# GLOBAL SEISMIC MONITORING NETWORK FOR CLASSROOM USE

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ABSTRACT
This paper describes the Seismic Internet Monitoring Application 2 (SIMA2) project and explains its use for teaching geology, physics, and computer science at the elementary, high school, and college levels. Earthquakes give us important knowledge about the movements of the continental plates and about the structure of our Earth. Shockwaves of any major earthquake propagate through the Earth's interior as well as the surface and can be recorded anywhere in the world. Being able to witness, record, and analyze earthquakes in real time substantially enriches courses of geology and geography. In cooperation between the USA and the Czech Republic, we have built a growing network of simple home made seismic stations that can be located in classrooms and are capable of detecting quakes globally. The seismometer design demonstrates the physical principles of pendulum movement, inertial momentum, magnetism, induction, and voltage amplification. Signals from the seismographs are digitalized by an embedded Java board and transmitted over the Internet to one of our servers. Once stored in a database, students and teachers worldwide can use our free computer application to receive and display both real-time and historical data from any number of servers. Even schools that do not participate in the physical part of the system can have a global seismic monitoring network in their classrooms. This project provides an excellent integrated workbench for teaching elementary and high school geology, physics, and computer science. It stimulates students' intellectual curiosity by showing the close connection of individual subjects and turning learning into adventure.

KEYWORDS
Internet-supported learning, Internet, seismology, geology, geography, physics, computer science

## INTRODUCTION

Earthquakes can be dramatic and devastating events which easily turn large urban areas into fields full of debris, killing thousands and leaving millions homeless. Earthquakes can also be hardly noticeable and subtle events that can be recorded only by sensitive scientific devices called seismometers. In this article, we are introducing the Seismic Internet Monitoring Application (SIMA). This project does not deal with the dramatic humanitarian impacts of major quakes, even though recent history taught us how bad they can be. It is not focused on earthquake prediction, triangulation or tectonic research. Instead, this system has two major *educational* aspects:

- It brings near-real-time seismic data[1] as well as historical seismic data to classrooms through the use of a computer with an Internet connection, substantially enriching education within geology, geography and physics.
- It gives schools a possibility to build their own home-made seismometer and join our amateur educational seismic network, applying and practically demonstrating essential principles of physics and computer science.

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[1] The seismic signal is displayed with a delay in the order of milliseconds, so it is not strictly real-time. The delay is due to the signal processing at the AD converter, the data manipulation at the server, and the Internet connection speed.

## PROJECT HISTORY

The project was initially started at Moravian College, Bethlehem, PA, USA (Gerencher and Jackson, 1991). Students in the introductory Earth Science course continue to fascinate with the real-time seismic signals of home made seismometers, which have been in operation for more than thirteen years. A television in the front of the Earth Science laboratory continuously displays signals from four long-period seismometers, which allow the students to observe many earthquakes, some of them originating on the opposite end of the world. The first author of this article, while being a student at Moravian College, had personally witnessed an earthquake during a class session, and experienced the excitement of finding the epicenter, determining the cause of the earthquake, and learning about the geology and geography of the affected area. However, for all these years, while the system has been in use at Moravian College, its educational impact was limited to one classroom.

In the late 90s, when the Internet speed became sufficient, Moravian College student Michael Sands designed the first version of the SIMA application, which employed the Seismometer-TINI-Server-Client architecture and allowed near-real-time transmission of the seismic signals to any PC computer with an Internet connection (Gerencher and Sands, 2004).

Since 2002, Palacky University student Michal Andrysek, under the supervision of David Skoupil, has been working on the second generation of the SIMA software, moving the whole system to the .NET Framework, replacing the binary communication protocols with XML, and adding many substantial features.

Presently, the second generation SIMA system is ready to be used by any school or individual worldwide. The project uses one server (located at Palacky University, Czech Republic) and gathers seismic data from six seismometers located at Moravian College (Pennsylvania, USA) and Kean University (New Jersey, USA). Any school or institution is also welcome to join the project and become another active source of seismic data.

