Report Title: Technical Progress Report 15418R03A

Report Type: Quarterly Report

Reporting Period Start Date: April 1, 2004

Reporting Period End Date: September 30, 2004

Principal Authors: M. Karrenbach

Date: Oct 15, 2004

DOE Award Number: DE-FC26-03NT15418

Subject: An Integrated Multi-component Processing and Interpretation Framework for 3D Borehole Seismic Data
DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.
ABSTRACT

This report covers the April 2004 – September 2004 time period. Work has been performed successfully on several tasks 1 through 16. Part of this work has been reported in 15418R03. Most of portions of these tasks have been executed independently. We progressed steadily and completed some of the sub-tasks, while others are still on going. We achieved the goals that we had set up in the task schedule. Reviewing the results of this work period indicates that our plan is solid and we did not encounter any unforeseen problems. The work plan will continue as scheduled. A midyear review will be presented in November or December 2004.
# TABLE OF CONTENTS

TITILE PAGE ........................................................................................................................................ 1
DISCLAIMER ........................................................................................................................................ 2
ABSTRACT ........................................................................................................................................... 3
TABLE OF CONTENTS ......................................................................................................................... 4
EXECUTIVE SUMMARY ....................................................................................................................... 5
RESULTS AND DISCUSSIONS .............................................................................................................. 6
  Model Building and Generation of Synthetic Data ........................................................................ 8
    3D – Layered – Circular Source Pattern ..................................................................................... 8
  Widget Classes Integrated into Work Bench .................................................................................. 13
    Trace-Related Displays .............................................................................................................. 13
    Composite Volume-style Displays .......................................................................................... 13
  Multi-Windowing with Docking/Un-Docking Features ................................................................ 25
  Basic Objects of the Work Bench ................................................................................................. 33
  Testing and Documentation .......................................................................................................... 35
  Analyzing Flow Requirements .................................................................................................... 36
CONCLUSIONS ..................................................................................................................................... 37
REFERENCES ....................................................................................................................................... 38
EXECUTIVE SUMMARY

Several independent tasks pursuant the statement of project objectives have been executed simultaneously and are still on-going.

Use of real seismic test data is augmented by the creation a 3D ray tracing synthetic test data. We used the previously constructed 3D layered model and simulated data acquisition from a set of circular source locations at the surface of the model, while a close to vertical VSP well was used to capture the wave field data. The source pattern was optimized with respect to Fresnel zone width at the target depth. Multi-component particle displacements were recorded every 50 ft down with an array length of 4,000 ft. P-P as well as P-S reflections were specified in the resulting wave field. We ensured a large enough aperture with enough fine sampling to perform advanced processing, imaging and analysis tests in the future during this project.

We constantly improved the interfacing of our software libraries with newly designed 3C display classes and mechanisms. We used the previously implemented 3C Work Bench tool as the primary prototyping tool. This work bench allows to load as well as manipulate and display data items in a flexible manner. We continued to demonstrate its basic functionality by loading source maps, horizons, seismic and velocity volumes, well logs into the tool, performing basic QC steps as is necessary in normal processing. We improved functionality by adding multiple windowing options to each of the display items. The windows can be docked or un-docked, which is advantageous in a practical sense, since the display real estate can be spread across multiple display monitors. All windows transparently tie into the same item tree and views get updated dynamically and transparently. Each display item can be associated with a particular display widget as is the case for the multi-component hodogram display widget.

All tasks were performed successfully, ensuring the continued progress of this project as outlined in the original proposal. Deliverables generated during this time period consist of reporting details and synthetically modeled seismic data for a 3D layered geological model. The numerically modeled SEGY data, as well as the model representation data, are ready to be sent out to DOE facilities for archiving.

Based on the successful conclusion of work performed during this three month period we continue to occasionally generate synthetically modeled 3D borehole seismic data, according to Tasks 2 and 3. At the same time we proceed to design, implement and test according to the original plan the basic data classes and the basic framework outlined in Tasks 5 through 11, as well as 16.
RESULTS AND DISCUSSIONS

Several tasks as outlined in the original project plan can be carried out independently and simultaneously.

