Chapter 6

Conclusions

I introduced the LSJIMP method, a general least-squares inversion strategy to solve the problem of how to combine information from multiple and primary images while simultaneously suppressing crosstalk noise on each image. Successful tests on real 2-D and 3-D marine seismic data confirm that LSJIMP holds great promise as a novel and useful tool in the quest for a better seismic image. While my particular implementation of LSJIMP uses a fast, but relatively inaccurate imaging methodology, the continued trend toward inexpensive parallel computing implies that we may soon have the ability to use more accurate (and expensive) prestack imaging operators in LSJIMP.

6.1 Conclusions on basic LSJIMP theory

In the following section, I discuss some potential future issues surrounding the LSJIMP method in general.

- **Which Multiples?** I cast the LSJIMP method in the fashion of explicit multiple imaging, e.g., one order, split, and multiple generator per operator. Implicit multiple imaging techniques like Guitton's (2002) or Shan's (2003) implicitly image all multiples with a reflection at the free surface. While the conceptual simplicity of the implicit methods is enticing, they have the same problems as the SRME method of multiple modeling. Because the imaging is done by correlating events, each of which has finite bandwidth, the wavelet of the imaged multiple will change, and may complicate the combination of multiple and primary images. Furthermore, the SRME method requires dense area source coverage, which is highly uncommon in today's 3-D marine geometries.

- **Regularization:** The regularization operators presented in section 2.1.3 exploit two forms of signal multiplicity in the image space: that along offset/angle and that between multiple and primary images. An unexplored possibility is to exploit the multiplicity of signal events across nearby midpoints, in the same fashion as Prucha-Clapp and Biondi (2002), by applying a differential operator along the dominant local reflector dip. As those authors showed, however, the quality of the result is sensitive to the prior estimate of reflector dip.

- **Imaging or Inversion in Image Space?** In section 2.1.2, I discussed some requirements for and existing choices of multiple imaging operators. Out of many choices, which is the best? The answer is hardly black and white, and the "correct" answer for one user or application may not suit others. For instance, prestack depth migration produces more accurate imaging results than, for instance, normal moveout or time migration. However, it is widely known that the lack of an accurate depth velocity model negatively affects prestack depth migration. Moreover, in practice, the velocity estimation and depth imaging methods are generally intertwined tightly, and make up the final step before well selection.

  Users may (reasonably) cast LSJIMP as a multiple separation algorithm. LSJIMP outputs a multiple-free estimate of the primaries, which have been enhanced by the inversion. Conventionally, such multiple-free data is a prerequisite to velocity model building and depth migration. Stacking velocities, on the other hand, are available almost at the beginning of the processing flow, so in these situations, users may prefer to use imaging techniques which are less sensitive to velocity, like any method which uses stacking velocity instead of interval velocity.

  One important point to emphasize is this: LSJIMP is an inversion algorithm which operates in *an* image space, not simply an imaging technique or a multiple separation technique. There are many choices of image space, but the central premises and potential of the LSJIMP method remain strong, regardless of the choice.

6.2 Conclusions on my LSJIMP implementation

In the following section, I discuss issues surrounding my particular implementation of the LSJIMP method.

- **Imaging:** Imaging of peglegs in this paper is this thesis is accomplished by HEMNO. Prestack migration implicitly scans over unknown, arbitrary reflector dips to remove the effects of wave travel between source and receiver. HEMNO is a single-CMP, analytic moveout equation that assumes known (small) reflector dips. While HEMNO may lack the accuracy and generality of high-end prestack migration methods, it retains convincing advantages in speed and memory usage. Still, improved availability of large cluster supercomputers indicates that least-squares migration methods may soon be feasible, even in 3-D.

- **Reflection Coefficient:** My modeling of the reflection coefficient of the multiple generator, outlined in Section 2.2.5, is quite simple: a single coefficient. Measuring and applying a higher-order parameterization of reflection coefficient would not be terribly difficult, but the gains might be negligible. My reflection coefficient estimation algorithm benefits from spatial regularization to filter “noise”; with more parameters, would the smoothing any longer make sense? Also, because LSJIMP is an inversion procedure, the estimated images to some extent will adapt to any unmodeled amplitude variation, though the residual will be biased.

- **Other Amplitude Effects:** Levin and Shah (1977) perform a detailed analysis of such acquisition-related amplitude effects like source directivity and the response of source arrays and receiver arrays. I have not accounted for any of these effects in this thesis, though such corrections may be straightforward to apply, given sufficient knowledge of acquisition parameters. Nontheless, deficiencies in the modeling are to some extent accounted for by the reflection coefficient.

6.3 Conclusions on the 2-D Data Results

In general, the LSJIMP method demonstrated high-quality separation results on the 2-D Mississippi Canyon data example. Primary energy was preserved and nicely uncovered from strong, shallow pegleg multiples. The method lacks somewhat in its ability to adequately model salt-related reflections, kinematically or in terms of their amplitudes. For one, the rugosity of the top of salt reflection negatively affected reflection coefficient estimation, especially since my model of reflection coefficients assumes spatial contuinuity, and thus to imperfect separation of salt-related multiples from the data.

While in some cases HEMNO could accurately model the kinematics of these multiples (see Figures 3.10 and 3.11), in cases where the salt geometry varied too fast spatially, HEMNO's performance suffered. I conclude that for moderate, spatially "smooth" dips, HEMNO works well. Failures point to migration (especially prestack depth migration) techniques to tackle the salt problem.

In section 3.2 I investigated what, if anything, the multiples add to the LSJIMP inversion. The improved separation results obtained after adding the multiples confirmed a central assertion about LSJIMP: the use of multiple reflections in a global inversion add a useful constraint to discriminate between signal and noise.

In section 3.3, I applied the LSJIMP nonlinear updating scheme outlined in section 2.1.8 and found that in particular, poorly-estimated reflection coefficients can be improved by the updating scheme, which in turn leads to improved separation results. However, I found that the result of updating the crosstalk weights was negligible to the separation results.

6.4 Conclusions on the 3-D Data Results

On the CGG Green Canyon 3-D dataset, LSJIMP again demonstrated an excellent ability to separate primaries and multiples. The data subset shown in the thesis came from a sedimentary minibasin, which boasts a simple velocity profile, high signal-to-noise ratio, and fairly mild (but non-trivial) dips. The full dataset released by CGG contains much data recorded over salt. In preliminary tests on one salt region, NMO and HEMNO proved unable to correctly image primaries or multiples. The salt bodies often exhibit crossline dips of over 30 degrees, which, when combined with the data's inherent sparsity, severely test even the most advanced imaging techniques.

The data subset is particularly well-suited for Radon demultiple, with its large velocity gradient and gentle geology. I tested least-squares hyperbolic Radon demultiple (LSHRTD) and found that LSJIMP compares quite favorably, both in terms of computational efficiency, multiple separation, and amplitude preservation.

The quantitative study of prestack reflection amplitudes in section 5.2.2 confirmed what was suspected; LSJIMP's ability to remove multiples and random noise, as well as its ability to use multiples and other constraints to interpolate missing traces, greatly improve prestack amplitude analysis.

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