A remote, wireless microseismic monitoring system

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ABSTRACT

We present a design for a remote, wireless network of seismic sensor stations. Each station includes a 3-C 28Hz geophone, signal processing module, power supply, and data communication facility. The seismic information is received by a control centre station and displayed and analysed. Surveys in the test area (Turtle Mountain, southern Alberta), through fractured limestone, indicate P-wave velocities of about 4600 m/s and S-wave velocities of about 2300m/s. Given a 6-station network and reasonable traveltime picking errors (5-20ms), microfracture hypocentres should be locatable to within about 30m in each direction.

INTRODUCTION

Interest in monitoring hydrocarbon reservoirs to provide improved recovery has increased with the maturation of many oilfields. Instrumentation and analysis advancements are now offering better tools for this monitoring (e.g., Eiken, 2003). More sophisticated production techniques require assessment of their performance with respect to fluid movements, saturation changes, and rock adjustments. Some of this monitoring technology is active – using repeated seismic surveys in a time-lapse or "4D" manner – while some is passive with permanently installed seismic sensors listening to microseismic activity. In the passive methods, emanations from fracturing rock are recorded and their origins (hypocentres) are located. Induced hydraulic fracturing for reservoir stimulation produces seismic vibrations that can be used to map the fractures themselves. In addition, fluid production or its consequences may produce microfracturing (Maxwell et al., 2003). This microfracturing may be recorded and, again, identify regions of fluid movement. In addition, recording of natural sounds and vibrations emanating from the subsurface can be used to create a picture of the subsurface (Okada, 2003; Tippee, 2003).

Seismic recording and analysis have also been used to identify rock bursts in mines (e.g., Dubinski and Mutke, 1996) and landslide movements on slopes for some time. Rockslides are almost always preceded by some type of motion or displacement "signaling" (Erismann and Abele, 2001). This forms the predictive rationale for monitoring hazardous regions. If the motion signals can be recorded and interpreted, then appropriate alerts could be issued. While there may be concerns about investigating geological hazards because of possible ramifications for, say, property values, it may be a greater public disservice to not investigate phenomena that might involve significant future calamity (Milam, 2003).

The applied geophysics group at the University of Calgary has participated in the installation of several seismic monitoring stations (at The Rothney Seismological and Astronomical Observatory at Priddis, a heavy oil production site in northern Alberta, and a satellite-connected site on Devon Is., Nunavut). We are currently constructing an installation in southern Alberta at Turtle Mountain.

Attention has been directed toward seismic activity in the Crowsnest Pass on account of the calamitous Frank Slide in 1903 and numerous rockfalls on Turtle Mtn. since then. Milne and White (1958) conducted seismic investigations in the Crowsnest Pass to study underground motion disturbances in mines called “bumps”. They concluded that these disturbances did not seem to be correlated with the minor earthquake activity occurring during the three years of their study. However, there was a strong association between the bumps’ occurrence and mining operations.

Wiechert and Horner (1981) reported the results of seismic monitoring efforts to investigate reports of shaking events near Turtle Mtn.. They did record three swarms of microseismic activity in the vicinity of Turtle Mtn. over their 2½ months of monitoring. However, with only one seismograph the direction of the events could not be determined. They did suggest that the events were at 10Hz or higher and corresponded to about a local magnitude zero earthquake (said to be well below human perception).

Maxwell et al. (2002) indicate that the frequencies emanating from hydraulic fractures, in the case of oilfield reservoirs, may be “up to several hundred Hz” at distances on the order of 500m. Closer to the source (in a reservoir), Maxwell and Urbancic (2001) suggest that frequencies may be even higher in the 1000s of Hz. Dubinski and Mutke (1996) report that typical dominant frequencies of rockbursts, recorded in cases from Poland, were 2-40Hz some 50-500m from their seismic sources. Lee and Stewart (1981) indicate that very small microearthquakes (magnitude 0) have corner (fall-off) frequencies of about 125 Hz.

SYSTEM DESIGN

Willenberg et al. (2002) report microseismic activity in a landslide area (Randa, Switzerland) of up to 250 Hz and probably greater. They used 28 Hz 3C geophones to record seismic energy with a Geode seismic recording system (from Geometrics Inc.) with a 24-bit A/D converter and sample rate of up to 50kHz.

We are using triaxial geophones (28Hz), encased in cement in a hole drilled in the bedrock, connects to the data acquisition and pre-processing modules. A schematic diagram of a sensor station is shown in Figure 1. The analogue inputs feature independently adjustable gain to four levels: 0, 20, 40, or 60 db. The optional higher gain enables resolution of small-amplitude seismic responses. In addition to the three channels of input from the geophone, the microprocessor receives timing and positional data from a GPS receiver, whose antenna is mounted on the solar-panel mast. Seismic and GPS data are wirelessly transmitted to the control centre. This station is powered by (4) 12V deep-cycle batteries, charged by a 100W solar panel.