This report covers work performed for

- Task 3: Forward Modeling
- Task 4: Model Generation
- Task 5: Collect Data Types
- Task 6: Design Display
- Task 7: Implement Display
- Task 8: Test
- Task 9: Analyze Flow
- Task 10: Install test MPI
- Task 11: Design Comm. Patterns
- Task 16: Apply and Tune

Task 3:
Travel times as well as multi-component data have been generated in a moderately dipping model. 3D ray tracing has been used to generate travel time tables for selected wave type reflections in a circularly optimized 3D VSP acquisition geometry.

Task 4:
Modeled data has been archived on a RAID storage device as SEGY data set and preliminary power point documentation has been generated.

Task 5
Work has continued on designing basic data type classes, such as seismic and velocity volumes, source location maps, 3C traces, hodograms, horizons, well log curves.

Task 6:
Work has continued on designing the multi-component display framework.

Task 7:
Works has continued on implementation of display classes and widgets.

Task 8:
Work has continued on testing functionality of the display framework and display items.

Task 9:
Work has continued on analyzing data flow requirements for individual items.
Task 11:
MPI has been installed as communication library.

Task 16:
Basic functionality tests have been carried out on real and synthetic data.

The following deliverables have been generated:
- 3D model and seismic data for a moderately dipping velocity model
- Documentation

The following staff members were carrying out these tasks:
M. Karrenbach, V. Soutyrine, J. Robinson, P. Milligan, A. Goertz, A. Hardin
Model Building and Generation of Synthetic Data

3D – Layered – Circular Source Pattern

For Task3 of the project we continued to generate realistic multi-component 3D VSP data. The velocity model had already been constructed in the previous six month period and consists of a 3D layered model with interval velocity changes at the layer boundaries. Figure 1 shows the p-wave velocity model. Other model details with pictures can be found in the previous semi-annually report.

We generated seismic data with an optimized circular source pattern. The optimization was based on Fresnel zone considerations at the target levels. We captured the entire wave field in the VSP receiver array to be used in future test processing. 3D ray tracing software was employed to generate true amplitude reflected multi-component seismic data. The source wavelet was a pressure pulse located at the surface.

The 3D VSP receiver array is located in a vertical well with receiver locations from 405 ft to 4355 ft depth below surface with 50 ft spacing. Sources are located at the surface at a maximum offset from the well head at 5,000 ft. The receiver array records z-component, x-component and y-component displacement. Thus we have a multi-component data set available in later tasks.

During the ray tracing we selected to generated p-p reflections as well as converted wave p-s reflections. The entire recorded data set consists of 3 files. It is currently stored for online access on a RAID disk. Figures 2-4 show selected shot records from these data.
Figure 1: P-wave velocity Model.
Figure 2: Vertical Component of the elastic reflected wave field.
Figure 3: Horizontal component of the elastic reflected wave field.
Figure 4: Horizontal component of the elastic reflected wave field.
**Widget Classes Integrated into Work Bench**

**Trace-Related Displays**

We added a particular widget which is able to display particle motion of multi-component seismic data within the multi-component work bench application. Up to now the work bench application had been using just one 3D viewer widget class. With this addition multi-component data sets can be displayed in a convenient way to analyse hodogram information.

Figure 5 shows the work bench tool with an initial view of Hodogram item added into the work space. The widget allows us to read multi-component seismic trace data and displays these data in various views into the right hand widget window. The widget contains three separate viewing areas. The right most sub-view is a conventional trace display, showing x, y and z component of the multi-component trace for a specific source-receiver combination. To the left of this view there are two sub views that project two separate component combinations into their windows. The lines in those views represent trajectories of the x-z and x-y projected particle motion vector for a number of sample points in time.

In Figure 6 the sub-views are zoomed to a particular region of the multi-component trace and the particle motion trajectories in the two planes are zoomed as well. We dynamically switch the viewers of this widget in Figure 7 to full 3D viewers, thereby allowing us to obtain a perspective view of the particle motion projection with respect to time. We are able to rotate, translate and zoom at will for detailed analysis.

**Composite Volume-style Displays**

Figure 8 through 15 show examples of composite interactive scenes using the 3C work bench application. These composite displays take place in a single display window. Display items communicate seamlessly within the window and to the controlling main window.

