QuakeView: A Quake Warning System for Southern California Edison

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ABSTRACT

A research team in the California State Polytechnic University, Pomona has developed a GIS-based earthquake warning software package called QuakeView for Southern California Edison (SCE). QuakeView is the core module of the SCE emergency preparedness system. It estimates wave fronts of earthquakes. It consists of two primary components: the earthquake simulation and the application environment. The earthquake simulation compiles recorded earthquake data and streams the data, in real time, into the application environment through TCP/IP[1] connections. The application environment contains the earthquake data processing server, the real-time event-tracking server, and an ArcView client application. It displays real-time wave fronts that move outwards from the epicenter of an earthquake.

INTRODUCTION

Southern California is a major region that suffers greatly from numerous seismic activities. More than ten thousand earthquakes rattle the region in a given year. Although most tremors are too small to be noticed, major earthquakes will wreak havoc to infrastructure and disrupt the general course of everyday life.

Recently there have been active research efforts in reducing the impact of earthquakes by establishing large-scale earthquake monitoring networks. TriNet, for example, is a network of earthquake sensors that focuses on the real-time detection of earthquakes in Southern California. The California Institute of Technology (Caltech), the U.S. Geological Survey (USGS), and the California Division of Mines and Geology (CMDG) use this network to collect and process earthquake data and provide maps of ground motion after a moderate to major earthquake occurs. The shake maps and their underlying acceleration and velocity of ground motion can be freely downloaded via Internet. The shake map data are thus the reliable sources for scientists, researchers, and agencies with interests in earthquakes and the Earth's behavior.

Southern California Edison, a major electric power provider to more than 10 million consumers in the Southern California region, has employed the TriNet earthquake data and developed an Emergency Management GIS Application called EMIGA. EMIGA, powered by ArcView GIS, overlays ground motion information with SCE's business data for assessment of earthquake damages and notification to concerned engineers of damaged sites.

EMIGA is an excellent system for evaluating and monitoring earthquake damage. However there are significant needs that require quick notification of an earthquake before the shake waves arrive at a particular site. This “real-time” warning system will transmit alert notifications a few seconds before the earthquake reaches a certain location of interest. This will help protect and alleviate damage to any particular site. Hydroelectric power turbines can be slowed down; power transmissions to and from areas ahead of the earthquake waves can be reduced; power from damaged regions can be rerouted; and the integrity of SCE computer systems can be preserved.

Additionally, early notification can also provide significant benefits to the public. It can help reduce earthquake losses by slowing trains, interrupting sensitive procedures such as medical operations, use of toxic materials, or recalling elevators to the ground or to nearest floor.

SCE’s EMERGENCY PREPAREDNESS SYSTEM

Considering the needs of a “real-time” earthquake warning alert, the SCE has been developing an Emergency Preparedness System that uses a satellite-based network for monitoring and warning earthquake activities. Figure 1 shows the conceptual framework of the Emergency Preparedness System. The Emergency Preparedness System collects earthquake activation signals from the *Ultra-Net satellite monitoring system* and the earthquake sensors/substations located in the SCE’s service area (see Figure 2). It then transmits the information to the *Data Streaming* component. The *Data Streaming* component feeds and converts the real-time data into dynamic spatial databases that will be used in the *QuakeView* component. The *QuakeView* component generates the wave fronts of an earthquake and estimates affected zones that can be notified through the *Ultra-Net satellite monitoring system* a few seconds before the earthquake hits the zones. In addition, the *QuakeView* component also displays the status of the USAT / RTU[2] antennas in the Ultra-Net system and the earthquake sensors installed at substations. Furthermore, it makes an alert when an USAT/RTU antenna or an earthquake sensor goes wrong.

Figure 3 shows the information flow in the Emergency Preparedness System. Assume a moderate to major earthquake trembles Southern California, sensors/substations close to the epicenter of the earthquake will first detect the ground motion and send earthquake-related data to the Ultra-Net satellite. As the earthquake waves move outwards from the epicenter, other sensors will “wake up” and send the earthquake data sequentially to the satellite. The satellite will forward the data down to the *QuakeView* system. The QuakeView system plots the wave fronts seconds by seconds and estimates affected zones (or substations) where damages could be reduced before the waves arrive at the zones. The notification will be transmitted via the Ultra-Net satellite to the affected targets for quick response. The entire data collection-alert notification process takes a few seconds and competes with wave movement for emergency response and management.

The Emergency Preparedness System is a large-scale satellite-based monitoring system. Its success is largely dependent on the functions provided by the *QuakeView* system and the integration between the *QuakeView* system and the *Ultra-Net satellite monitoring system*. This paper describes the development of the QuakeView system, a joint research effort made by the Cal Poly Pomona’s research team, and the system engineers and GIS experts in Southern California Edison. The focus of this paper is centered on the system design of the *QuakeView* system and the methodology used for the display of wave fronts. The methodologies used for predicting affected zones and mapping status of USAT/RTU antennas can be found in other references [Tiong and Chang, 2001], [Sun and Lin, 2001].