In addition to the remote station on Turtle Mountain, we have installed a control centre at the Frank Slide Interpretive Centre (FSIC) for data reception and visualization (Figure 2).

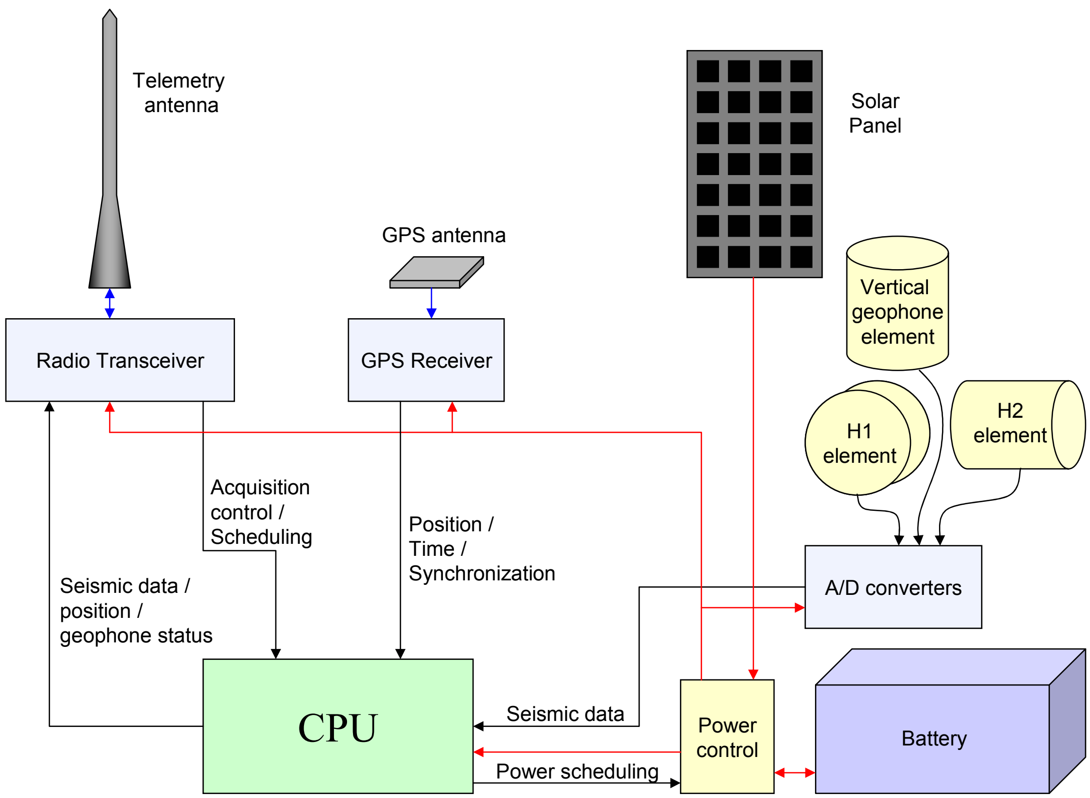

Figure 1. Seismic sensor station

TEST 3C LINE

We conducted a short 3-C refraction survey to determine the elastic characteristics of the limestone in the near-surface. Twenty 3-C geophones were deployed at the Blairmore quarry over a distance of some 40m. We used a sledge hammer as a seismic source. The first-breaking arrivals indicate a velocity of about 4600m/s. In addition, we observe a spectrum of about 100-500Hz.

Milne and White (1958) found reasonable epicentral locations for microseismic events recorded in the Crowsnest Pass when they used P-wave velocities between 4 km/s and 6.5km/s. They suggested an S-wave velocity of ½ the P-wave values. Wiechert and Horner (1981) used "upper crustal velocities" that are reported by Milne and White (1958) to be between 5.6 km/s and 6.2 km/s for hypocentral estimates. The also considered a lower velocity of 4 km/s for limestone and a Vp/Vs value of 1.73 for further estimates in monitoring efforts at Blairmore. Slotboom et al. (1996) used values of 3300-4400 m/s for clastic rocks of Mesozoic and Tertiary ages and 5500-6000 m/s for carbonates of Devonian age in processing seismic surveys through similar rocks in the Alberta Foothills.

