POIC-Radon Filtering of Near-offset Multiples
Min Zhou, University of Utah

Summary
The primary only imaging condition (POIC) can effectively remove some of the migration artifacts generated by multiple energy in the far-offset data. The multiples predicted by a POIC filter in the far-offset data are used to predict and eliminate the near-offset multiples in the $\tau-p$ domain with the Radon transform. The hybrid algorithm is tested on a simple synthetic example and the 2-D SMAART JV Pluto 1.5 dataset which is associated with a complicated velocity model. Results indicate that this approach is effective in predicting and attenuating some of the surface related multiples. The POIC image with both near and far-offset data has higher image resolution than the one obtained with just the far-offset data. The high resolution Radon transform is helpful in improving the resolution in the $\tau-p$ domain so that the performance of the hybrid approach can also be improved.

Introduction
The primary-only imaging condition (POIC) is used for discriminating primary reflections from multiple reflections during the migration process by using a traveltime constraint, an incidence angle constraint and a take-off angle constraint. Though POIC was only used for migration in the previous work (Wang et al., 1999; Sun, 2001; Liu and Sun, 2002; Zhou et al., 2003), it can be used as a filter which separates the primary and multiple events. The cost of POIC migration is almost the same as the standard prestack Kirchhoff migration since it exploits the computationally efficient prestack wavepath migration (Sun and Schuster, 1999). POIC is also very flexible, it can easily cascade with other demultiple approaches, such as the moveout-based methods in the $f-k$ or $\tau-p$ domains (Foster and Mosher, 1992) and the prediction/subtraction methods (Verschuur and Berkhout, 1997a-b).

Zhou et al. (2003) applied POIC to the Pluto 1.5 data, a 2D synthetic elastic dataset provided by the SMAART JV (www.smaartjv.com). The dataset has strong surface related and interbed multiples associated with the water bottom and salt interfaces; however, they are challenging for multiple suppression algorithms due to the complex structures. The multiples are frequently non-hyperbolic and the deep water sediments are slow so that the standard moveout-based methods do not work well. Results from POIC indicated that the migration artifacts generated by the free-surface multiples associated with the water bottom, and the top boundary of the salt bodies are successfully removed by POIC (Zhou et al., 2003). However, due to the small angle differences between the primary and multiple events in near offset data, the near offset data were usually excluded for POIC migration (Sun, 2001; Zhou et al., 2003). The lack of the near-offset data results in poor vertical resolution for the salt boundaries and some of the flat sediment reflectors.

In this paper, the multiples in the near-offset data are predicted and subtracted in the $\tau-p$ domain with a parabolic Radon transform, with guidance by the multiples separated with the POIC filter in the far offsets. Tests on a simple synthetic example and the SMAART dataset both indicate that the proposed hybrid approach with the POIC filter and the Radon transform is effective in removing the multiples in the near-offset data. The POIC migration image with the near-offset data has higher image resolution. However, with the standard Radon transform, the resolution in the $\tau-p$ domain is not very high which can degrade the overall performance by attenuating some of the primary energy. A high resolution Radon transform in an iterative mode and a more sophisticated subtraction algorithm are the subjects for future research.

Predict and Subtract Multiples at Near Offsets
As mentioned above, POIC works well with the far-offset data but it does not work well with the near-offset data. To separate the primaries from the multiples in the near-offset data, the information from the far-offset data should be used. A straightforward way to predict the near-offset multiples is to trace the events from the near offset to the far offset. This is only possible for the data associated with a simple model where the events are clear, continuous and isolated from each other. When the events become discontinuous or conflict with each other, it is very hard to trace the events one by one. A prediction filter or Radon transform (Sacchi and Ulych, 1995; Trad et al, 2002) which predicts or interpolates the near-offset data based on the far-offset data, could be the alternatives when the events are hard to trace.

In this paper, the parabolic Radon transform is used to interpolate and remove the multiples in the near-offset data in the $\tau-p$ domain. To illustrate the procedure, a simple synthetic example is used. The synthetic data in a common-mid point (CMP) gather are shown in Figure 1a. 
POIC-Radon Filtering of Near-offset Multiples

with the primary and multiple events shown in Figures 1b and 1c, respectively. The data simulate a CMP gather after NMO and DMO corrections so that the primaries are flat and the multiple trajectories are still curved. The predicted multiple events are shown in Figure 1d with a large gap in the near offsets and small ones in the far offsets which simulates the multiples predicted by POIC.

The data and the predicted multiples are transformed to the \( \tau-p \) domain as shown in Figures 2a and 2b with the parabolic Radon transform. The \( \tau-p \) section for the predicted multiples is similar to the corresponding part for the data panel, but with smaller amplitudes and some background noises. These differences are due to the gaps in the predicted multiple section. The amplitudes of \( \tau-p \) sections in Figures 2a and 2b are locally compared in a window of 3 horizontal traces and 11 vertical samples by summing the squared amplitudes. If the ratio of the summed amplitudes in the local window from the predicted multiple panel with respect to the one from the data panel is larger than 0.5, the amplitude value in the data panel (Figure 2a) is assigned to the corresponding point in the fitted multiple panel which is shown in Figures 2c; otherwise, zero is assigned which means the value in the predicted multiple panel is totally due to the noise. By this process, the fitted multiple panel eliminates the small background noise in the \( \tau-p \) section of the predicted multiple panel and fits the amplitudes associated with the multiple events to their true values, e.g., the ones in the \( \tau-p \) section of the data panel. The subtraction of the fitted multiple panel from the \( \tau-p \) section of the data panel gives the desired primary panel (refer to as fitted primary panel) as shown in Figure 2d. It is obvious that this simple subtraction process can not work well when the multiple and primary events are overlapping in the \( \tau-p \) domain.

