Robust Moveout Without Velocity Picking

Kevin Wolf, Daniel Rosales, Antoine Guitton and Jon Claerbout, Stanford University*

SUMMARY

At every point in a CMP gather, a local estimate of RMS velocity is:

$$V_{RMS}^2 = \frac{x}{t}\frac{dx}{dt}, \tag{1}$$

where dt/dx is the local stepout. We form a median stack of these local velocity estimates to obtain stable estimates of RMS velocity without the conventional need to form many hyperbolic stacks.

INTRODUCTION

Initial velocity estimation is still a fundamental problem in the seismic exploration industry. There are numerous methods to estimate the initial stacking velocity model based on velocity spectra (Taner and Koehler, 1985; Lumley, 1992). However, all these methods depend on the ability to pick the velocity from a series of coherency panels. These methods of velocity estimation are sensitive to noise levels in the data.

A way to make velocity estimation robust under large noises is to use median stacks within CMPs. A problem with CMP stacks is that data from a large range of offsets is merged despite intrinsic variations in gain, frequency, NMO stretch, array response, and AVO. We estimate V_{RMS} with a robust median estimator of terms; each term manufactured from neighboring traces only. Our goal is to develop a robust code that will reasonably move out all 40 of the worldwide Yilmaz-Cumro shot profiles (Yilmaz, 1987) without need for individualized parameter choices.

METHOD

A simple way to represent a wave travelling with slowness s is as an expanding circle:

$$t^2 = \tau^2 + x^2 s^2, \tag{2}$$

where t is traveltime, τ is traveltime depth and x is offset (Claerbout, 1995). Differentiating with respect to x at constant traveltime depth τ we obtain:

$$s^2 = \frac{t}{x}\frac{dt}{dx}, \tag{3}$$

where dt/dx is Snell's parameter p. Snell's parameter is related to the apparent horizontal velocity. It can also be regarded as a measure of the local stepout (dip) at any given time and offset along a hyperbola.

Therefore, from equation (3) it can be seen that multiplying the local dip of hyperbolas in the (x,t) plane by the ratio of their time and space cordinates yields an estimate of slowness squared. This estimate of slowness is independent of where it is measured along the event in the (x,t) plane; consequently a NMO correction of the slowness squared section will result in horizontal lines of constant slowness.

In order to obtain a dip estimate for the events in the plane we employ the method of Fomel (2002). This technique estimates local stepouts with plane wave destructor filters. Only one dip is estimated at every time and offset position which makes this method sensitive to the presence of crossing events and/or coherent noise. A solution to this problem is to estimate multiple dips at every location and to select those of interest (Fomel, 2002). Once the dips have been estimated, the slowness can be computed in a straight forward manner by mulitplying each dip estimate by t/x. We then obtain a map of local slowness (squared) that we need to convert in to one velocity profile for a given CMP gather.

To achieve this goal, a NMO correction with an approximate velocity trend can be applied to roughly flatten the hyperbolas. Finally, a median stack over the x coordinate should provide a reasonable estimate of s^2 as a function of τ. To ensure local bad dip estimates do not skew the results of the method, data points corresponding to atypical slowness values are disregarded, and the final result is smoothed in time. Once the estimate of slowness squared is obtained, we convert it to V_{RMS}.

TEST CASES

To assess the usefulness of the proposed method we appled it to a synthetic data set and to several shots from the set of 40 worldwide Yilmaz-Cumro shot profiles.

Synthetic Example

The proposed methodology was first tested on a simple synthetic example in order to check the validity of the approach. Figure 1a shows the synthetic example, an idealized case with no crossing events and no aliasing, which will allow for a robust dip estimate.

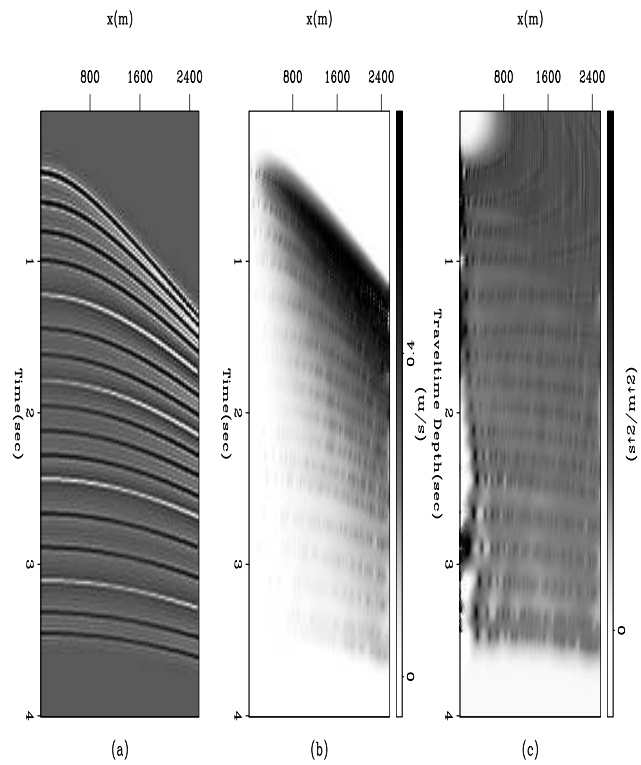

Figure 1: (a) Synthetic data, (b) estimated local dip, and (c) estimated s^2 after NMO correction.