Hyprocentre analysis includes implementing software for: 1) synchronizing and storing data from multiple sensors (seismic, weather, and crack monitoring), 2) discriminating micro-seismic events from noise (e.g. cultural artifacts), 3) visualization (input seismic responses and inverted hypo-centre location), 4) display of the weather station and crack gauge monitor information

Additionally, it will be useful to undertake a tomographic survey, using the installed seismic network, to refine the velocity model, and therefore improve the fidelity of the inverted hypo-centre locations.

The Control centre has four separate installations:

1) A roof-mounted antenna assembly, 2) a computer-based display centre on the FSIC exhibition floor, 3) an administration and analysis workstation (anywhere in the FSIC), 4) an equipment rack housing the central network switch, and three computers (one for data acquisition, one for web serving, and one for SQL and file storage). Work flow for the installation of the system is shown in Figure 3. Attendant equipment and tasks are outlines in the Appendix (Tables1-3).

The data from the mountain-based sensors are transmitted wirelessly to the FSIC rooftop. Data are then transferred via cable to the equipment rack network hub. Data from all sensors is processed in near-real-time on the acquisition computer, and then inserted into an SQL database on a database server system. This database server provides a large amount of RAID-5 based disk storage, and will also be connected to removable media backing-up data to an off-site facility.

Data are presented to the public in two ways: via the computer-based interpretive display on the FSIC exhibit floor and via a website. The interpretive display uses a combination of three large high-resolution display monitors to present data. Each screen is driven by a small computer stored in the base of the display cabinet. The monitors are protected by a tempered glass cover, while the computers are protected by lockable doors.

There are a few significant advantages of using several “smaller” high-resolution displays rather than a single large display. Currently-available large-format display panels are well suited for low-resolution imaging functions, such as watching movies. Despite their large size, there are few pixels available on these displays. High-end models only support display sizes of 1366x768. By comparison, three smaller monitors combine to provide a resolution of 4200x1200 pixels (4.8 times the number of pixels). By partitioning the display into three we can logically split the data display in three ways. Three different applications will be used to display the various sensor data, and each application will run on its own computer. This simplifies system configuration and maintenance, while providing the ability to update portions of the display while other portions remain active.

A web server provides internet access to the data. The web server is a separate computer which only serves to process internet data requests. A separate computer is used to eliminate the possibility that data acquisition is slowed by high volumes of internet access and to provide a clear demarcation between the public internet and the (more secure) internal network. The web server will typically request portions of data from the database server, reformat these data for display, and transmit them to web clients throughout the world.

