Earthquake Monitoring System Using Ranger Seismometer Sensor

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***Abstract*--**As cities become larger and larger worldwide, earthquakes cause serious threat to lives and properties for town areas near major active faults on the land. Earthquake Early Warning (EEW) can be a useful tool for dropping earthquake hazards, if the relation between cities and earthquake sources in terms of location is constructive for such warning and their citizens are properly trained to respond to earthquake warning messages.

In this paper we present an automation of earthquake monitoring system using Ranger Seismometer sensor. For high precision monitoring, we have developed a Labview application. Sensor nodes of the system sample acceleration with less than 0.5 jitter. The system provides earthquake engineering researchers the ability to measure vibrations of structures during earthquakes at less cost and higher node density compared with other systems.

***Keywords*--**Seismic Sensor, Earthquake Monitoring, Design, Experimentation, Reliability.

I. Introduction

Because of the extreme complexity involved in the earthquake processes, reliable earthquake prediction is not currently possible [3]. Present technological advances in seismic instrumentation and in digital communication and processing permit the implementation of a real-time earthquake monitoring system. From the point of view of seismic hazards mitigation, earthquake early warning (EEW) is becoming a practical tool to reduce the loss caused by a damaging earthquake [3].

Earthquake monitoring is a technology which measures vibrations of structures during earthquakes. Researchers of earthquake engineering are concerned in getting raw and time-synchronized acceleration measurements from sensors deployed on building structures. Previous works [1, 2] propose methods to obtain acceleration measurements from densely deployed wireless sensors. However,[2] does not provide a user with time synchronized data. Though [1] provides time-synchronized data, it is not suitable for earthquake monitoring because its target is ambient vibrations.

In this paper we have developed a system in which an individual node records acceleration measurements locally during earthquakes. The data recording is done so that the collected raw data is gathered by the one node and can be used for further analysis after the earthquake. In this paper, we will present a design and preliminary evaluation of the earthquake monitoring system.

In addition, a new technique which is developed by Yih-Min Wu and Hiroo Kanamori in 2008 is added to this system in order to reflect up-to-date technology and consider as an early warning technique which can be applied to any motion or earthquake monitor.

The frequency range of earthquake wave is between 0.1 Hz and 20 Hz. Most Seismic (acceleration) sensors are capable of measuring acceleration at higher frequencies, but there are a few sensors capable of measuring acceleration at lower frequencies such as earthquake frequency. Besides our consideration of sensor frequency, we considered the following characteristics: sensitivity, noise level, measurable acceleration range and cost. Since tall buildings vibrate for about 10 minutes and more by an earthquake, the large external storage is necessary.

Yih-Min Wu and Hiroo Kanamori [6] have explored a practical approach to EEW with the use of a ground-motion period parameter τc and a high-pass filtered vertical displacement amplitude parameter Pd from the initial 3 sec of the P waveforms. At a given site, an earthquake magnitude could be determined from τc and the peak ground-motion velocity (PGV) could be estimated from Pd. In this method, incoming strong motion acceleration signals are recursively converted to ground velocity and displacement. A P wave trigger is constantly monitored. When a trigger occurs, τc and Pd are computed. The earthquake magnitude and the on-site ground-motion intensity could be estimated and the warning could be issued. In an ideal situation, such warnings would be available within 10 sec of the origin time of a large earthquake whose subsequent ground motion may last for tens of seconds [6].

τc and Pd method

Determinations of magnitude and the strength of shaking from the initial P wave are two important elements for earthquake early warning. Strength of shaking can practically be represented by peak ground acceleration (PGA), peak ground velocity (PGV), and peak ground displacement (PGD). PGA, PGV, and PGD are the peak values of the three components.

In real-time operation, velocities and displacements are recursively filtered with a one-way Butterworth high-pass filter with a cutoff frequency of 0.075 Hz for removing the low frequency drift during the first integration process [6] as shown in figure 1.

