 6 ~ 7 km/s
- **S Wave (shear wave or secondary wave)**: 3 ~ 4 km/s
Two Types of EEWS

- Regional EEWS
Two Types of EEWS

- On-site EEWS

On-site EEWS detect P wave, then predict the seismic intensity. If predicted intensity higher than threshold, raise alarm.

Epicener

P-wave: 6~7km/s
S-wave: 3~4km/s

P-wave: 6~7km/s
The 311 Earthquake in Japan and the 921 Earthquake in Taiwan illustrate the difference in warning time.

- Epicenter was far from city (300 km) - Long warning time (~80S)
- Epicenter was close to city (100 km) - Short Warning Time (~45S)
On-site EEW
Support Vector Regression (SVR)

2013 Ting-Yu Hsu et al.

Earthquake Data (CWB Database)

Features
- Pa
- Pv
- Pd

CAV: \[ \int_0^3 |\ddot{u}(t)| dt \]

IV2: \[ \int_0^3 |\dddot{u}(t)| dt \]

\[
\text{TauC: } \frac{2\pi}{R} \sqrt{r} \quad \left( \frac{r = \int_0^3 \dddot{u}^2(t) dt / \int_0^3 u^2(t) dt}{} \right)
\]

Six P-wave features
Real PGA

Training
Regression Model

Prediction Accuracy Rate (PAR): 99.22%
(CWB Validation)

On-line Result
(Nan-An Junior High School)

PAR: 99.7%

Real PGA (gal)
Predicted PGA (gal)
I
II
III
IV
V
VI
VII

10^{-1} 10^{0} 10^{1} 10^{2} 10^{3}

10^{-1} 10^{0} 10^{1} 10^{2} 10^{3}
Integration Test of On-site Earthquake Early Warning System

ChiChi Earthquake
• Time: 88/9/21 1:47
• Depth: 8 km
• Magnitude: 7.3

Photo of the press conference of the integration test on the shaking table on 2,22,2011
EEWS for Schools
EEWS Demonstration Station: Regional + On-site EEWS

- On-site Sensor
- Regional EEWS Message
- CWB
- E-mail SMS Message
- EEW Broadcast
- EEW LED Display
Typical System Arrangement of On-site EEWS for School
Installation of Shallow down hole Sensor

**Kinematics EpiSensor ES-T**
- Dynamic range: 155 dB+
- Bandwidth: DC to 200Hz
- Full-scale range:
  - User selectable at ± 0.25g, ± 0.5g, ± 1g, ± 2g or ± 4g
- Outputs:
  - User selectable at: ± 2.5V single-ended, ± 10V single-ended
  - ± 5V differential, ± 20V differential
Installation of Backup Sensor on structure

AS-305C1W5 Sensor
Dynamic range: 155 dB+
Bandwidth: DC to 250Hz
Full-scale range: User selectable at ± 2000gal
Scale Factor: 5mv/gal
Problem in Real World

How to mitigate the false alarm
Application of Backup Sensor
Threshold can change

On-site EEWS detects the earthquake P-wave, and then predicted seismic intensity.

Predicted Intensity | Measured Intensity
---|---
7 | 7
6 | 6
5 | 5
4 | 4
3 | 3
2 | 2
1 | 1

Actual Example

Threshold can change

<table>
<thead>
<tr>
<th>Predicted Intensity</th>
<th>Number of times (year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Over 5 class</td>
<td>0</td>
</tr>
<tr>
<td>Over 4 class</td>
<td>1</td>
</tr>
<tr>
<td>Over 3 class</td>
<td>7</td>
</tr>
</tbody>
</table>

Nan'an junior high school
2014.07.01~2015.06.30
Education and Drill for Schools

- Education of Seismic Disaster Reduction
- Seismic Disaster Prevention Drill
In School – when earthquake is coming…

Move to outside quickly.

Drop, Cover and Hold On.

Earthquake Warming

Please take cover immediately.

1F Move to outside

Strong wave arrive

In School – when earthquake is coming…
Video: Earthquake Disaster Prevention Drill
• Epicenter distance: ~60km

Students take cover and evacuate in 13s.