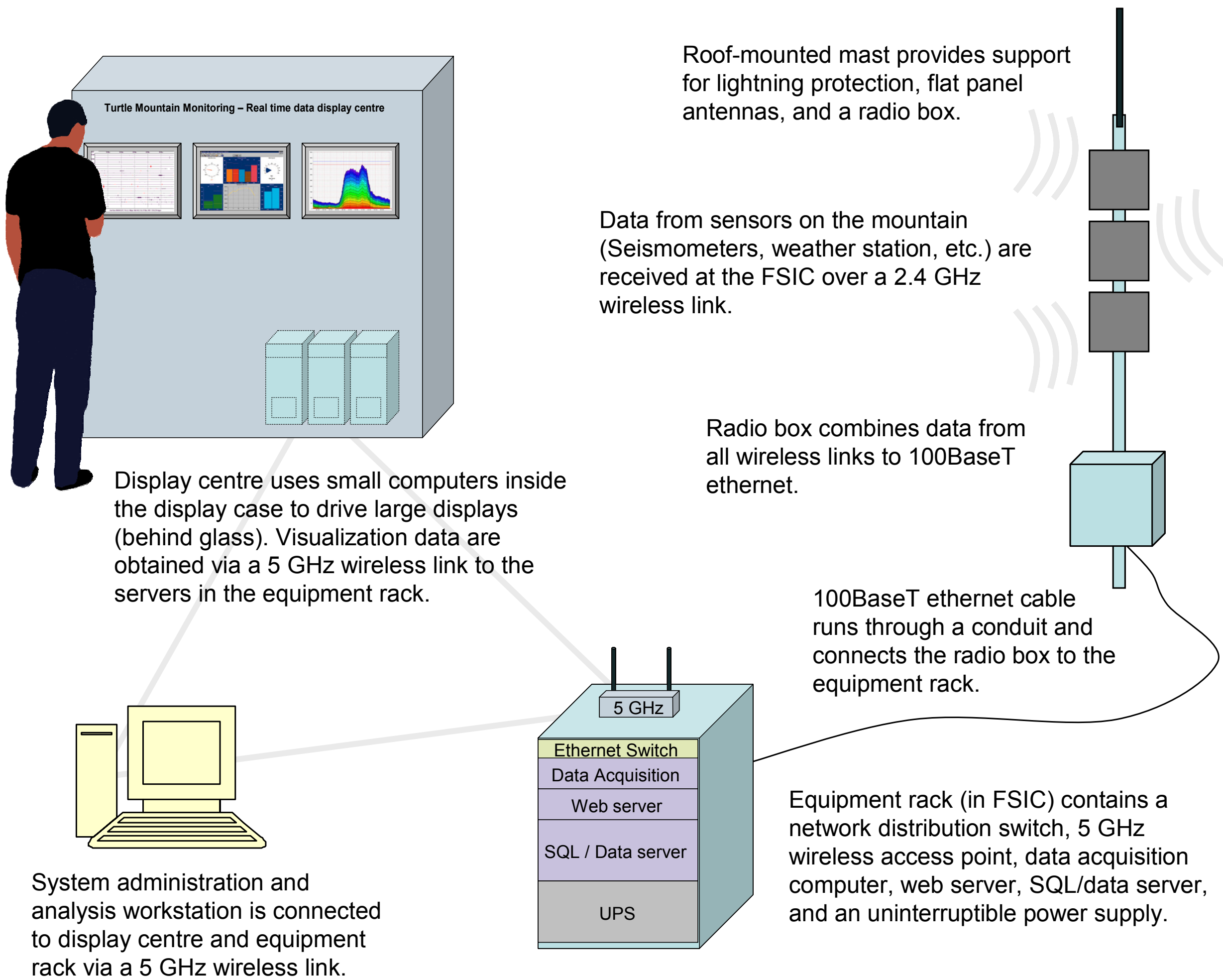

Figure 2. Schematic diagram of planned control centre at the analysis centre.

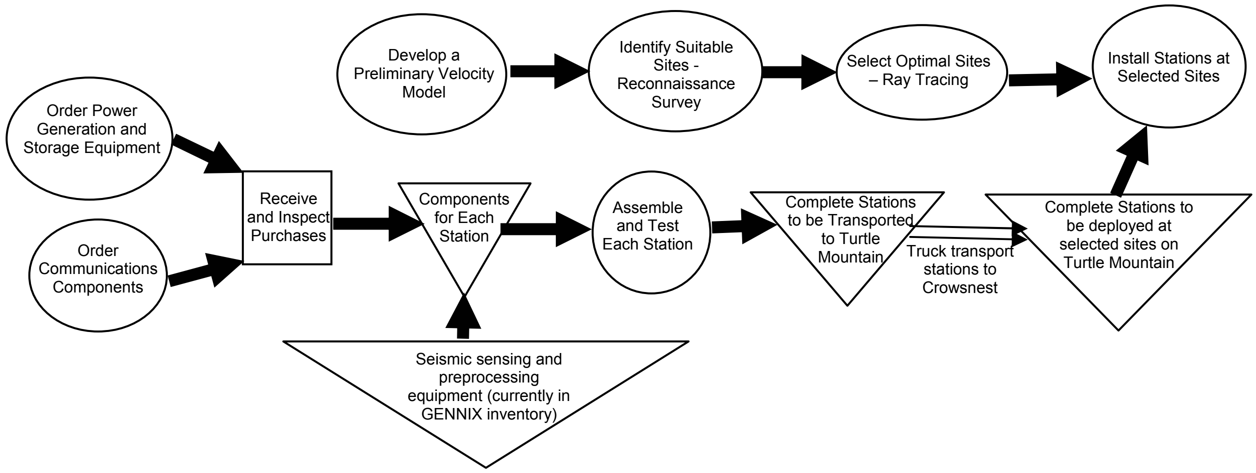

Figure 3. Process flow for installation of seismic stations.

HYPOCENTRE LOCATION

We have tested a range of receiver station distributions and numbers in an effort to determine the requisite number of stations, their placement, and their efficacy at hypocentre location. We used ray tracing code ANRAY4.20 and hypocentre location software HYPO71 and HYPOMH. We assumed a range of picking errors (5 – 30ms) and used to S-P traveltime differences for hypocentre determination. With picking errors of 5ms for P waves and 10ms for S waves, we find hypocentre errors of about 30m x 30m x 30m. We note that for a microseismic event close to the seismic station, say 200m, the transit times would be about 50ms for the P-wave and 100ms for the S-wave.

RESULTS

We have presented a design for a remote, wireless seismic sensor station. The station includes 3-C 28Hz geophones, signal processing, power supply, and data communications. The seismic information is received by a control centre station and displayed and analysed. Given a 6-station network and reasonable traveltime picking errors, hypocentres should be locatable to within about 30m in each direction.