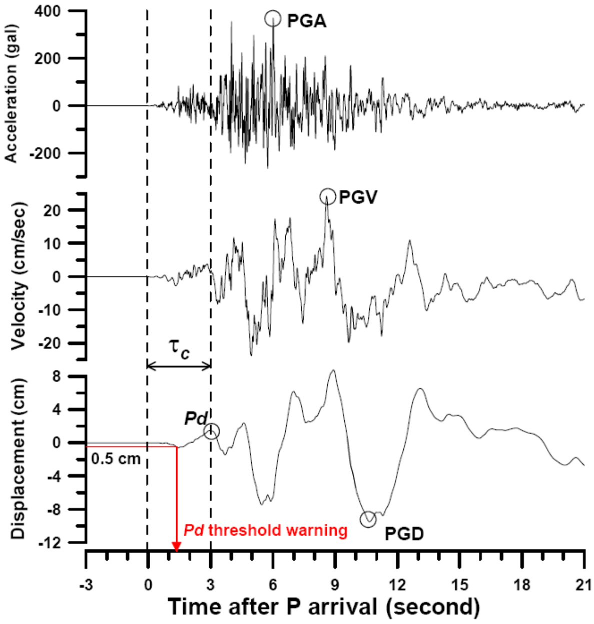


Figure 1. A ground-motion period parameter τc and a high-pass filtered displacement amplitude parameter Pd are determined from the initial 3 sec of the P waveforms.

Another important element of EEW is to estimate the strength of S wave shaking at a site from the initial P waves at the same site. Wu and Kanamori [6] showed that the maximum amplitude of a high-pass filtered vertical displacement during the initial 3 sec of the P wave, Pd, can be used to estimate the PGV at the same site. When Pd ≥ 0.5 cm, the event is most likely damaging. c τ and Pd are the two basic parameters used for EEW in their approach[6].

$$r = \frac{\int_0^{\tau_0} \dot{u}^2(t)dt}{\int_0^{\tau_0} u^2(t)dt},$$

$$r = \frac{4\pi^2 \int_0^{\infty} f^2 \left|\hat{u}(f)\right|^2 df}{\int_0^{\infty} \left|\hat{u}(f)\right|^2 df} = 4\pi^2 \left\langle f^2 \right\rangle,$$

$$\tau_c = \frac{1}{\sqrt{\left\langle f^2 \right\rangle}} = \frac{2\pi}{\sqrt{r}}$$

$$\log \tau_c = 0.296 M_w - 1.462 \pm 0.122 \text{ and}$$

$$M_w = 3.373 \log \tau_c + 5.787 \pm 0.412$$

In our system, which is a flexible system we will take the results of the above theory and consider it as an early warning system.

II. Design

This phase is divided into several steps which depend on three items:

- National Instruments Data Acquisition Card (DAC)
- LabVeiw 7.1 software
- Seismic Sensor

Step1: Read data every 1 ms with a sample rate of 9600 as shown in figure 2.

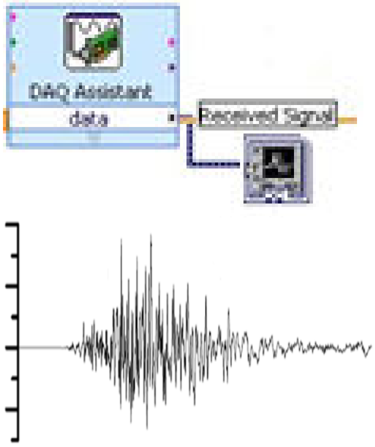
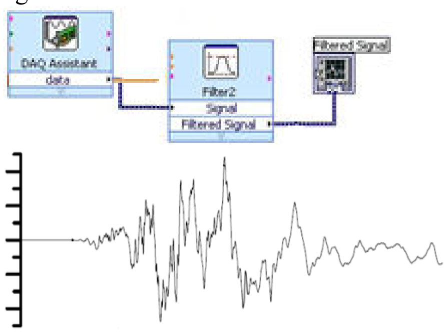


Figure 2: Reading from the DAC.

Step2: Filter the signal with a bypass filter as shown in figure3.



Figue 3: Pass the signal via a band bass filter

Step3: Apply a polynomial equation to the signal to get a sampled signal as shown in figure 4.

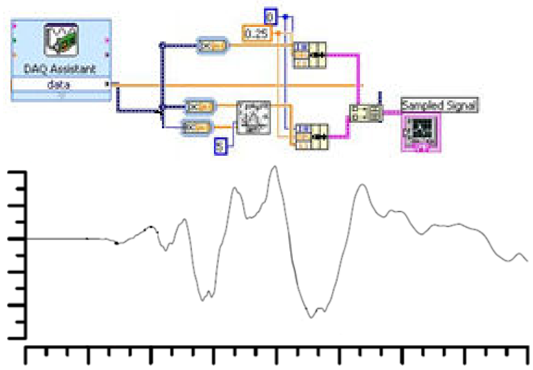


Figure 4: pass the signal through a sampler

Step 4: Compare the signal with a certain threshold. If it is more, then the signal will be recorded and a sound of a buzzer will rise as shown in figure 5.