## SEISMIC WAVES

Earthquakes are caused mainly by the motions of the Earth’s tectonic plates. Although the plate movements are continuous, they are resisted by friction along their mutual boundaries, causing the motions to be failures that are abrupt and episodic. Seismic shockwaves easily propagate through the Earth and often affect the whole planet. Seismologists distinguish three major types of waves that propagate from the hypocenter:

- P-waves (“push-pull”) are longitudinal compression waves in which the particles move back and forth in the direction of the propagation. P-waves travel through the body of the Earth at a very high speed.
- S-waves (“shake”) cause particles to move transversely to the direction of propagation and travel through the body of the Earth at an intermediate speed.
- Surface waves, similar to sea waves, travel relatively slowly, and are confined to the region on and near the Earth’s surface.

In the body of the Earth, P and S waves travel through materials with different density and the physical laws of reflection and refraction apply. Particularly, the waves reflect and refract when they reach the boundaries of the inner and outer core and when they hit the surface. Any body wave is typically reflected both as P and S wave. Seismology introduces a complex system of wave labeling, which shows each wave’s history. For instance, a PS wave is an S wave that was created by a reflection of a P wave from the Earth surface, and a PKI wave is a P wave refracted by entering the outer core and later refracted again by entering the inner core. Figure 1 shows a schematic model of an Earth cross-section 3, 7 and 15 minutes after a large earthquake.

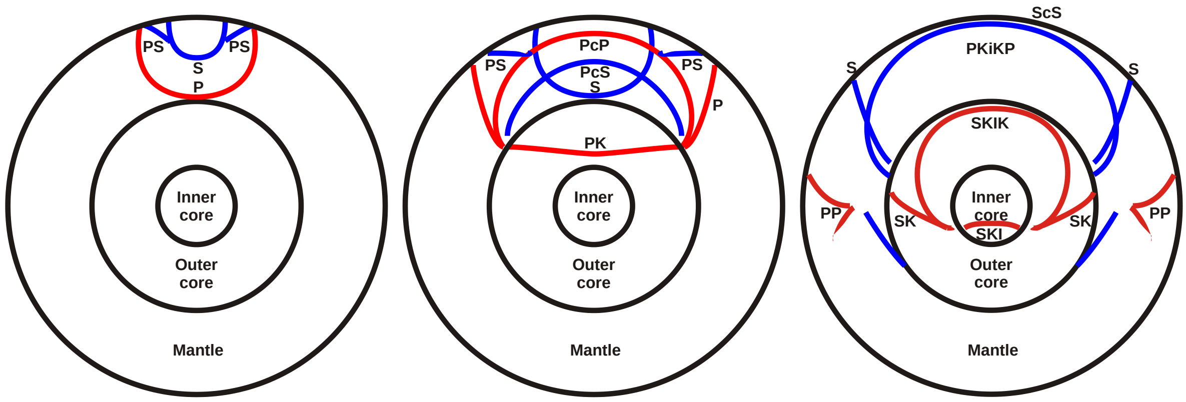

Figure 1. Model of an Earth cross-section 3, 7 and 15 minutes after a major earthquake

Any major earthquake can be recorded anywhere in the world. It takes about 20 minutes for the P wave to propagate through the Earth's core and reach the other side of the globe. The S wave arrives a few minutes later, and the surface wave takes over an hour to circle the globe. The relative amplitude of the surface waves depends on both the magnitude and depth of the earthquake.

## SYSTEM LANDSCAPE

The SIMA project has four major components:

- Set of seismometers measuring the velocity of the Earth's surface movement
- Device for analog to digital conversion, data processing, and Internet transmission of the seismic signal
- Server software for receiving, storing, and organizing the data received from the Internet
- Client software for fetching and displaying near-real-time ("online") data or historical ("offline") data from any of the servers.