Figures 3a - 3d show the fitted multiples in the \( t-x \) domain, fitted primaries in the \( t-x \) domain, and their errors with respect to the real data in Figure 1b and 1c, respectively. The primary and multiple events are recovered very well after processing. The errors in the primary panel result from the overlap of the primary and multiple events in the \( \tau-p \) domain. The remedy to this overlap problem in the \( \tau-p \) domain is to use the sparse Radon transform (Trad et al, 2002; Trad et al, 2003) which has a higher resolution than the standard Radon transform used in this report.

Depth Imaging For SMAART Data

The SMAART JV Pluto 1.5 data were computed on a 25 by 25 foot grid. In this report, a smoothed version of the true velocity model with a 75 by 75 foot grid is used for all migrations. A CMP gather with a CDP of 8703 and an offset range of \(-9000 \text{ft} \) to \(+9000 \text{ft}\) is shown in Figure 4a. The predicted multiples from the POIC is shown in Figure 4b with the free-surface related multiples associated with the water bottom and the salt body marked in the figure. All the multiples are correctly predicted by POIC except for those in the near offsets where the predicted multiple events are either missing or discontinuous.

Following the same procedure mentioned above, the multiples in the near-offset data are predicted and subtracted from the data in the \( \tau-p \) domain. The primaries are then transformed back into \( t-x \) domain and migrated. Figures 5a and 5b show the fitted primaries and multiples in the \( t-x \) domain, respectively. The multiples associated with the water bottom and the salt body are mostly attenuated. The Kirchhoff depth migration (KM) image with the fitted primaries in an offset range of \(-4000 \text{ft} \) to \(+4000 \text{ft}\) is shown in Figure 6b (referred to as the POIC-Radon image) and compared with the KM image with the original data in the same offset range (Figure 6a). In the POIC-Radon image, the multiple artifacts associated with the water bottom and the top of salt body are well attenuated which indicate that this hybrid approach is effective. However, due to the low resolution in the \( \tau-p \) domain, the subsalt structure located near the multiple artifacts are also somewhat attenuated. This indicates that the sparse Radon transform is preferred.

The POIC-Radon depth image from the near-offset data is then added to the POIC image from the far-offset data (Figure 7a) to form the POIC image from all offset ranges as shown in Figure 7b. The multiple artifacts in both POIC images are well attenuated except for those associated with the dipping bottom of the salt. The POIC image obtained from all of the data is comparable to the KM image and has better image resolution than the POIC image from only far-offset data due to the contributions from the near-offset data.

Discussion

Although POIC is both effective and efficient in attenuating the migration artifacts associated with some of the surface-related multiples, it can not handle the near-offset data very well due to the small angle differences between the primary and multiple events. A \( \tau-p \) domain approach which predicts and subtracts the multiples in the near-offset data guided by the multiples predicted by POIC in the far offsets, is proposed and tested on the 2-D SMAART dataset. Results indicate that the approach is effective in separating the primary and multiple events in the near offsets. The POIC image with the near-offset data has higher resolution than the one with only the far-offset data. However, due to the low resolution in the \( \tau-p \) domain, the current version of the hybrid approach attenuates some of the primary energy close to the multiple events. In addition, among the multiples pre-
POIC-Radon Filtering of Near-offset Multiples

dicted by POIC, some primary events were also picked by POIC due to the conflicting primary and multiple events, the ray-tracing errors, incidence angles errors, and the smoothed velocity model. Possible improvements to this approach include improving the performance of POIC, using it in an iterative mode with a high resolution Radon transform, developing more sophisticated subtraction algorithms, and incorporating it with other $\tau-p$ domain demultiple approaches to separate the multiples from the primaries.

Figure 1: Synthetic CMP data. a) Data with primary and multiple events; b) primary events; c) multiple events; d) the predicted multiple events with the gaps in near offsets and far offsets. The primary events are flat while the multiple events are still curved.

Figure 2: The $\tau-p$ sections of a) CMP data in Figure 1a, b) predicted multiples in Figure 1b, c) the fitted multiples, and d) the fitted primaries obtained by subtracting the fitted multiples in (c) from the data in (a).

Figure 3: Fitted multiples and primaries. a) Fitted multiples; b) primaries; c) normalized errors of the fitted multiples in (a) with respect to the true multiples in Figure 1c; d) normalized errors of (b) with respect to the true primaries in Figure 1b.

Figure 4: CMP8703. a) Data; b) the predicted multiples by POIC. The free-surface related multiples associated with the water bottom and the salt body are marked in (b). All the multiples are correctly predicted by POIC except for those at the near offsets. The predicted multiples at the near offsets are discontinuous or missing.

Figure 5: CMP8703 in $t-x$ domain. a) Fitted primaries; b) fitted multiples.
POIC-Radon Filtering of Near-offset Multiples

Figure 6: Depth image of SMAART dataset with near offset data (offset < 4000 ft). a) Kirchhoff migration (KM) image; b) POIC-Radon image. Surface related multiples are greatly attenuated with the exception of those associated with the dipping bottom of the salt. Because of the limited resolution of the Radon transform, the sediment layers under the multiple artifacts are also somewhat attenuated.

Figure 7: a) POIC image with only the far offset data (offset > 4050 ft); b) POIC image with all the data formed by adding (a) to the POIC-Radon image from the near offset data (Figure 6b).

Acknowledgements

We are grateful for the financial support from the members of the 2003 University of Utah Tomography and Modeling/Migration (UTAM) Consortium (http://utam.gg.utah.edu). We also thank SMAART JV (www.smaartjv.com) for the dataset.

References


