Footprint reduction by angle-weighted stacking after migration

Joanna K. Cooper, Gary F. Margrave, and Don C. Lawton

November 21, 2008
Outline

- Review of 2007 footprint simulations
- Description of method for angle-weighted stacking
- Application of method in 2D
- Illustration of method in 3D
- Conclusions and future work
Recap: 2D Footprint Simulations

- Modelled an exhaustive 2D dataset: shots and receivers spaced at 5 m intervals over a 400 m long model
- Created five shot decimations with shot spacings of 10 m, 25 m, 50 m, 100 m, and 200 m
- Applied Kirchhoff prestack migration and stacked migrated shot records
Recap: 2D Simulation (after Cary, 2007)

- Prestack migrated sections:

  - Exhaustive
  - $\Delta S = 2 \Delta R$
  - $\Delta S = 5 \Delta R$
  - $\Delta S = 10 \Delta R$
  - $\Delta S = 25 \Delta R$
  - $\Delta S = 50 \Delta R$
Recap: 3D Footprint Simulations

- Modelled an exhaustive dataset via Rayleigh-Sommerfeld and created one decimation
- Migrated with 3 prestack migration algorithms
Recap: 3D Footprint Simulations

- Comparison: exhaustive vs. decimated on a featureless reflector

Exhaustive

Decimated
Recap: 3D Footprint Simulations

- Comparison of different migration algorithms for the decimated dataset:

**Shot record mig**

**Common-offset mig**
Recap: ‘07 Footprint Simulations

- 2D: Footprint manifests as residual migration wavefronts in decimated datasets
- 3D: Periodic amplitude variations appear in migrated depth slices
- 3D: Migration algorithms, in particular migration weights, make a big difference in observed footprint

→ Can footprint reduction be achieved via prestack migration weights?
Method

- Bleistein migration weights convert from uniform, infinite source and receiver coverage to uniform angular illumination of image point
- Still need to compensate for discrete, finite, irregular sampling (e.g. decimated dataset)
- Normalization may allow wavefronts to properly interfere
Method

- Analogy: numerical integration

\[ \int f(x) \, dx \approx \Delta x \sum_{j} f(x_j), \text{ only if samples are regular and infinite} \]

- For irregular sampling, must compute a weighted sum:

\[ \sum_{j} f(x_j) \Delta x_j \]

- Kirchhoff migration: multidimensional integral in space, approximated by a sum, and weighted in order to achieve uniform illumination of the image point
Method

- Concept: illumination of imaging hemisphere by delta angles
Method

- Delta is also the normal to the migration impulse response
Method

- Consider illumination of imaging hemisphere by delta vectors
- Each source-receiver pair defines a delta angle for each image point
- Want to achieve uniform illumination by normalizing by delta hit counts
Method

- Delta bin hit counts vs. shot decimation
Method

- Fold weights: 1/decimated_hits
Method

- Ratio weights: exh_hits/dec_hits
Method

- Migrate each shot record into delta-limited volumes and apply weights during stacking:

\[
\text{Im}(x_i, y_i, z_i) = \sum_{j \text{ shots}} \left[ \sum_{k \text{ bins}} W_k \cdot \psi_j(x_i, y_i, z_i, \delta_k) \right]
\]

- Or, precompute weights and apply during conventional migration, because weights are only a function of image point position and delta
2D Application

- Results: delta ratio weights

- Exhaustive

\[ \Delta S = 2 \Delta R \]

\[ \Delta S = 10 \Delta R \]

\[ \Delta S = 25 \Delta R \]

\[ \Delta S = 50 \Delta R \]
2D Application

- Results: delta fold weights

- Exhaustive

- $\Delta S = 2\Delta R$

- $\Delta S = 5\Delta R$

- $\Delta S = 10\Delta R$

- $\Delta S = 25\Delta R$

- $\Delta S = 50\Delta R$
2D Application

- **Comparison: ratio vs. fold weights**

\[ \Delta S = 10 \times \Delta R \]
\[ \Delta S = 25 \times \Delta R \]
2D Application

- Comparison: bin widths (ratio weights)

\[ \Delta S = 10 \times \Delta R \]

\[ \Delta S = 25 \times \Delta R \]
2D Application

Comparison: delta ratio vs. abs(delta)

\[ \Delta S = 10 \Delta R \]

\[ \Delta S = 25 \Delta R \]
2D Observations

- Delta ratio weights appear to reduce footprint artefacts
- Delta fold weights compensate for aperture but enhance edge artefacts
- Bin width affects results
- Considering the sign of delta produces better results than abs(delta)
3D Method

- Full simulations, similar to in 2D are currently being produced
- Hit count maps for single shots show how the method will apply
3D Delta Hit Counts

- Delta = 0° hit count is identical to CMP fold
3D Delta Hit Counts

- Exhaustive survey non-zero deltas:

![Heatmaps of hit counts for different angular ranges](image)
3D Delta Hit Counts

- Decimated survey non-zero deltas:

  - Hit count for $\delta c [0.01,10]^\circ$
    - 0.01-10°
  - Hit count for $\delta c [10,20]^\circ$
    - 10-20°
  - Hit count for $\delta c [20,30]^\circ$
    - 20-30°
  - Hit count for $\delta c [30,40]^\circ$
    - 30-40°
  - Hit count for $\delta c [40,60]^\circ$
    - 40-60°
  - Hit count for $\delta c [60,90]^\circ$
    - 60-90°
3D Observations

- Delta hit counts for single shots reflect differences in illumination between exhaustive and decimated datasets
- Delta weights result from summing the hit count maps for all shots
Conclusions

- Delta weights attempt to compensate for irregular image point illumination.
- In 2D simulations, footprint appears to be reduced when delta ratio weights are applied during stacking of migrated shot records.
- The method is similarly applicable in 3D.
Future work

- More work determining optimal binning
- Implementation of Gaussian windowing
- Production of weighted stacks in 3D
- More work on theoretical weights
Acknowledgements

- Sponsors of CREWES
- Sponsors of POTSI
- NSERC
- Alberta Ingenuity