Figure 2 shows the relationship of the four major components of the SIMA system. Seismometers are wired to the device performing the AD conversion and the Internet transmission of the signal. In the current configuration, up to four seismometers can be connected to one transmitter. Typically, the earth movement should be detected in three axis (East-West, North-South, Up-Down), requiring the use of three seismometers, and leaving one channel free for experimental use. The server can gather data from an arbitrary number of transmitters (using TCP Internet connections); each transmitter can transmit data to one server at a time. The client can connect via the Internet to any number of servers and display data from their databases. Whereas the seismometers must be in physical proximity of the AD converter and the Internet transmitter, the server(s) and client(s) can be located anywhere in the world.

## SEISMOMETERS

Our system can incorporate any number of commercial or home-made seismometers. Presently, data from five home-made and one commercial seismometer are being recorded, stored in the database and transmitted through the Internet.

Commercial seismometers are often heavy, fragile, and expensive devices that are not easily available and affordable to small schools and individuals. Commercial devices give a high sensitivity, a good signal to noise ratio, and are ready to use. Output of these devices is calibrated, which enables a determination of the magnitude of an earthquake.

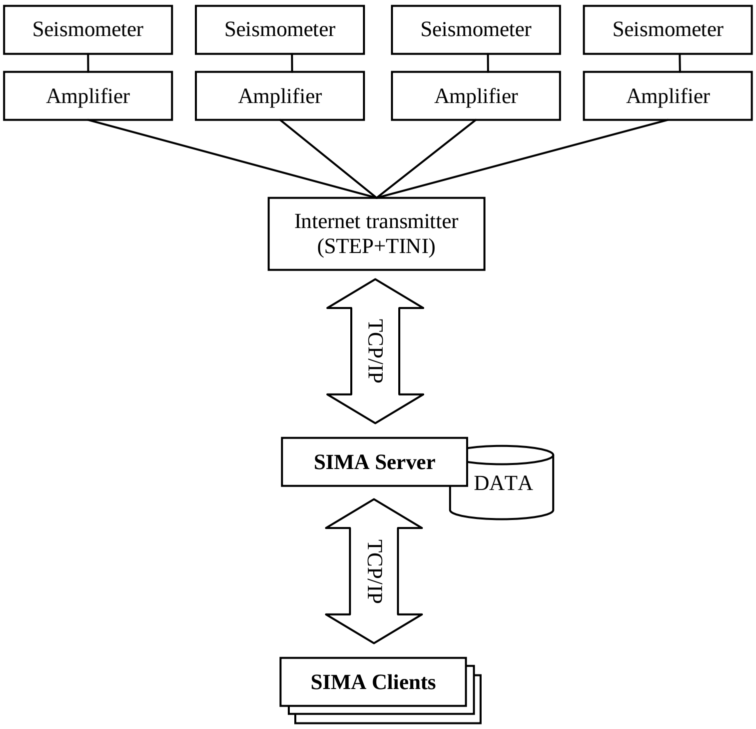

Figure 2. SIMA system landscape

For both financial and educational reasons, however, we prefer amateur home-made seismometers to commercial ones. Amateur seismometers can be built easily and cheaply, for instance, as a part of a student project. Building a home-made seismometer and using it for seismic signal detection brings the students a lot of excitement and demonstrates several important principles of physics.

For our project, we use seismometers based on the Lehman horizontal seismometer design (see Figure 3), described in Lehman, 1977. The design is based on the idea of using the inertial momentum of a heavy pendulum and recording its movement relative to the Earth. During an earthquake, the arm of the seismometer moves relative to the seismometer base, and the attached magnet induces an electrical potential in the adjacent coil. The induced voltage is directly proportional to the speed of the arm movement.

