Upgrading the CREWES Seismic Physical Modeling Facility

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ABSTRACT

From 2008 to 2015, the CREWES Seismic Physical Modeling Facility utilized acquisition software and hardware that executed under the Windows XP operating system. With Windows XP no longer being supported, CREWES has taken the prudent step of upgrading software and hardware to be compatible with the replacement operating systems (i.e., Windows 7, 8, and/or 10). Also, the growing emphasis in industry on high-resolution 3D surveys has motivated us to add capabilities that enable the completion of physically-modeled such surveys within reasonable time frames. To this end, we replaced the old single-channel A/D module with faster two- and eight-channel A/D modules. Employing multi-channel acquisition with multiple source transducers firing simultaneously, the upgraded modeling facility is expected to be able to complete a 3D survey (supported by efficient post-survey deblending algorithms) with over 10 million deblended seismograms within 240 hours.

INTRODUCTION

The last major upgrade of the CREWES Seismic Physical Modeling Facility was completed in 2008 (Wong et al., 2009; 2008a, 2008b). At that time, we installed high-precision linear motors for the 3D positioning, a fast 14-bit A/D computer board for digitizing ultrasonic waveforms, and automatic motion control and data acquisition software that executed under the Windows XP operating system. In April of 2015, Microsoft ended standard support for the Windows XP operating system, meaning that, in the long term, the essential hardware and software components in physical modeling system would become obsolete. We therefore undertook a major upgrade to change over from the XP operating system to the new Windows 7/8/10 operating systems. This required the purchase of some new hardware and the re-writing of the system software that automatically controlled 3D positioning, digitization of ultrasonic waveforms, and recording of digitized seismograms in SEGY files.

The bulk of activity in seismic exploration/imaging by industry is trending strongly away from 2D surveys to 3D surveys. More and more high-resolution seismic surveys are aimed at the monitoring of production and injection processes rather than at exploration. In order that the Seismic Physical Modeling Facility can be used to efficiently produce datasets representative of high-resolution 3D surveys, the upgrades were designed to include multi-channel acquisition as well as simultaneous multi-sourcing.

Table 1 lists the new hardware and software components that replace the old equivalents.

TABLE 1. List of replacement items.

Item	Function	Replaces
Parker-Hannifin ACR-9600	Eight axes motor controller (Model No. ACR9000-P3-U8-B0)	ACR8020
Sola SDN-2.5-24100P	24 VDC power supply	---
Gage CSE4424	Two channel, 16-bit A/D	Gage CS1450
Gage FCiX (FCI-OCT-001)	Eight channel, 14-bit LAN A/D	Gage CS1450
Olympus NDT 5660B	Ultrasonic preamplifiers	---
Windows 7	PC operating system	Windows XP
mSEGY_Avg.cs	System control software	mSEGY_AB.cpp

NEW HARDWARE

Figure 1 is a block diagram showing how the components of the upgraded Physical Modeling Facility are organized.

Figure 2 shows the main features of the two-gantry, 3D Positioning Subsystem in the Physical Modeling Facility, i.e., eight linear motors mounted on a fixed steel frame. Also shown are the new ACR-9600 motor drive controller and its 24 VDC supply. The fuse box contains 5-ampere fuses that connect to the eight Aries motor drives and provides power to the Parker-Hannifin LXR linear motors. It also contains 1-ampere fuses for the digital controls on the Aries motor drives and for the position/speed/acceleration encoders on the LXR motors. The labels XA, YA, ZA identify Parker-Hannifin linear motors for Gantry A. The labels XB, YB, ZB identify Parker-Hannifin linear motors for Gantry B. The labels XAA and XBB identify backup motors for Gantries A and B, and are not used in normal operation.

New motor controller

The original linear motor controller board (Parker-Hannifin ACR8020 with breakout box) fits in an ISA slot in a personal computer. The ISA interface is obsolete, and it is almost impossible to find a computer with such a slot. That means the ACR8020 controller is also obsolete and cannot be used with current designs of desktop computers and Windows XP. We replaced it with the ACR-9600 controller module shown on Figure 3. This module is external to the system computer, and connects to it via RS-232, USB, and Ethernet links rather than the ISA interface.