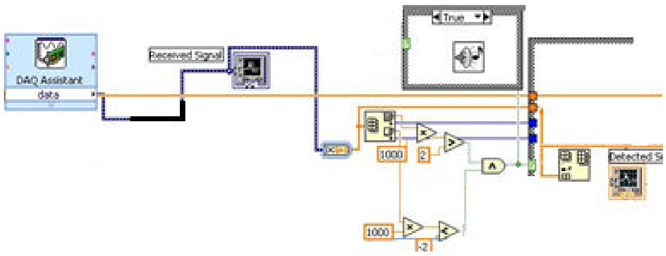


Figure 5: Determination of the thresholds

Step 5: Separate S (Secondary) wave from P (Primary) wave signal as shown in figures 6(a) and (b).

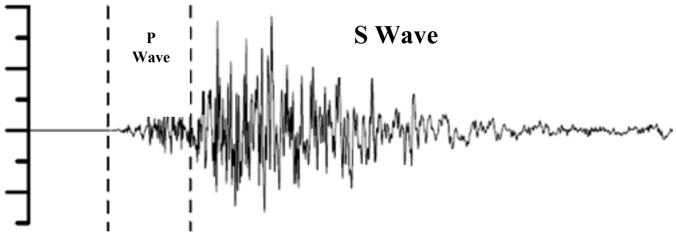


Figure 6 (a): Signal separation to measure the period.

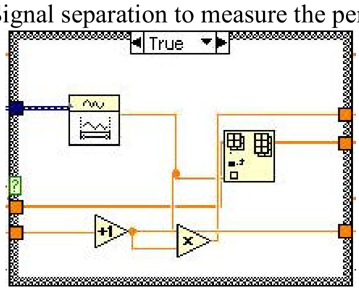


Figure 6 (b) measuring period schematic

Step 6: Store all required parameters out from the sensor equation to a text file for further analysis as shown in figure 7. The parameters are as follows:

Duration (DU) = P wave (P) + S wave (S)
Distance (Di) = 10.5 * P
Weight (W) = (0.7 + 1.54 * log (DU) + 0.001 * Di) ± 0.1

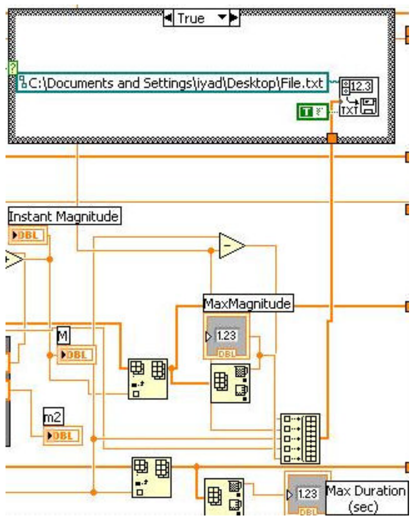


Figure 7: Determined the stord data

User Interface:

The Graphical User Interface (GUI) for the designed system is shown in figure 8.

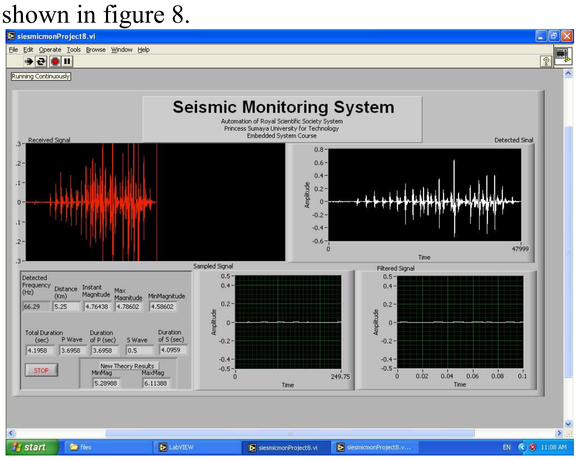


Figure 8: Graphical user interface.

Sample output data:

A sample measured data is shown in table.

Table 1 : A sample of measured data.