In a school setting, the seismometer serves as an ideal workbench for demonstrating several aspects of classical mechanics, electricity and magnetism. Teachers can take advantage of this system for demonstrating the physical principles of pendulum movement, inertial momentum, magnetism, induction, and voltage amplification. Furthermore, students can gain hands-on experience during construction, setting, and interaction with the system. For instance, changing the period of the pendulum immediately leads to different signal outputs. Systems with long period (our seismometers use a long period of 18 seconds) are relatively insensitive to local vibrations caused by surrounding traffic, elevators in the building, air-condition units, etc., and respond to long seismic waves coming from large distances. Short period systems respond more sensitively to smaller, more local events.

## INTERNET TRANSMITTERS

The analog seismic signal is normalized to a given range. Our seismometers produce signals with amplitude range of 0V to 5V, taking 2.5V as a zero value. The seismic signal needs to be digitalized and transmitted to a SIMA server.

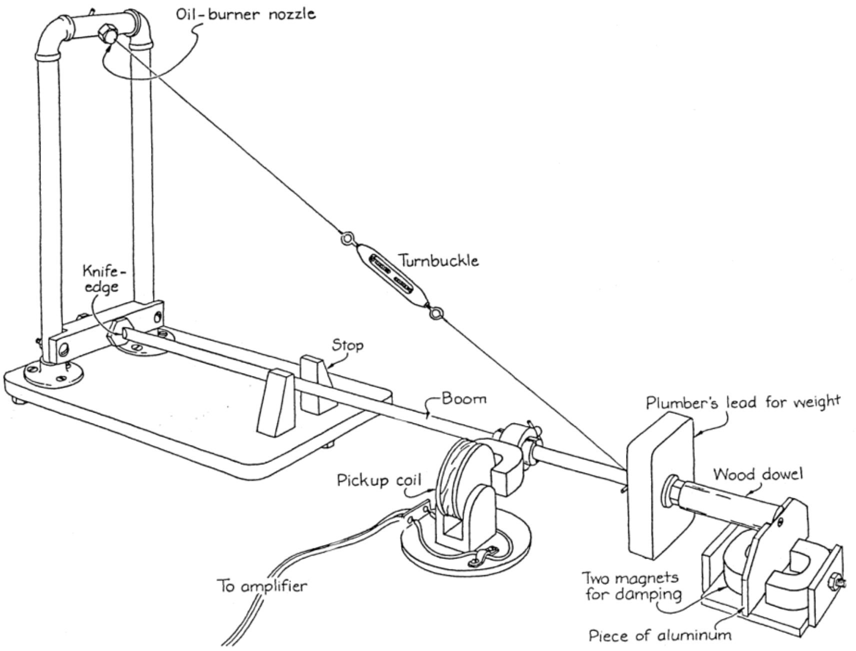

Figure 3. Lehman horizontal seismometer

For this project, we use a combination of STEP board (made by Systronix), which makes a motherboard for the TINI SIMM module (made by Dallas Semiconductors)[2]. The STEP board provides connectors for a power supply, a serial port, and the network. It also includes the AD converter chip. The TINI SIMM module contains a microprocessor, the internal memory, and an embedded Java Virtual Machine. It runs a Linux-like operation system (SLUSH) and supports telnet and ftp connections.

The first software part of our SIMA system is the Java code that runs on the TINI board. The software has several program threads executing concurrently and performing the following tasks:

- Reading configuration values form initialization files
- Synchronizing system time with a public NTP server
- Reading digitalized data from the AD converter that is located on the STEP board
- Listening on specified port(s) for a network connection from a SIMA server
- After a network TCP connection is established, sending the current seismic data to the server.

The communication protocol between the Internet transmitter and the server is based on XML. The protocol consists of an initial handshake followed by a stream of the current measured voltages. For the long period seismometers, transmitting approximately one sample per second is sufficient.

The computational power of the TINI is limited, so there can be very little numerical transformations of the measured data done directly on the board. The current software does two kinds of transformations on the data:

- Data integration–several (usually 10) digitized values are averaged together to make one output value
- Drifting zero correction–a long term running average of the data stream is computed, and the signal is numerically centered at 2.5V, to compensate for the case when an amplifier drifts away from the 2.5V zero level.