EEW

Time (Sec)
Validation in field

On-site EEWS developed by NCREE

NAR Labs
National Applied Research Laboratories
Earthquake No.: 104022
Origin time(Taiwan Time: GMT+08:00):
4/20/2015 09:42:58.5
Location: 24.05N 122.37E
Depth: 17.5km
Magnitude(ML): 6.3
EEWS Station Response of Nan'an junior high school

Warning Time = 17.70 sec

Epicenter Distance ≈ 77.34km

- Warning Time: 17.70 sec
- Epicenter Distance: 77.34 km

<table>
<thead>
<tr>
<th>Performance</th>
<th>Online</th>
<th>Real</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intensity</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>PGA(gal)</td>
<td>31.57</td>
<td>39.67</td>
</tr>
</tbody>
</table>
EEWS Station Response of Earthquake No.104022

- **South An National Middle School**: Epicenter Distance = 77.34 km, Warning Time = 17.7 sec
- **Yilan National Junior High School**: Epicenter Distance = 99.8 km, Warning Time = 18.15 sec
- **Guangfu National Junior High School**: Epicenter Distance = 104.65 km, Warning Time = 15.82 sec
- **Yu Dong National Middle School**: Epicenter Distance = 123.69 km, Warning Time = 18.71 sec
- **Tonghe National Junior High School**: Epicenter Distance = 180.73 km, Warning Time = 23.96 sec
EEWS Station Response of Earthquake No. 104022

EEWS station response of 104022 earthquake.png

- **雲林廠房**
  - Epicenter Distance = 192.94 km
  - Warning Time = 24.05 sec

- **雲林鐵路**
  - Epicenter Distance = 212.83 km
  - Warning Time = 27.19 sec

- **育人國小**
  - Epicenter Distance = 209.13 km
  - Warning Time = 26.26 sec

- **港坪國小**
  - Epicenter Distance = 208.15 km
  - Warning Time = 5.16 sec
## EEWS Station Response of Earthquake No. 104022

<table>
<thead>
<tr>
<th>EEWS Station Name</th>
<th>Warning Time (sec)</th>
<th>Predicted Intensity</th>
<th>Measured Intensity</th>
<th>Predicted PGA</th>
<th>Measured PGA</th>
<th>Remark</th>
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</thead>
<tbody>
<tr>
<td>東和國小</td>
<td>23.96</td>
<td>3</td>
<td>3</td>
<td>16.43</td>
<td>9.20</td>
<td>SVM ver2</td>
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<td>斗六</td>
<td>24.05</td>
<td>4</td>
<td>3</td>
<td>27.78</td>
<td>10.08</td>
<td>Tc</td>
</tr>
<tr>
<td>雲林</td>
<td>27.19</td>
<td>2</td>
<td>2</td>
<td>3.18</td>
<td>5.09</td>
<td>SVM ver1</td>
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<tr>
<td>港坪國小</td>
<td>5.16</td>
<td>4</td>
<td>2</td>
<td>27.26</td>
<td>4.47</td>
<td>Tc</td>
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<tr>
<td>育人國小</td>
<td>26.26</td>
<td>4</td>
<td>2</td>
<td>30.63</td>
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<td>宜蘭國小</td>
<td>18.15</td>
<td>5</td>
<td>4</td>
<td>157.87</td>
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<td>南安國中</td>
<td>17.70</td>
<td>4</td>
<td>4</td>
<td>31.57</td>
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<td>SVM ver1</td>
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<td>光復國小</td>
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<td>19.35</td>
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<td>玉東國中</td>
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<td>54.91</td>
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</table>
## EEWS Station Accurate Rate on Last Year