QUAKEVIEW

QuakeView is a powerful software package that simulates and processes the data streams from the earthquake sensors and the *Ultra-Net satellite monitoring system*. It provides real-time display of USAT/RTU antenna status and earthquake wave fronts. It consists of two primary modules: the *earthquake simulation* and the *application environment*. As shown in Figure 4, the *earthquake simulation* module compiles and processes recorded earthquake data, essentially generating real-time electronic earthquake waves to continuously fed through a TCP/IP connection to the *application environment*. The *application environment* contains the earthquake (EQ) data processing server, the real-time event-tracking server, and an ArcView client application. Within the *application environment*, the incoming data stream is processed into dynamic spatial data and passed onto the ArcView subsystem. The ArcView subsystem displays the status of USAT/RTU antennas and the real-time wave fronts generated by an earthquake.

Earthquake Simulation

The *Earthquake Simulation* module creates earthquakes and wake-up sequences of sensors and transmits them to the *Earthquake Data Processing* module. Ideally, information about an earthquake and its activation to sensors should be generated directly from a network of seismic sensors in the *Ultra-Net satellite monitoring system*. In the development of *QuakeView*, however, the *Earthquake Simulation* module mimics the functions of the *Ultra-Net Satellite monitoring system* and generates ground motion and its activation to sensors using data recorded from historical earthquakes.

Raw earthquake data collected from the California Division of Mines and Geology were used in this project because they can be easily downloaded from an FTP site at ftp.consrv.ca.gov/pub/dmg/csmip. The FTP site contains data for many different earthquakes, which are organized into different folders accordingly. Within each folder, data are further categorized into subfolders corresponding to sensor locations. The sensor location folders contain the data in various formats, including compressed/uncompressed text and binary pictures. The Joshua Tree/Hector Mine earthquake occurred on October 16, 1999 was used for the testing of the *QuakeView* system.

The *Earthquake Engine* shown in Figure 4 compiles and synchronizes a chosen set of earthquake raw data. As different sensors collect information at different periods, or intervals of time, the data are normalized, then synchronized. Table 1 shows that the earthquake data are synchronized with respect to time. The synchronized table records the activation of all sensors for a given earthquake in a chronological order and represents the live period of shake waves that traverse all the sensors. In this table, a single row represents ground acceleration of all sensors at a given time. For example, the third row corresponds to the ground acceleration of all sensors at exactly 2:46:00.03 AM.

Table 1 Synchronized Earthquake Data of All Sensors

Time	**Sensor 1**	**Sensor 2**	**Sensor 3**	**Sensor 4**	**…**	**…**	**…**
2:46:00.01							
2:46:00.02							
2:46:00.03							
2:46.00.04							
2:46.00.05							
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The first “wake-up” time of activated sensor(s), whose ground acceleration is greater than a certain threshold, is determined from the table and used to initialize an earthquake simulation clock. The simulation clock is then incremented by an appropriate interval until the last “wake-up” time of activated sensor(s) is reached. The appropriate interval is often set according to the needs of simulation.

With this table, the *Earthquake Simulation* begins by sending one row at a time to the *Earthquake Data Processing* component of the *Application Development* module through a TCP/IP connection. This process continues until all the data in the table are exhausted or the user interrupts the process.

Earthquake Data Processing

The *Earthquake Data Processing* component is contained within the *Application Development* module of the *QuakeView* system. It filters all incoming earthquake data from the *Earthquake Simulation* module and directs them either to the *ArcView Environment* or to the *Wave Front Logic*. If the data are filtered to the *Wave Front Logic,* calculations are performed on the data to delineate wave fronts, otherwise creating spatial data. After the calculations are completed, the data are continuously streamed into the *ArcView Environment* for further processing. Otherwise, the data are streamed directly into the *ArcView Environment.*

The *Filter Process* within the *Earthquake Data Processing* component is an initial screening for relevant earthquake data streamed from the *Earthquake Simulation* module. When earthquake data are transmitted from the *Earthquake Simulation* module, they contain information about active and inactive sensors. The *Filter Process* filters out inactive sensors and sensors with their ground acceleration less than a predefined value. The sensors that pass through the *Filter Process* are compiled and directed to the *Wave Front Logic*.

The *Wave Front Logic* implements the Angle Sweep algorithm to delineate wave fronts. The Angle Sweep algorithm can be described as follows:

Step 1: Determine the most southerly, easterly, northerly and westerly sensors that are active.

> When a data stream of activated sensors is transmitted to the *Wave Front Logic*, each sensor is represented by a point of static X and Y coordinates. The most southerly sensor is the one with the smallest Y-coordinate in the set of active sensors. The most southerly sensor is taken to be the origin of the *Wave Front* polygon (see Figure 5).

Step 2: Determine wave fronts in Quadrant I

> Given the origin of the *Wave Front* polygon, the *Wave Front Logic* will search for active sensors in Quadrant I ($X_{\text{active sensors}} > X_{\text{origin}}$), calculate the angle between the origin and

each of the sensors in Quadrant I, and determine the sensor whose angle is the smallest. A line is then drawn from the origin to that sensor (See Figure 5). The origin is then moved to the point (or the sensor) with the smallest angle as shown in Figure 6.