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[2] STEP stands for Systronix Tini Engineering Platform; TINI stands for Tiny Internet Network Interface.

## SERVER

SIMA Server is the second software component of the system. It is implemented as a Microsoft Windows Service, and it uses the Microsoft .NET Framework. The server works as a proxy between the individual TINI Internet transmitter boards and the client applications. The server receives the data from any number of transmitters, stores them in a local database, and serves incoming clients' requests. The following list summarizes the main tasks performed by the server:

- It maintains a list of transmitters' IP addresses and port numbers and keeps open a TCP connection with each of them; when a connection drops due to network failure, it tries to reconnect the transmitter as soon as possible.
- It received data from all active transmitters and stores them into a Microsoft Access-based database. The servers overcome the 2GB file limit by transparently splitting the database into several files, giving the administrator a possibility to backup old data to a DVD-R medium and free the disk space.
- It communicates with the administrator management console application using its native protocol.
- It handles requests from clients for historical ("offline") data.
- It handles requests from clients for near-real-time ("online") seismic data.

Under normal circumstances, the SIMA server runs quietly as one of the Windows services and requires no attention from the administrator of the machine. It also does not impose any significant load on the server hardware, with exception of the disk space needed to store the received seismic data.

## CLIENT

SIMA client is the third software part of our system, and it is the only one that is visible to the end user. SIMA client is a managed Windows application running on the Microsoft .NET Framework and using Microsoft Managed DirectX. It can be installed on any machine running Windows NT, 2000, or XP. For the historical releases of Windows, the .NET Framework and the Managed DirectX need to be separately installed.[3]

Using the client software, end users can perform two main operations:

- Request seismic data for any given time period from any available SIMA server ("offline" access).
- Request a running stream of current data from any available SIMA server ("online" access).

The signal coming from one seismometer is plotted as a *seismic trace*. Traces are plotted to windows called *trace panels*. Using a comfortable interface, users can choose to display data from any combination of servers, transmitters connected to the servers, and seismometers connected to the transmitters. For example, in one trace panel, the user can compare corresponding traces streaming from three different sites.

Display properties of each trace panel, such as colors and spacing of each trace, can be adjusted. Within a trace panel, the user can search for seismic events and bookmark a time with a time stamp marker; the trace panel can be also saved to a file and loaded back later. Figure 4 shows a typical screen of a SIMA client application. The peak, visible on one of the traces, is a test signal, which demonstrates the proper operation of the system.

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[3] .NET framework and Managed DirectX will be fully integrated in the future releases of the Windows operating system.