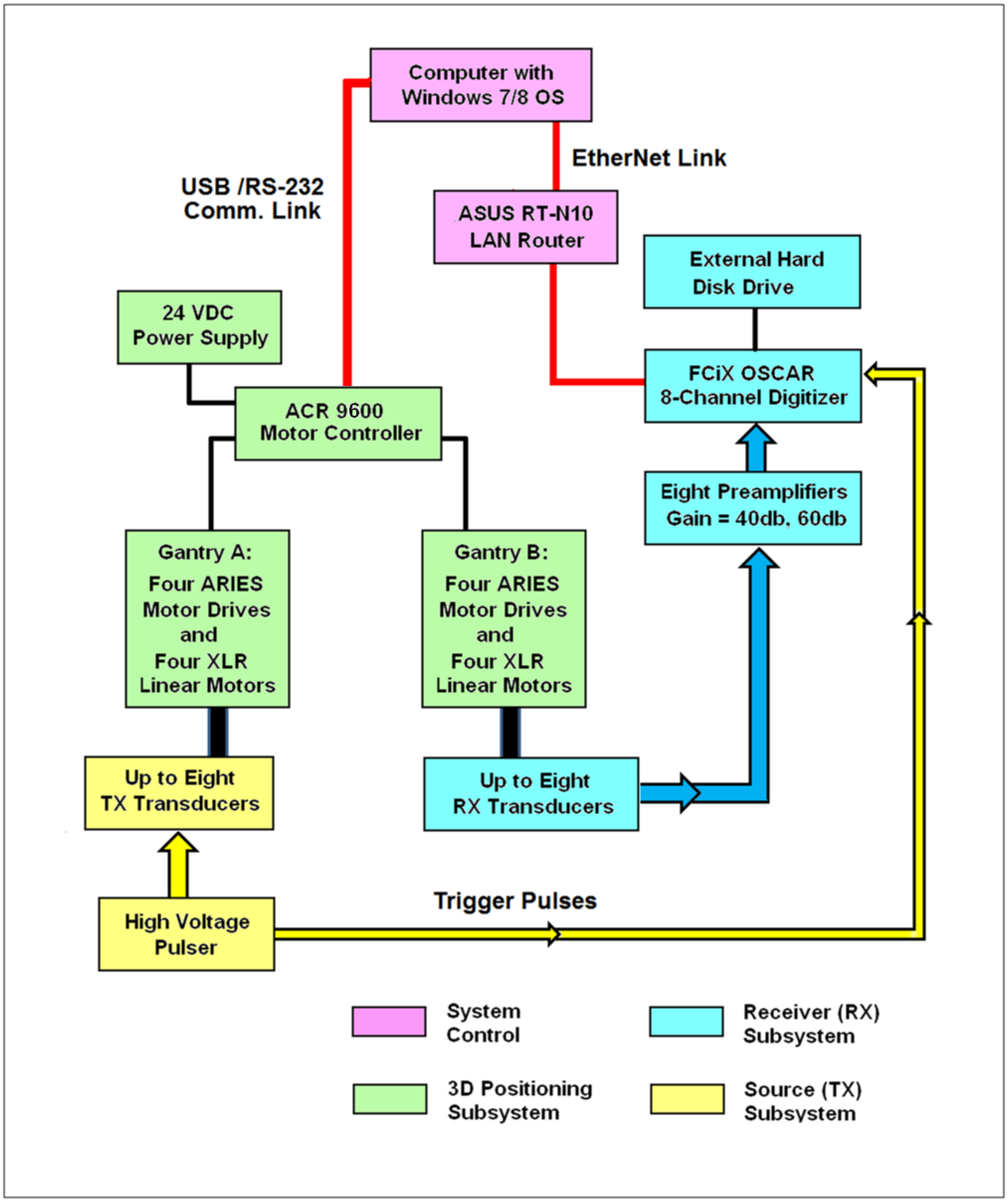

Figure 1: Block diagram of upgraded CREWES Seismic Physical Modeling Facility.