Following the same approach, the *Wave Front Logic* determines a point (or a sensor) with the smallest angle with respect to the new origin and draws a line between the new origin point and the point with the smallest angle. This process continues until the most easterly point (or the point with the largest Y-coordinate in the set of active sensors) is reached.

Step 3: Determine wave fronts in Quadrant II

When the most easterly point is reached, the search for the smallest angle is shifted to Quadrant II. The most easterly point is determined to be the point with the largest X-coordinate amongst all points in the set. As shown in Figure 7, the search for the smallest resultant angle using the angle sweep algorithm is continued in Quadrant II until the most northerly point is reached. The most northerly point is defined as the point with the largest Y-coordinate.

Step 4: Determine wave fronts in Quadrant III

When the most northerly point is reached, the search for the smallest sweeping angle is switched to Quadrant III. The Angle Sweep algorithm is performed in Quadrant III the same way as in Quadrant II (see Figure 8) until the most westerly point is reached. The most westerly point is the point with the smallest X-coordinate.

Step 5: Determine wave fronts in Quadrant IV

When the most westerly point is reached, the Angle Sweep algorithm is performed in Quadrant IV as in Quadrant II (see Figure 9). The process continues until the most southerly point is reached. The result is a shape representing the wave front as shown in Figure 10.

The points that represent the outer-most activated sensors of an earthquake wave front are transmitted in their traversing order to the *ArcView Environment* of the *Application Development* module via a TCP / IP connection for the actual mapping.

TCP / IP Connections

The *TCP / IP* connections from the *Earthquake Simulation* to the *Application Development* are crucial for the real-time display of front waves. TCP/IP constitutes the means by which communication is shared between the various application environments. Figure 11 shows the *TCP / IP* connections within QuakeView. The first TCP/IP connection in Figure 11 simulates the communications between the *Ultra-Net Satellite Monitoring system* and the *Earthquake Data Processing* component. The second TCP/IP connection sets up a client/server communication channel within the QuakeView system for the display of front waves. In the *Application Development* module, the Tracking Analyst extension of ArcView GIS is used because it has capabilities of mapping objects (or the front waves in this project) in real time. The QuakeView system uses the port 5102 to feed the vertices of front waves into the event-tracking server as required by the Tracking Analyst extension. The vertices of front waves are packaged in the following format:

Time stamp, Latitude, Longitude, Height, Track ID, Plot Type and Status

The first three fields (Time, Latitude and Longitude) provide critical information with which real-time front waves are plotted in ArcView GIS. All other fields are optional.

ArcView GIS and Its Tracking Analyst Extension

The *ArcView Environment* module of the QuakeView system, powered by the ArcView GIS and its Tracking Analyst extension, reads off the streamed data from port 5102. It triggers tracking actions based on the type of the streamed data. In this project, two types of the streamed data are involved: USAT/RTU status and wave fronts. Figure 12 shows the use of an action handler in the *ArcView Environment* module to detect the type of the data streams and display the status of USAT/RTU antennas or the shape of wave fronts. Figure 13 shows the wave fronts moving outwards from the epicenter of the Joshua Tree/Hector Mine earthquake.

It is noted from Figure 13 that the Angle Sweep algorithm takes full use of the spatial relationships of sensors. The higher the density of the sensors, the more accurate the shape of the front waves represents the true wave movement. A comparison of wave fronts generated from the Joshua Tree/Hector Mine earthquake with those generated from other earthquake such as 1994 Northridge earthquake indicates that the density of sensors or the spacing between sensors greatly affects the shape of wave fronts.

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

QuakeView is a fully functional software package with capabilities to display *USAT / RTU* status and wave fronts and provide acceleration prediction of affected zones ahead of the waves generated by an earthquake. It is a stepping-stone towards the development of SCE’s Emergency Preparedness System.

This paper describes the Angle Sweep algorithm used in the QuakeView system to generate the shape of wave fronts. The Angle Sweep algorithm is effective in creating and displaying wave fronts in a few seconds. It opens a new way of analyzing the dynamic nature of earthquake waves when the shapes of waves are linked to the geophysical and soil conditions of the sites traversed by the waves.

There are still a number of research areas to be explored. The current QuakeView system uses the Earthquake Simulation module to mimic the functions of the *Ultra-Net Satellite Monitoring System*. Much more work can be done with the integration of the QuakeView system into the *Ultra-Net Satellite Monitoring System*, including exploring performance measurement.

The *Wave Front* display component of QuakeView currently archives the shapes of wave fronts only. QuakeView is not capable of archiving other information such as time stamps of wave fronts. These types of information are important for future studies on the impacts of geophysical and soil conditions on wave fronts. Thus, it is highly recommended that the current QuakeView system should be improved to consider these types of information.

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[1] TCP/IP – Transmission Control Protocol/ Internet Protocol

[2] USAT/RTU – Ultra Small Aperture Terminal / Remote Terminal Units that are antennas used for communications with SCE's satellites