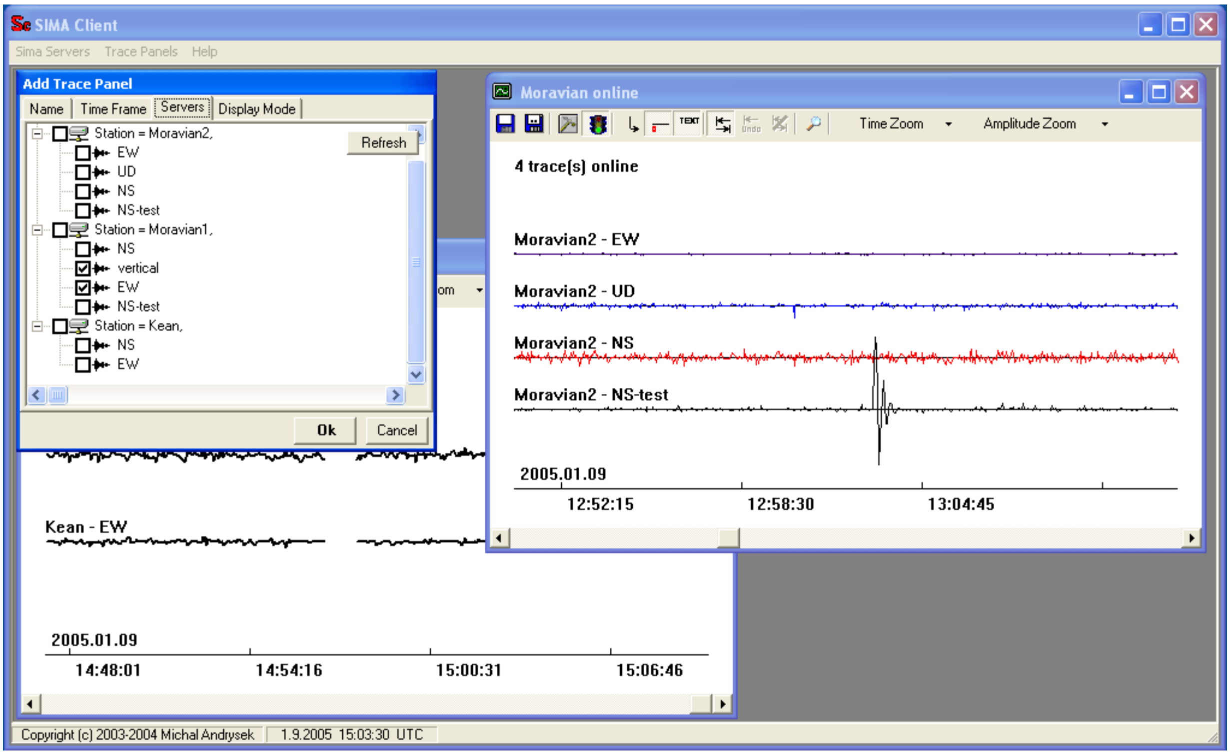

Figure 4. SIMA Client screen

## CLASSROOM USE OF THE SYSTEM

The SIMA system is ready to be used and all software components can be freely downloaded from the project web site. We encourage elementary and high schools, as well as universities, to use the software in their courses and actively participate in the program.

Schools that decide to use our client software can significantly enrich their geology and geography classes by downloading and demonstrating the seismograms of recent earthquakes. Students understand and enjoy teachers' explanations of plate tectonics much better when the explanations are linked to real traces of recent events. By analyzing the traces, students can discover the P, S, and surface waves and learn about the wave refraction and reflection as well as about the structure of the Earth. By comparing the times when the seismic waves are received by geographically distant places, students can try to triangulate the earthquake epicenter. They may be able to relate it to plate boundaries and known faults that caused the quake.

In the geology labs, teachers may decide to dedicate one computer to the SIMA client application and leave the program running 24 hours a day, instantly turning their classroom into an earthquake research and monitoring center. Hopefully, their students will witness an earthquake in real time, watching the individual wave arrivals as they encounter geographically distant seismic stations.

Ideally, enthusiastic teachers may decide to build their own seismometers and run their own servers. This provides an excellent framework for teaching elementary, high school and even university-level geology, physics, and computer science. Understanding the individual parts of the system stimulates students' intellectual curiosity and turns learning into adventure. It helps students understand the direct connection of moving tectonic plates, spreading of the seismic wave, moving of the ground relative to the seismometer arm, induction of electrical potential, voltage amplification, data digitalization and Internet data transmission, and presentation.

## RECORDED SEISMOGRAMS

Based on our experience, our home-made seismometers are sensitive enough to detect an earthquake of magnitude 7 or greater anywhere in the world. In this article, we will demonstrate the seismogram of magnitude 7.0 Colombia earthquake of November 15, 2004, and the seismogram of the devastating 8.5 magnitude Sumatra earthquake of December 26, 2004. Both seismograms were recorded at Moravian College, Bethlehem, PA, approximately 200 km east of New York City.