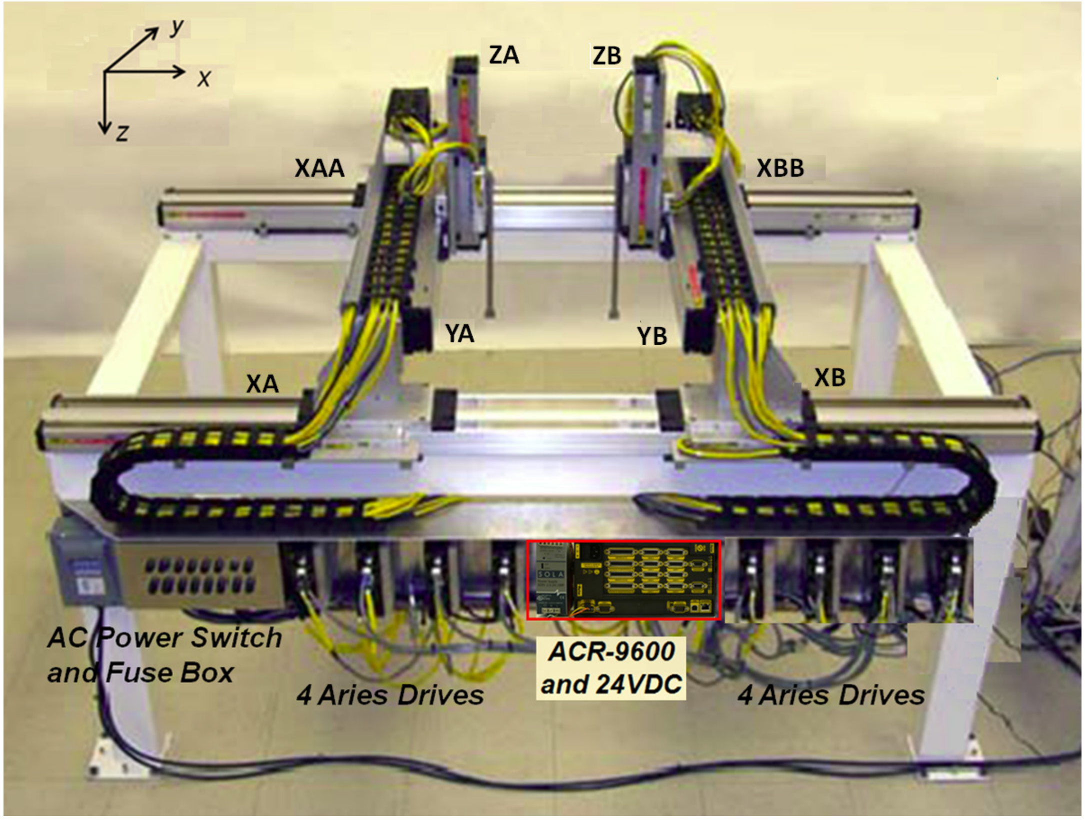

Figure 2: CREWES 3D Positioning System, with the upgraded motor drive controller ACR-9600 and its 24 VDC power supply The Z1 and Z2 404LXR linear motors are mounted in a way that enables their forcers/carriers to approach each other as closely as possible in the X-direction.