<table>
<thead>
<tr>
<th>Station Name</th>
<th>Date</th>
<th>Accurate Rate</th>
<th>Number of Times(Per Month) Trigger Event</th>
<th>Method</th>
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</thead>
<tbody>
<tr>
<td>宜蘭國小</td>
<td>2014.07.01</td>
<td>61.17%</td>
<td>126.4</td>
<td>τc</td>
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<td></td>
<td>2015.06.30</td>
<td>928/1517</td>
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<td></td>
</tr>
<tr>
<td>港坪國小</td>
<td>2015.01.18</td>
<td>60.00%</td>
<td>1.8</td>
<td>τc</td>
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<tr>
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<td>2015.06.30</td>
<td>6/10</td>
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<tr>
<td>南安國中</td>
<td>2014.07.01</td>
<td>98.04%</td>
<td>457.4</td>
<td>SVM ver1</td>
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<td></td>
<td>2015.06.30</td>
<td>5592/5704</td>
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<tr>
<td>光復國小</td>
<td>2014.07.01</td>
<td>88.10%</td>
<td>20.8</td>
<td>τc</td>
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<tr>
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<td>2015.06.30</td>
<td>148/168</td>
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<tr>
<td>玉東國中</td>
<td>2014.07.01</td>
<td>91.98%</td>
<td>68.6</td>
<td>τc</td>
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<td>2015.06.30</td>
<td>757/823</td>
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<tr>
<td>育人國小</td>
<td>2014.07.01</td>
<td>77.09%</td>
<td>14.9</td>
<td>τc</td>
</tr>
<tr>
<td></td>
<td>2015.06.30</td>
<td>138/179</td>
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<tr>
<td>新興國小</td>
<td>2015.01.10</td>
<td>97.95%</td>
<td>43.3</td>
<td>SVM ver1</td>
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<td>2015.06.30</td>
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<td>東和國小</td>
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<td>85.78%</td>
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<tr>
<td></td>
<td>2015.06.30</td>
<td>199/232</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
EEWS for High-Tec Plant
On-Site EEWS for High-Tech Plant

- EEW Hardware Equipped in the Cabinet
- Down Hole Sensor + Shallow Down Hole Sensor + Backup Sensor: Reduce False Alarm
- Annually EEW Report
- Customized EEW
Real Performance in EQ. 104011

- **Event Announce**
- **PGA Reach**

**Warning Time** = 26.6 sec

- **Announce Time**: 04:06:55
- **Warning Time**: 26.6 sec
- **Epicenter Distance**: ≈ 130 km

**Performance**

<table>
<thead>
<tr>
<th></th>
<th>Real</th>
<th>On site</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intensity</strong></td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td><strong>PGA</strong></td>
<td>11.9</td>
<td>11.8</td>
</tr>
</tbody>
</table>
New Approach of On-site EEWS

Online Status

New Prediction Method

New Solution

Future Work

• Accuracy Rate: 81.8%
• Accuracy Rate becomes 100%
• Accuracy Rate keeps 100%
• The non-earthquake events are highly eliminated.

More Customized
Application of EEWS
At Home — when earthquake is coming...

Electric bulletin board will show the evacuate icon.

The door will open automatically.

Elevator will stop at the closest floor and open the door.

Emergency exit light will open to give direction.

The LED light will provide spot light to the safety zone for shelter.

Gas will be closed automatically.
In Plant — when earthquake is coming…

EEW broadcast, waning light, LED Display, SMS message will help people to take shelter. Also, the digital signal will be sent to EOC or the automatic production control system to proceed the emergency operation procedure.

Think

15s, there’s lots of thing we can do to save money.

Speaker SMS Others Devices (Dry Contact, RS485, etc.)
There’s more
Integrated Earthquake Early Warning System for Science Park

NCREE Regional EEWS

NCREE On-site EEWS at Hsinchu

NCREE On-site EEWS at Taichung

NCREE On-site EEWS at Tainan

Global Seismograph Network

Warning time / Epicenter distance
~15s / ~60km
~20s / ~100km
Structural Health Monitoring System

<table>
<thead>
<tr>
<th>Traditional</th>
<th>SSHMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centralized sampling</td>
<td>Decentralized sampling</td>
</tr>
<tr>
<td>Wired, analog</td>
<td>Multiple communications</td>
</tr>
<tr>
<td>w/o embedded calculation</td>
<td>Online SHM calculation</td>
</tr>
</tbody>
</table>
Structural Health Monitoring System
Office Building of Central Taiwan Science Park
Total Solution of Seismic Disaster Prevention

Combined the EEW and Structural Health Monitoring

**Hardware**
- EEWS
- SHM
- Automation

**Software**
- DP Program
- DP Drill
- DP Service

Office building

Hi-Tec plant
THANKS

The Total Solution of Seismic Disaster Prevention will get ready soon