The first of the earthquakes occurred off the west coast of Colombia on November 15, 2004, 9:07 UTC. The recorded seismogram, shown on Figure 5, exhibits the arrival of the P wave at 9:12 UTC, approximately 5 minutes after the earthquake. A weak PP wave reflected from the Earth’s surface can be identified on the lower trace at 9:15. At 9:19 and 9:22, S and SS waves reached the station. Surface waves arrived to the seismometer location at approximately 9:25 UTC, 18 minutes after the earthquake. Notice that the seismic signals were picked up by the North-South and vertical seismometers, while the East-West seismometer registered no unusual activity. This was due to the malfunction of that seismometer; a drift of the arm had placed the magnet too far from the pick-up coil.

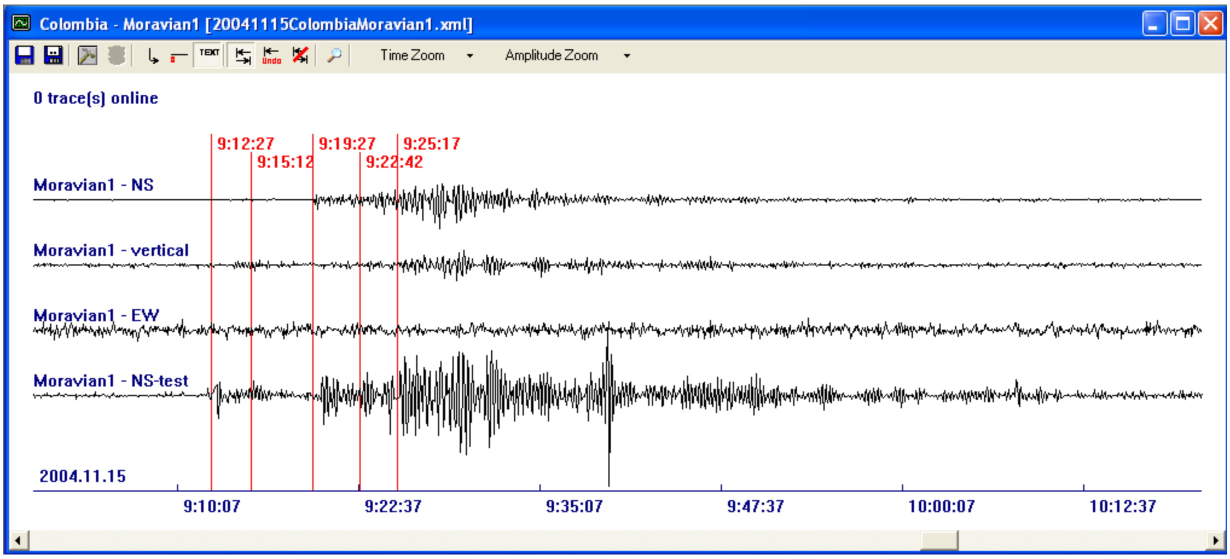

Figure 5. 7.0 magnitude Colombia earthquake of November 15, 2004, 9:06:55 UTC

The second seismogram on Figure 6 shows seismic records of the vastly devastating 8.5 magnitude earthquake, which occurred on December 26, 2004, 00:58:50 UTC, off the west coast of Northern Sumatra. The epicenter was almost exactly on the opposite side of the Earth from the location of our seismic station. The P wave traveled through the Earth’s core (PKIK) and reached the seismometers at 1:21, 22 minutes after the quake. The reflected PP wave could be seen five minutes later at 1:26. Approximately 40 minutes after the quake, the seismometer registered arrival of S waves. Surface waves arrived at 2:08, almost 70 minutes after the quake, and caused the system to go completely out of scale. As with the Columbia earthquake, the E-W seismometer again malfunctioned due to instrumental drift, although the large surface waves caused that seismometer boom to bounce off its extreme limiting arrest.