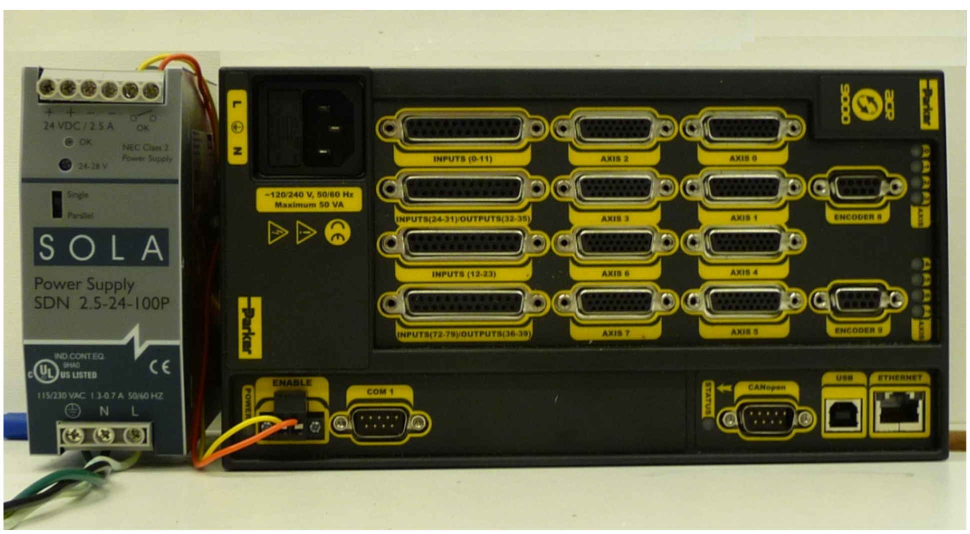

Figure 3: The Sola 24 VDC power supply and the front panel of the Parker-Hannifin ACR-9600 motor controller (Model No. ACR9000-P3-U8-B0).

Figure 4: Gage FCiX Octopus eight-channel LAN digitizer.

New multichannel A/D modules and transducer arrays

In the old data acquisition subsystem, we used a Gage CS1450 A/D computer board. This board had two input channels, and was capable of doing 14-bit conversions at a maximum rate of 25 million samples per second. This board also required an ISA interface in the system computer. Over time, one input channel on the board failed, and we were forced to conduct surveys using only one receiver.

We replaced the CS1450 board with two modules from Gage: a two-channel, 16-bit Oscar CSE4424 board, and an eight-channel, 14-bit FCiX Octopus LAN digitizer (Figure 4). The CSE4424 board fits in a PCIe bus slot on the motherboard of the desktop computer, and is capable of digitizing 50 million 16-bit samples per second. The FCiX module is a LAN device and links to the desktop computer via Ethernet, and can digitize up to 125 million 14-bit samples per second. The high conversion speeds and the multichannel inputs means that high-resolution 3D surveys with millions of seismograms can be carried out in timely fashion.

Figure 5: Left - Olympus 5660B Ultrasonic preamplifier. Right - ASUS RT-N10 LAN router

Eight ultrasonic preamplifiers (Figure 5) are used to amplify the electrical signals from an array of eight receiver transducers (Figure 6). The amplified signals are digitized by the eight-channel FCiX A/D module (Figure 4). The digital outputs of the FCiX are sent to the system computer via an Ethernet connection implemented with an ASUS RT-N10 LAN router (Figure 5).

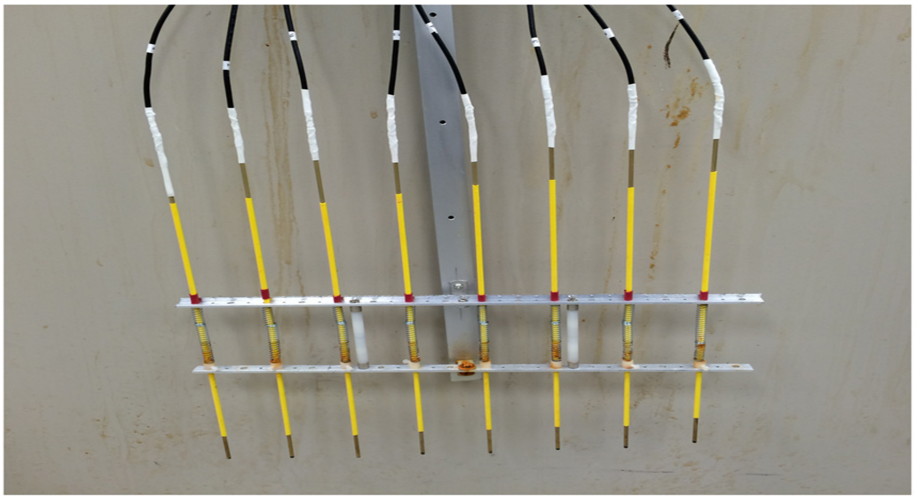

Figure 6: Array of eight piezopin receiver transducers. The receiver real spacing is 40mm; the scaled spacing is 400m.