P Wave	S Wave	Total Time	Distance	Weight
0.200	0.599	0.799	6.294	3.656
1.201	1.199	2.897	12.587	4.524
1.698	3.297	4.995	34.615	4.910
1.998	5.395	7.093	56.643	5.167

For early warning system:

We used the research results to forecast the results, where **τc** represents the time of P wave as shown in figure 9.

$$\log \tau_c = 0.296 M_w - 1.462 \pm 0.122 \text{ and}$$
$$M_w = 3.373 \log \tau_c + 5.787 \pm 0.412$$

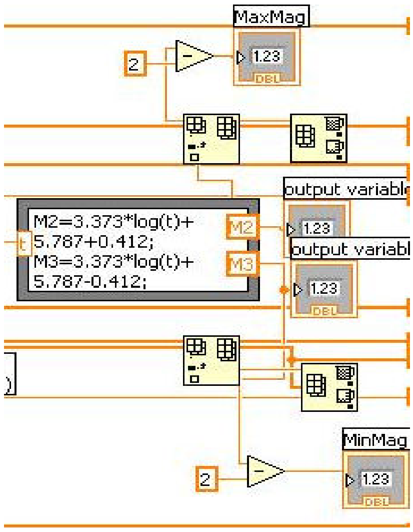


Figure 9: EWS schematic

Table 2: Comparison between our system results and EWS results

P Wave	S Wave	Total Time	Distance	Weight Min	Weight Max	Yih & Hiroo theory Min	Yih & Hiroo theory Max
0.2	0.599	0.799	6.294	3.656	3.701	3.785	3.901
1.201	1.199	2.400	12.59	4.524	4.597	4.609	4.797
1.698	3.297	4.995	34.62	4.91	5.03	5.109	5.23
1.998	3.395	5.393	56.64	5.167	5.201	5.282	5.301
1.552	4.135	5.687	62.66	5.321	5.372	5.398	5.415
2.534	4.382	6.916	66.32	5.441	5.453	5.481	5.501
2.756	4.441	7.197	69.03	5.492	5.506	5.561	5.674
2.978	4.628	7.606	71.18	5.503	5.514	5.588	5.710
2.543	5.096	7.639	73.08	5.517	5.536	5.597	5.757
2.876	5.173	8.049	74.11	5.529	5.548	5.607	5.789
2.998	5.299	8.297	75.89	5.538	5.553	5.634	5.811
3.213	5.308	8.521	77.05	5.560	5.576	5.706	5.847
3.534	5.377	8.911	83.77	5.593	5.614	5.744	5.876
3.765	5.42	9.185	91.43	6.004	6.155	6.227	6.325
3.867	5.466	9.333	106.47	6.153	6.206	6.269	6.403
3.978	5.478	9.456	120.41	6.199	6.377	6.488	6.546
4.132	5.505	9.637	144.37	6.267	6.392	6.502	6.642
4.324	5.803	10.13	164.87	6.438	6.503	6.664	6.821
4.345	5.844	10.19	172.52	6.487	6.601	6.865	6.911
4.567	5.864	10.43	179.32	6.508	6.689	6.906	6.989
5.123	5.906	11.03	187.49	6.536	6.700	6.986	7.068
5.867	6.395	12.26	198.31	6.578	6.754	6.994	7.101

By comparing results of Ranger sensor equation with [6] we can conclude that Yih & Hiroo theory can be used as an early warning System as seen in the graph below as shown in table 2 and figure 10.

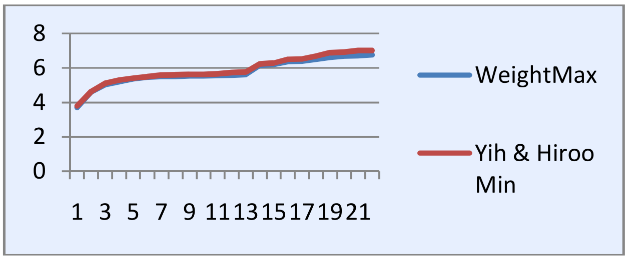


Figure 10: Relation between our design and EWS results

III. Implementation:

To implement this system you have to:

A. Install a data acquisition card to your computer
B. Install labveiw software to you computer
C. Connect the sensor to the DAC by one pair wire
D. Open code folder and double click on the file and press on run button as shown in figure 11.