The variable brightness of the estimated local dip in Figure 1b represents the calculated value of dip, and shows that the estimate is robust for this simple synthetic example. Figure 1c, calculated s^2 after NMO correction with the synthetic velocity profile, shows the expected trend with slowness values decreasing slightly at later times. There are some anomalous values of s^2 at small offsets due to the minimal dip of the reflectors in the area, but they will be removed by the median stacking procedure.

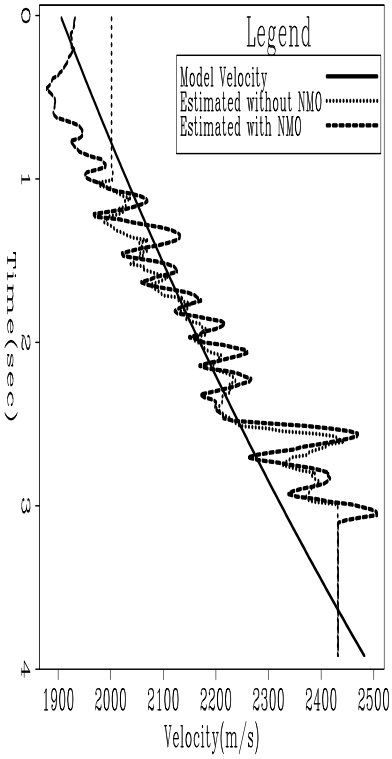

Figure 2: RMS velocity profile used for the synthetic model, and estimated RMS velocity profiles with and without the NMO correction applied to the estimate of s^2.

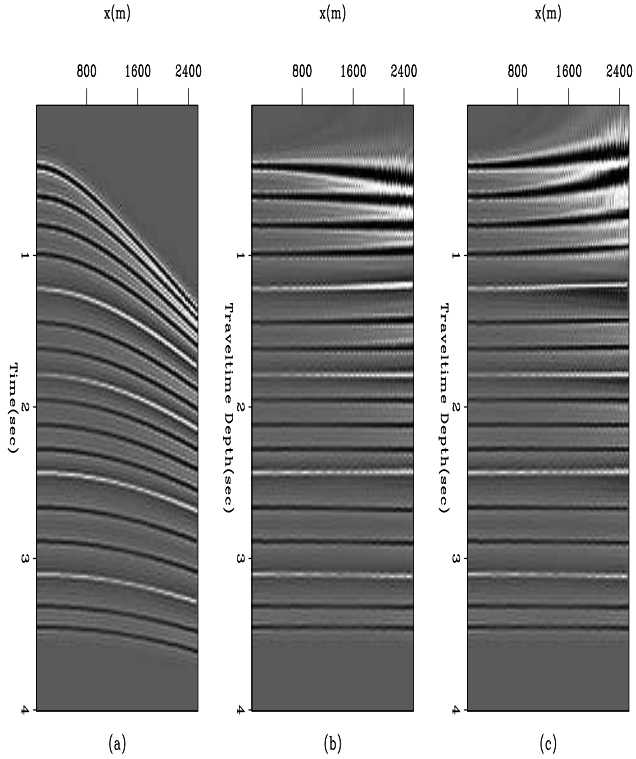

Figure 3: (a) Synthetic data, (b) NMO corection using velocity estimated without NMO correction, and (c) NMO correction using velocity estimated with NMO correction. No picking was required to flatten this gather.

The estimated RMS velocity function of the synthetic data is shown in Figure 2. The solid line represents the actual velocity function used to create the synthetic data. The two dashed lines show the estimated velocity, one estimate from the orginal s^2 panel, and the other from the s^2 panel that has been NMO corrected (Figure 1c). The two results obtained are very similar, suggesting that in order to obtain a robust estimate of slowness the velocity used to approximately flatten the hyperbolas of s^2 before the median stack does not need to be very accurate. As long as the data does not have extremely large offsets a rough estimate of velocity for NMO correction should adequately flatten the hyperbolas of s^2, allowing the median stacking routine to obtain a reasonable estimate of s^2.