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APPENDIX

Tasks	Time (days)
Display design, educational signage design, coordination with FSIC staff	1
Ensure adequate electrical supply, suitability for antenna installation, airflow, lightning protection, wireless network coverage, and internet proximity to equipment rack	1
Public display cabinet design, drawing	1
Draft drawing of system components and connection logistics	2
Coordinate FSIC control centre renovations with Alberta Community Development	1
Develop specifications for individual system components	2
Arrange logistics for transport of equipment, and confirm arrival	1
Ensure receipt in good working order	1
Assemble and test the equipment rack hardware	1
Install operating systems on equipment rack systems	1
Install and configure SQL database server	1
Install and configure 5GHz wireless network for use within FSIC	1
Install display computers and monitors in educational display enclosure	1
Install MS Office Professional on data management system	1
Document equipment rack OS, SQL server and Webserver installation and maintenance procedures	2
Install and configure commercial data visualization software	1

Install and configure commerical graphics and plotting software	1
Configure software to produce near-real-time displays of sensor data	2
Undertake tomographic survey and use the results to refine the velocity structure of Turtle Mountain	1
Analyzed tomographic data to refine the velocity structure of Turtle Mountain	3
Provide documentation of acquisition, processing and visualization software and procedures	1
Write custom software to insert sensor data into the SQL database	5
Coordinate internet service installation.	1
Develop website distribution of data, including display formats and distribution	4
Develop and document data management procedures, flowcharts, and database structure	4
Develop backup procedure using removable media plan for off-site data replication	2
Test and implement data backup procedure	1
Develop a project website structure in conjunction with Alberta Governemnt	1
Implement the project website including live data displays and access to archive data	3
Develop quality assurance procedures for the control centre.	2
Install and document secure remote access procedures via internet.	1

Table 1. Work allocation for control centre at the FSIC.

Tasks	Time (days)
Measure acoustic and elastic rock properties from hand samples	0.5
Obtain/format digital elevation model of Turtle Mountain	1
Estimate velocity structure of the mountain	2
Model microseismic events to determine optimal station location	4
Select potential sites (photographs, Digital Elevation Model)	1
Use the results of these studies to select optimal station locations	1
Ensure proper operation of existing system	1
Submit station design, and sample of data acquired from currently installed station, for Alberta Government approval	1
Order components, from government, for purchase from third parties	1
Ensure receipt in good working order	2

Assemble and test each station prior to deployment on Turtle Mountain	4
Test GENNIX supplied seismic acquisition components	2
Arrange logistics for transportation of equipment to selected sites, and confirm arrival	1
Arrange helicopter transportation of system components to each site	1
Install individual stations	10
Install individual stations	10
Install individual stations	10
Install individual stations	10
Submit visualization examples and processed data from current FSIC control centre to Alberta Government for approval	1
Provide documentation of acquisition, processing and visualization software and procedures	4
Develop website display routines	3
Specify quality assurance and maintenance procedures	2
Analysis of legacy database to distinguish long-run background response and microseismic events related to potential landslides	2
Analyze seismic data to distinguish microseismic events from cultural noise, and use these as the basis for establishing alarm criteria	2

Table 2. Work allocation for surface seismic stations.

Equipment

Item	Qty
Educational Display	
Viewsonic SyncMaster 21"	3
Dell Dimension 4600 Desktop	3
Custom Cabinet for Display	1
Seismic Processing Hardware	
Dell Dimension 8300 Desktop PC	3
8 port gigabit ethernet switch	1
Sub-total	
Seismic Processing Software	
Continuous Recording	1
Event Detection	1
Real Time Hypo-Centre Location/Visualization	1

Sub-total	
Wireless Communication	
Wireless Access Point (D-Link, 2.4 Ghz)	3
Antenna (2.4 Ghz)	3
Cables	3
Sub-total	
Internet Connection	
FSIC ASDL Internet Connection (/ month)	12

Table 3. Equipment list.

Item	Qty
Power Storage and Generation	
Solar module (100 W)	1
Panel Mount	1
Power Controller	1
Battery	4
Battery Box	1
Battery Cable	6
5 M Copper Cable	1
Sub-Total/Station	
Wireless Communication	
Wireless Access Point (D-Link, 2.4 Ghz)	1
Antenna (2.4 Ghz)	1
Cables	1
Sub-Total/Station	
Data Acquisition and Pre-Processing	
Geophone (3-Component, 40 Hz)	1
GPS Receiver Garmin GPS 35 HVS	1
Seismic acquisition hardware	1
Seismic acquisition software license	1
Sub-Total/Station	
Transportation	
Trucking	1
Helicopter	7

Table 4. Equipment list