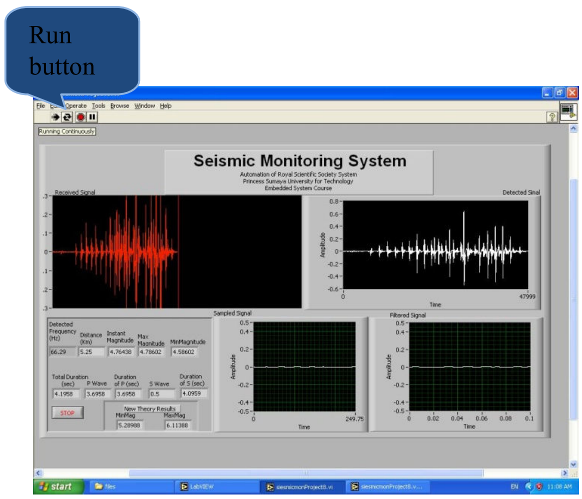


Figure 11: How to implement this project

IV. Conclusion and Future Work

In this paper we have presented an automation process and preliminary evaluation of Royal Scientific Society earthquake monitoring system.
An EEW system forewarns an urban area of forthcoming strong shaking, normally with a few sec to a few tens of sec of warning time, i.e., before the arrival of the destructive wave part of the strong ground motion. Even a few second of advanced warning time will be useful for pre-programmed emergency measures for various critical facilities, such as rapid-transit vehicles and high-speed trains to avoid potential derailment. It will be also useful for orderly shutoff of gas pipelines to minimize fire hazards, controlled shutdown of high-technological manufacturing operations to reduce potential losses, and safe-guarding of computer facilities to avoid loss of vital databases. Figure 12, shows our final system block diagram.

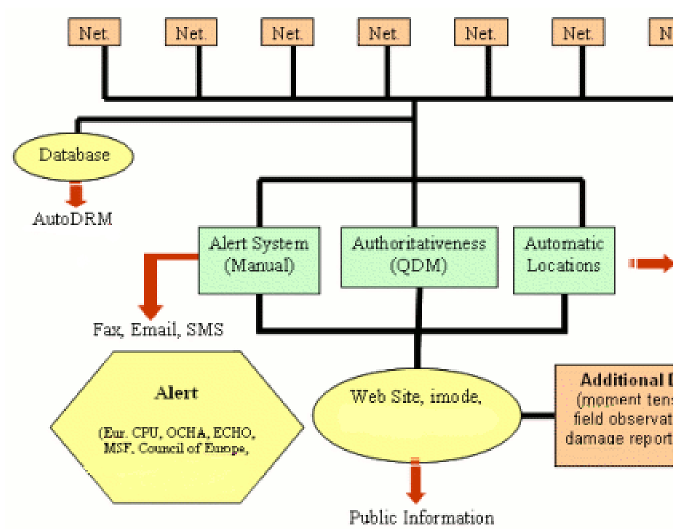


Figure 12: Block diagram of the final system

Finally, there is a reference for all seismology action in the region which is the European-Mediterranean Seismological Center as shown in figure 13 [4]. This center has many nodes (stations) in different locations, so we can consider it as a reference.

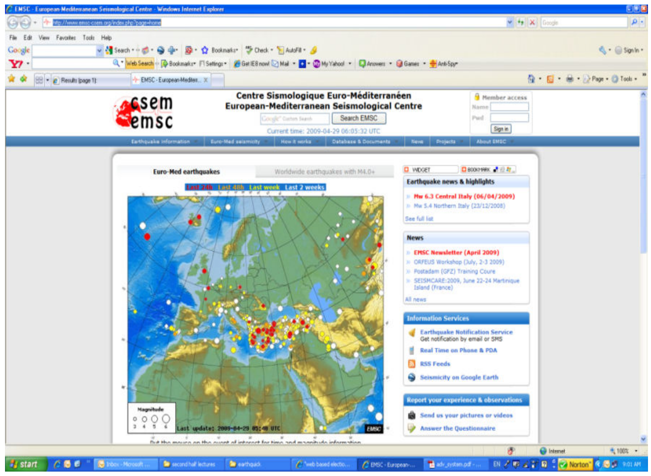


Figure 13: European-Mediterranean Seismological Center home page

V. Acknowledgment:

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VI. References:

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[3] *Kanamori et al., 1997; Teng et al., 1997; Wu and Teng, 2002; Allen and Kanamori, 2003*

[4] *http://www.emsc-csem.org/index.php?page=home*

[5] *IASPEI, INTERNATIONAL ASSOCIATION OF SEISMOLOGY AND PHYSICS OF THE EARTH'S INTERIOR ASSOCIATION SYMPOSIA AND WORKSHOPS*

[6] *Yih-Min Wu 1,* and Hiroo Kanamori; Development of an Earthquake Early Warning System Using Real-Time Strong Motion Signals*

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