Figure 8 starts out with a First-Break Pick item in the tree view of the main window, while Figure 9 shows a selected point view of the same data item. Figure ten shows a display of a well log curve with a cylinder type view, consisting of color coded values mapped onto the circumference of the cylinder. The Display Type option in the main window was set interactively to Cylinder by the user. With this display type a correlation between well log data and seismic image volume slices is particularly easy to see.

Figure 10 shows arbitrary slice of the seismic image volume data item along one of the horizontal axes, while Figure 11 shows a depth slice display of the same data volume.
Figure 13 composes a scene consisting of source location information, a well log curve and a depth image slice of the seismic volume. Rotating the entire scene in Figure 14 overlays the well log curve on a vertical slice where a zoom reveals correlation of events on the well log curve with the seismic events in the image volume. Figure 15 shows the back side view of the volume with the well log overlay and just reaching the target horizon in depth.

Usually, if we have several complex items we would like to compare, analyze and view certain sub-items or composites in their own window. As we see in the current display, this window already contains a large amount of information, which we would like to remain unchanged, while we are examining a particular detail. The next section shows how the multi-windowing combined with the undocking feature is a an efficient way to create a user-friendly work space.

Figure 5: Hodogram display integrated into the work bench. Viewers used are x-y plane viewers.
Figure 6: Besides simple 3D Viewers multi-paned widgets and sub-viewers can be integrated. Here they are used to display particle motion information (Hodogram).
Figure 7: Hodogram display integrated into the work bench. Viewers used are full 3D viewers, that allow 3D visualization of particle trajectory with respect to time.
Figure 8: Picked first-break display of travel time on the source location.
Figure 9: Picked first-break display with point selection enabled, retrieving first-break times for selected source locations.
Figure 10: Well log curve displayed as texture map along the well track.
Figure 11: Seismic data volume displayed with various arbitrary volume slices.
Figure 12: Seismic volume displayed as a depth slice with bounding sides
Figure 13: Composite interactive display of source locations, first-break picks, well log curve and slices through the seismic image volume.
Figure 14: Animated view of the composite interactive scene.
Figure 15: Back side view of the composite scene, well log curve superimposed on volume slice.
Multi-Windowing with Docking/Un-Docking Features

Figure 16 through 20 show how multiple windows can be created within the work bench that contain different sub-item views and composite views. Figure 17 shows the work bench with the main window containing the item tree, option tree and parameter tree. In the item tree various items have been loaded that are displayed in the work space area. When loading individual items, the user can select if a new window should be opened. By default the display will go to the already opened view window. On the bottom of the display once can recognize the four work space windows that are currently active, entitled: Workspace, Grid Volumes, Wells Data and Shot Map. The windows have been undocked but are still constraint to be within the main work space.

Once can clearly see that for certain analyses it is advantageous to maximize the view of certain windows while being unconstraint where to place the sub-views. Especially if multiple display monitors are attached to the computer. Figure 18-20 show the individual composite displays in their respective windows. Figure 17 contains the composite view of source locations, well log and image volume slice, while Figure 18 contains the depth slice view only. Figure 19 and 20 display the well log curve and source location respectively in their own viewing windows.

In the snapshot shown in Figure 21 all display windows have been undocked from the main work space window and are free to be placed anywhere on the desktop display. In this way particular user views can be custom tailored to the needs and requirements of particular users, as well as certain prescribed work flows.

Figure 21 shows the successive state of the composite display arrangement where the user changed the display type of the well log curve in the main window’s item tree. Dynamically two sub-view windows got updated and adjusted. The sub-view window containing the seismic image volume slice view has been manipulated at the same time by curser movement in the 3D display window, which in turn dynamically updated the main windows option and parameter view list.