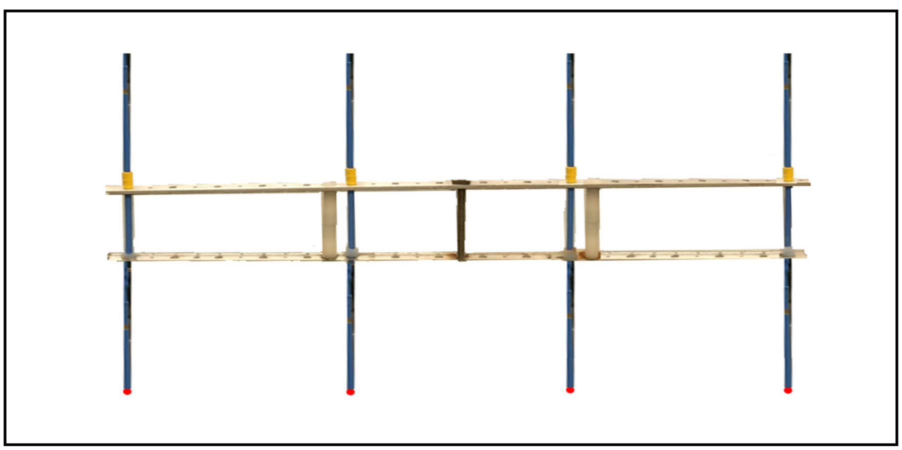

Figure 7: Array of four piezopin source transducers for simultaneous shooting. The source real spacing is 100mm; the scaled spacing is 1000m.

The ability to synchronously digitize and record eight separate receiver signals results in a significant decrease in 3D survey time. An optional alternative to single-source shooting is simultaneous shooting of the four sources shown Figure 7. Simultaneous multi-sourcing leads to further savings in survey time, but it results in summed or blended data that must be separated into ordinary common-source gathers before standard processing and imaging techniques can be applied.

UPGRADED SOFTWARE

System Control/Acquisition

The original system control and acquisition software was written in C/C++ and compiled using Visual Studio 2005 IDE (Integrated Development Environment). The APIs and DLLs for the new Parker-Hannifin ACR9600 controller and the new Gage digitizers changed significantly from the versions used by the old ACR8020 controller and the old CS1450 A/D board. These changes made it necessary to use Visual Studio 2010 to re-write the motion control and acquisition methods in the C# language. The APIs for motion control and for data acquisition are provided in separate Software Development Kits (SDKs) by Parker-Hannifin and by Gage. For 3D surveying we must perform the two essential tasks automatically and in concert, i.e., control 3D motion and record digital seismograms. This required the linking of the separate APIs into one master computer program (provisionally named mSEGY_Avg.cs) for system control...

ACR-View, an application program provided by Parker-Hannifin, is required to initialize the ACR9600 controller before mSEGY_Avg can be used. The system computer is connected to the ACR controller using both the USB and the RS-232 links (ACR-View uses the USB link, while mSEGY_Avg uses the RS-232 link; the separate links prevent communications conflicts).

The new digitizer modules possess at least 80 MB of internal memory, much more than the old CS1450 digitizer. Taking advantage of the extra memory, the re-written software performs fast vertical stacking of up to 4000 repeated waveforms to improve signal-to-noise ratios for seismograms with large source-receiver offsets (vertical stacking on the old CS1450 digitizer board was restricted to 200 to 400 repeated waveforms). The extra stacking capability also is important because, while P-type source transducers can be driven by pulses of up to 365 volts, shear-type source transducers are damaged if they are driven by pulses that exceed 50 volts. Therefore, much more vertical stacking must be used on data produced by S-type sources to bring signal-to-noise ratios up to required levels.