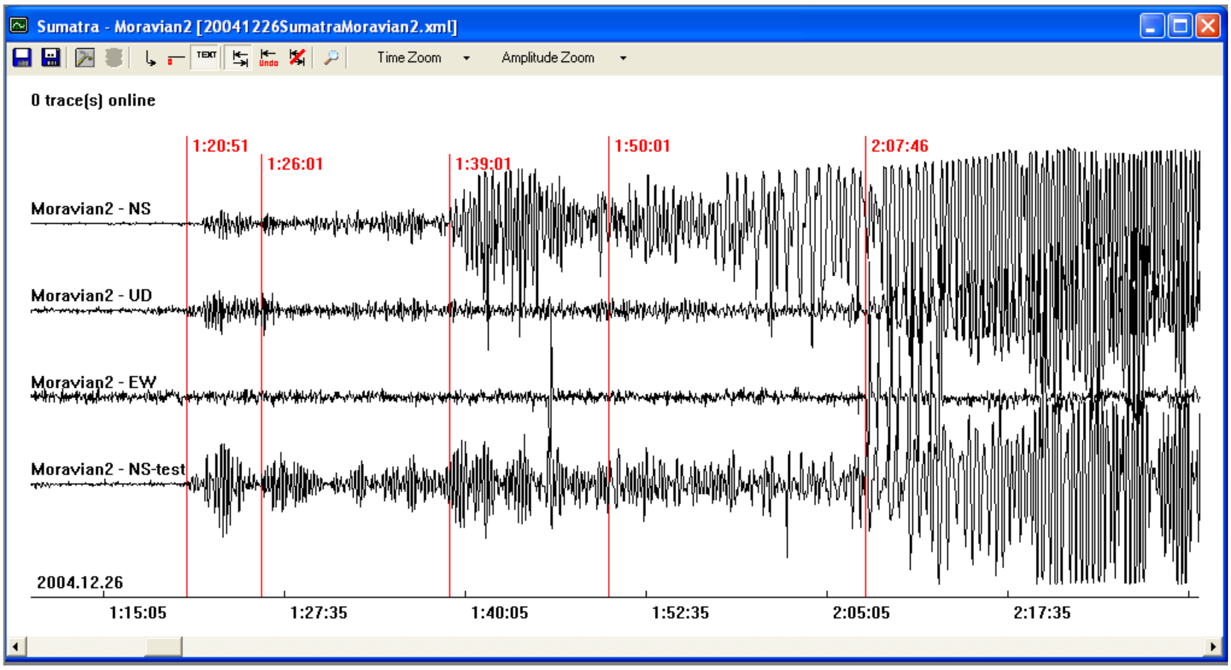

Figure 6. 8.50 magnitude Sumatra earthquake of December 26, 2004, 00:58:50 UTC

## FUTURE DEVELOPMENT OF THE PROJECT

The system will be further developed to include more features and support additional educational applications. The biggest potential for further development can be seen in the following areas:

- Extending the size of the project by introducing new amateur or professional based seismic stations
- Improving seismometer design by using optical (rather than electrical) ways of determining the arm movement
- Improving the XML communication protocol to allow easier coexistence of different versions of the SIMA system, and to provide interoperability with other real time seismic systems
- Implementing data exchange and service relay among individual SIMA servers, using the web-services technology
- Importing and exporting of seismic data from and to different scientific standards
- Applying numerical filtering methods on the recorded seismic data
- Designing other separate but compatible educational applications for 3D simulation of the earthquake wave spreading, triangulating earthquake epicenters, etc.

## CONCLUSIONS

Seismic Internet Monitoring Application is a four-layer system, consisting of seismometers, network transmitters, communication and storage servers, and front-end clients. The system is intended for use in elementary, middle, high school, and even the university to facilitate teaching of geology, geography, and physics.

All software components of the system are available for download from the project web site at http://www.inf.upol.cz/activities/sima and can be used under the GNU General Public License.

Presently, six seismic signals are available from two institutions to demonstrate the functionality of the system. Any classroom or person with an internet connection can receive the seismic signals in near-real-time by downloading and running the SIMA client software on a computer that runs any version of Windows NT, 2000 or XP.

**Note:** The full PowerPoint conference presentation of this paper can be found on the project web pages at http://www.inf.upol.cz/activities/sima/.

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