All the displayed data are taken from a high-resolution data set and a subset has been used to run basic quality control on the seismic imaging results. The usability of the work bench tool is constantly being improved and adjusted.
Figure 16: Workbench with multiple views of various composite display items. Views are still constraint to be within the primary work space.
Figure 17: Window 1, composite view displaying three different display items: shot locations, well log and seismic image volume.
Figure 18: Window 2, view displaying seismic image volume slices.
Figure 19: Window 3, view of well log curve item.
Figure 20: Window 4, displaying source locations.
Figure 21: Undocked windows of main windows and four display windows, allowing ergonomic use of display real estate. Processor and interpreter can zoom compare, correlate, match properties of various data items.
Figure 22: Undocked windows, consisting of main and four display windows, each window can be manipulated independently. Notification is sent if the same data item is displayed in other active windows as well. The ability to efficiently analyze borehole seismic data is greatly enhanced.
Basic Objects of the Work Bench

The work bench application is composed of several high level objects. The most important ones are the User Interface item and the Display Item. The application framework library manages lists of such items. The User Interface items are displayed on the left hand side of the work space. The Display Items are visualized on the right hand side of the display windows. Figure 23 shows the basic relationship between those two items. Both item types communicate through direct method calls or through a signal and slot mechanism. This clear separation between data management and visualization allows to separate tasks in an efficient manner. The user can modify either U-Item or DI-Item. Actions initiated on either side are communicated instantaneously to all objects through the main application.

Basic Objects within PGSI MDI Application

U-Item: a User Interface item
It is an instance of the PGUItem class that represents one unit of data in a PGSI MDI interface.

DI-Item: a Display Item
It is an instance of the PGDItem class, which is a wrapper class for Open Inventor and other visualization objects.

U-Item normally contains the actual data which the user wants to manipulate.
DI-Item has the ability to display these data on a user-prescribed manner.
Each DI-Item has a U-item attached to it and can communicate transparently, through method calls or signal and slots.

Figure 23: A PGSI MDI application consists of several basic objects that are managed transparently through direct calls or signal and slot mechanisms.
From the end user perspective we step through a simple set of steps to create a work space. The user can create a new document within the application, this will open a work space in which several categories of items are displayed. Right clicking on those items shows a list of possible actions: load, save, delete, open in window, and so on. In this manner actual geophysical data are attached to the U-item, which completely hides the loading or the creation process from the user. Depending on the type of object and the data used, a list of configurable and fixed parameters are displayed on the left hand side of the application. The options are displayed in this viewing area and the user can edit those options. Upon hitting the “Apply Changes” button all changes are propagated to their respective recipients and evaluated by the display items. These display items then work through their internal algorithm and update the visualized scene accordingly. The U-item list is visualized as a nested tree structure, with items logically grouped and ordered.

Figure 24: The top-level work flow from the user perspective. Each item in turn has its unique set of options, choices, actions and visualizations.
Testing and Documentation

Previously outlined concepts have been tested on synthetic and real data sets that we selected for this project. We applied simple display schemes to work flows as shown in the previous figures and found that signal and slot mechanisms for communication of actions and status works well in this desktop environment. We will continue to perform such testing throughout the remaining duration of the project.

We selected the open-source tool doxygen to perform basic documentation of the display classes. Class relationships and functionality is reported by this tool in standard formats that can easily generate PDF or HTML outputs.

Figure 25: Workflow performed with real data set.
**Analyzing Flow Requirements**

Examining data flow requirements in the interactive tool shows the need for more sophisticated caching, loading, tracking of data subsets contained in individual objects. The Uitem tree keeps track of the status of its objects and sub-items can retrieve related information by requesting traversal of the Uitem tree. This mechanism will be worked on in the remaining project time frame and is likely to be evolving to an efficient data tracking and flow scheme.
CONCLUSIONS

We executed several independent tasks simultaneously:

- Generation of multi-component 3D borehole seismic data using 3D ray trace modeling for optimized circular source geometry.
- Adding display capabilities to the 3C work bench application.
- Extensive testing of scene graph communication.
- Multi-view implementation and testing.
- Dock/Undock implementation and testing.
- Item tree ordering and manipulation and communication.
- MPI installation and testing
- Data flow analysis
- Application to synthetic and real data of basic functionality.

All, these tasks were performed successfully, ensuring the continued progress of this project as outlined in the original proposal. Deliverables generated during this time period consist of:

- reporting details
- synthetically modeled seismic (We expect guidance from DOE as to the preferred transfer medium for the modeled data.).

The project will continue as scheduled. A mid year review is being planned for November or December 2004.
REFERENCES