The results of using the two estimated velocity functions for NMO correction are shown in Figure 3. Figure 3b uses the s^2 estimate without NMO correction, and Figure 3c uses the s^2 velocity estimate with NMO correction. In both cases the estimated velocity function has done a good job of flattening the hyperbolas in the synthetic data. The results are encouraging and suggest that the method will work even if the velocity for NMO correction of the plane of s^2 is inaccurate.

Field Data Examples

Once the method was shown to work on an idealized synthetic case, we tested it on some real shot gathers to see how robust the method is when working with real data and the problems inherent with it. Theoretically, CMP gathers should be used for this analysis, however we have decided to use the Yilmaz-Cumro shot gathers to test our method. The 40 shots in the dataset provide varying data quality and numerous challenges, which will thouroughly test the robustness of our method.

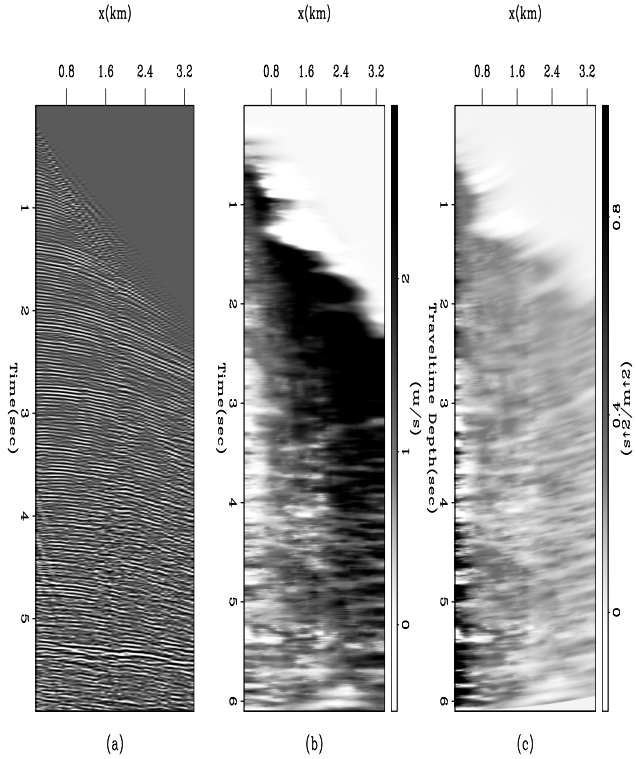

Figure 4: (a) Shot gather 14 with AGC, (b) estimated local dip, and (c) estimated s^2 after NMO correction of 2.5 km/s.

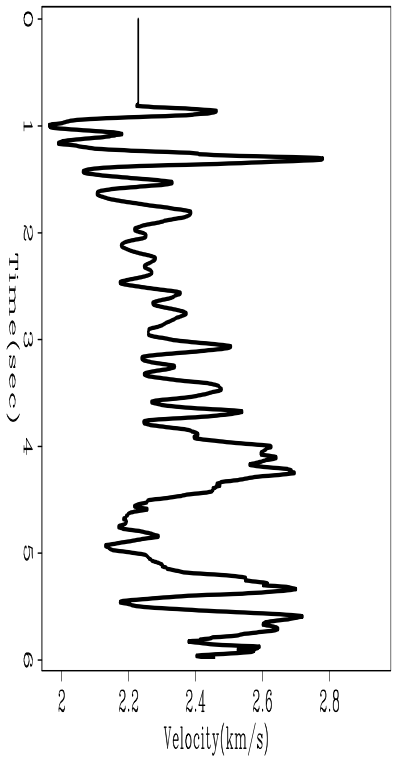

Figure 5: Estimated RMS velocity profile for the data in Figure 4.

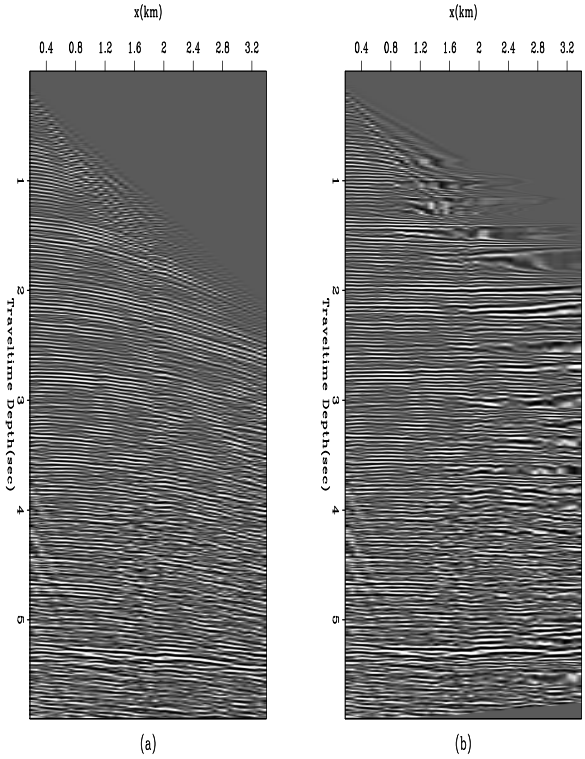

Figure 6: (a) Shot gather 14 with AGC, (b) results of the NMO corection on shot 14 using the estimated RMS velocity in Figure 5.