Saving data on SEGY files

An essential component of the system control software is the module that writes the acquired seismic traces and all the most important trace headers into standard SEGY files. The original module for doing this was coded in the C/C++ language. This was also re-written in C# to be consistent with the motion control and acquisition codes.

Deblending algorithms

The upgraded system has the option of simultaneous firing of four or eight simultaneous source transducers, so that the completion times for high-resolution 3D survey are greatly reduced (Vermeer, 2009). However, surveys using simultaneous sources results in ”supergathers” (or “salvos”) for which individual seismograms are the sum or blend of signals from all the sources. Before standard processing and imaging techniques can be applied to data from simultaneous source, the supergathers must be separated or deblended to yield ordinary common-source gathers.

In industry, one technique used for deblending is to ensure that the sources are sufficiently far apart so that clear differences exist in the time moveouts of the signals arriving from the different sources. The moveout differences are then exploited to extract the individual common-source gathers from the supergathers. Sacchi et al. (2004) describe a technique using generalized deconvolution with a library of local waveform operators to do this. The technique is summarized in Appendix A. Alternatively, Trad (2003) and Trad et al. (2012) developed the ASRT (apex-shifted Radon transform) method, in which the blended data are fitted to individual hyperbolas with apexes shifted in time and space.

EXAMPLES OF CSGS ACQUIRED WITH UPGRADED SYSTEM

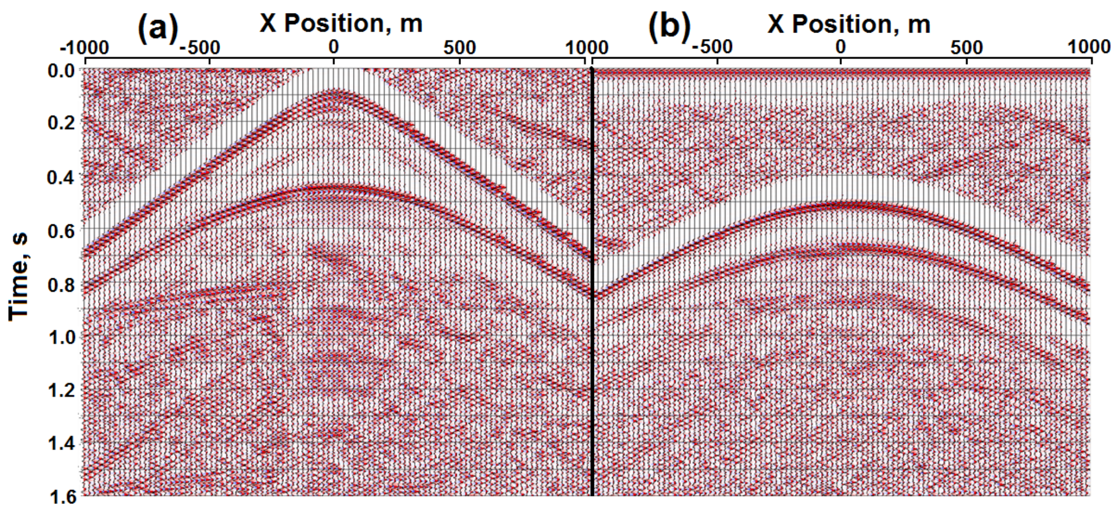

Figure 8: Common source gathers for two receiver lines, recorded using single-source shooting. Receiver line offset = (a) 140m; (b) 740m.

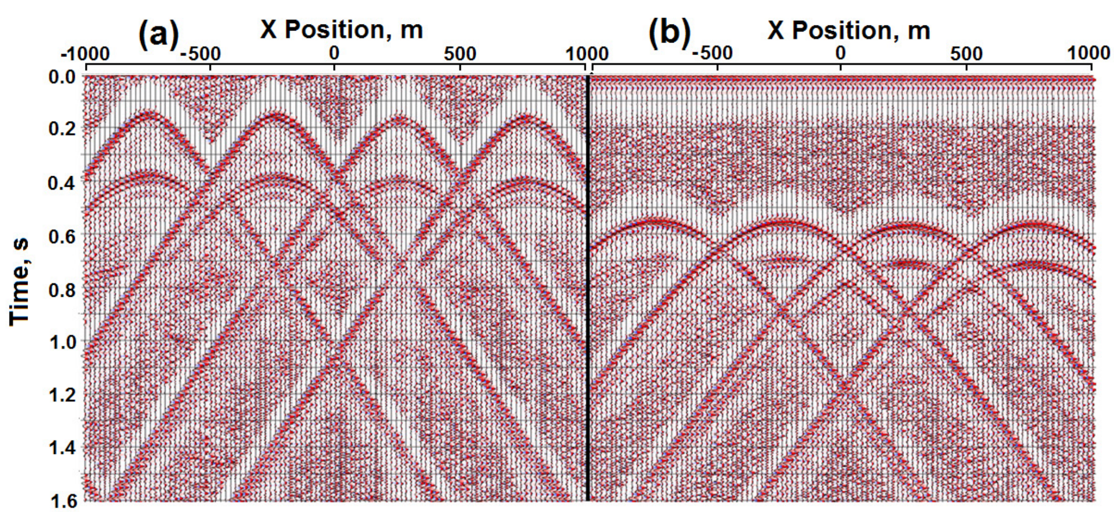

Figure 9: Common source gathers for two receiver lines, acquired using simultaneous shooting of four sources. Receiver line offset = (a) 200m; (b) 800m.

Figure 8 is an AGC plot of physically-modeled marine data recorded with a single source transducer and two receiver transducers. Figure 9 is an AGC plot of physically-modeled marine data recorded with simultaneous shooting of four source transducers (Figure 6) and two receiver transducers. The two receiver signals were digitized with the two-channel CS4424 module.

The times taken to acquiring the data on Figures 8 and 9 were equal (in each case, recording 202 traces took about 250 seconds of survey time). However, successful deblending of the two supergathers of Figure 9 will yield eight ordinary CSGs each separately associated with the four sources. This is four times the number of CSGs on Figure 8 obtained using single-source acquisition.

CONCLUSION

CREWES has been forced to make upgrades to the Seismic Physical Modeling Facility by the demise of support for the Windows XP operating system, and by changes in the design of key hardware components of the 3D Positioning and Data Acquisition Subsystems. Purchasing of modern components to replace their older equivalents was done with the goal of enabling the upgraded system to completed high-resolution 3D surveys much more efficiently. The increased efficiency comes principally from the inclusion of an eight-channel A/D module, the use of four simultaneous sources for acquisition, and the implementation of effective deblending of multisource seismogram gathers into four individual common source gathers.

By implementing the above upgrades, we ensured that the CREWES Seismic Physical Modeling Facility will function well into the future, and will continue to be an important part of the geoscience research infrastructure within the University of Calgary.

ACKNOWLEDGEMENT

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APPENDIX A

Local wavefield decomposition by generalized deconvolution

Define a set of compact 2D wavefield operators:

$$b(t,x,p) = F^{-1}\{S(\omega)h(x)e^{-i\omega px}\}, \quad \text{(A1)}$$

where F^{-1} is the inverse Fourier transform, $S(\omega)$ defines the spectrum of a wavelet, $h(x)$ is a spatial taper, and p is a ray parameter equivalent to the slope of a local plane wave component. The local wavefield operator (LWO) $b(t,x,p)$ takes on many forms depending on the value of p. Figure A1 shows a set of 15 LWO based on p values ranging from -4.75 x 10^{-4} s/m to = 0 s/m.

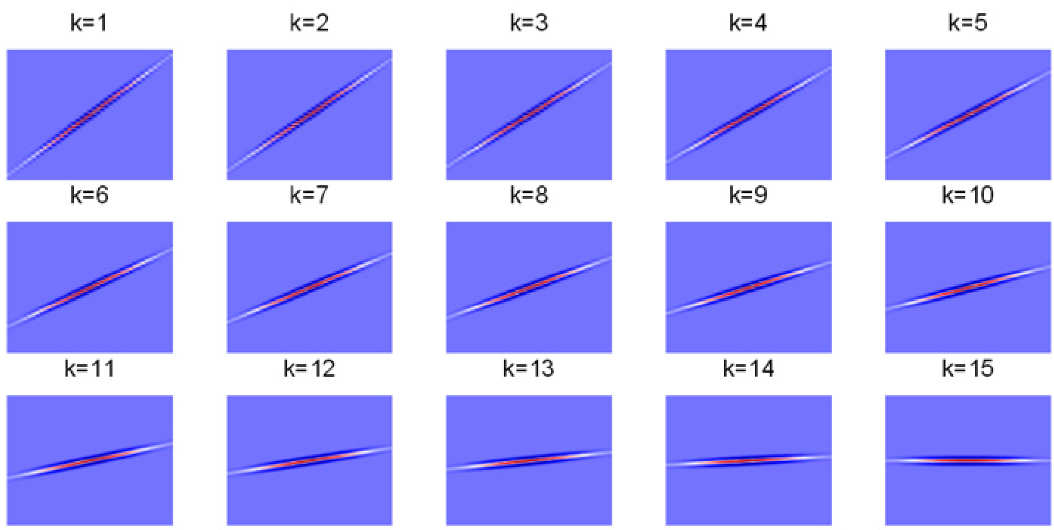

Figure A1: a set of fifteen LWOs, The operator size is 41 spatial samples by 274 time samples, with dt = 4ms, dx =53m (after Sacchi et al., 2004).

Given a set of LWOs, we can approximate a field dataset $d(x,t)$ such as the one shown on Figure 9(a) by the following equation:

$$D(x,t) = \sum_{\mathrm{p}} \sum_{\mathrm{t_i}} \sum_{\mathrm{x_j}} f(t_i,\ x_j,\ p) b(t,\ x,\ p)\ . \quad \text{(A2)}$$

Equation A2 is a 2D convolution involving the coordinates t and x. Generalized deconvolution means finding the coefficients $f(t_i,\ x_j,\ p)$ so approximation to $d(x,t)$ is optimal. We do this by minimizing the objective function

$$J = ||\ W * \{d(x,t) - D(x,t)\}\ ||^2 + R(f) \quad \text{(A3)}$$

using standard optimization techniques such as conjugate gradients. In Equation A3, where W is a sampling matrix used to handle spatially under-sampled data, and $R(f)$ is a regularization term.

Once the coefficients $f(t_i,\ x_j,\ p)$ are found for all $(t_i,\ x_j,\ p)$, individual events with unique $(x,\ t)$ moveout can be reconstructed by selecting appropriate subgroups of the LWOs for summation.

Decomposition of wavefields using seislets

We note that the local wavefield operators are based on a wavelet that is invariant in time and space (the spectrum $S(\omega)$ is constant through the analysis). This is a shortcoming in cases where attenuation causes seismic arrivals to be non-stationary. Fomel (2006) addressed this issue by introducing seislets for fitting waveform found on seismogram gathers.

Seislets are based on wavelet theory. In his analysis, Fomel fits seismic gather data through iterations of Equations A1 to A3 employing wavelets with varying scale at each iteration. Using wavelets with different scales rather than the constant form defined by the fixed spectrum $S(\omega)$ allows for fitting of seismic arrivals that change in shape with time.

A key operation in the construction of seislets is the prediction of one trace from the other by following local seismic event slopes. The local slopes can be estimated using plane wave destruction or by localized velocity analysis. Formal's procedure predicts a trace from its left and right neighbors by shifting seismic events according to their local slopes. The predictions operate at different scales, i.e., uses traces separated by different distances