Figure 4a shows shot 14 from the Yilmaz-Cumro shot gather dataset. The shot is a fairly clean record with many hyperbolic events on it which should give a good estimate of velocity. Examining Figure 4b, which shows the dip estimate, there are areas at the top of the profile that have negative dips. These result from the low velocity direct arrivals visible in the data; the dip estimator picks the aliased energy for its dip estimate. In the same area in Figure 4c the negative dip estimates have resulted in a negative estimate for the value of s^2. Although this is an undesirable result, these values will be accounted for and disregarded by the median stacking routine. The estimate of s^2 has had an NMO correction applied to it with an arbitrary velocity of 2.5 km/s. Although it can be seen that most of the hyperbolas are not flattened very well, the results from the synthetic example show that this should not have much affect on the output from the median stack.

The estimated RMS velocity profile is shown in Figure 5. At early times the estimate varies due to the fact that there is not any information from large offsets to help constrain the velocity. For this reason the begining of the estimate is erased and replaced by extending a reasonable value back to time zero. The estimate also fluctuates at later times in the record. This is because the data becomes noisier in this section, which affects the dip estimate causing the velocity estimate to become unstable. The result of applying the NMO correction with the estimated velocity function is shown in Figure 6b. The data has been flattened in most areas, especially in areas away from the begining of the section where there is little offset information, and before the data becomes nosier at later times. Examining the strong reflector at approximately 5.2 seconds in Figure 6a, which is in the nosier part of the record and clearly non-hyperbolic, Figure 6b shows that enough velocity information is present in order to effectively flatten the event. This result is encouraging.

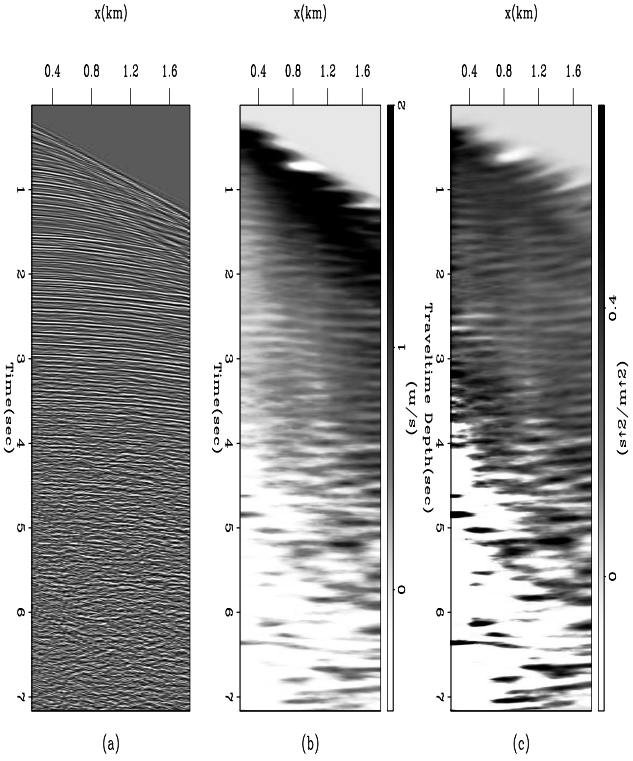

Figure 7: (a) Shot gather 27 with AGC, (b) estimated local dip, and (c) estimated slowness^2 after NMO correction with velocity of 2.5 km/s.

The method was also tested on shot 27 from the Yilmaz-Cumro shot gather dataset, shown in Figure 7a. The shot has numerous hyperbolas at early times, but noise levels hide any hyperbolic events at later times. The dip estimate (Figure 7b) and s^2 estimate (Figure 7c) each show some negative values associated with the direct arrival, and the noisier part of the record, but again, these will be handled by the median stacking routine.

The estimated RMS velocity is shown in Figure 8. This estimate was also extended back to zero time in order to remove bad values where there is little far offset information. It seems a reasonable estimate until around 4.5; where it starts to fluctuate. This is where the noise level in the data is increased, and the poor estimate in this location is expected. The results of the NMO correction with this velocity estimate is shown in Figure 9b. Again the data has been reasonably flattened, particularly in areas where the velocity estimate was well constrained.

CONCLUSIONS

The proposed method for velocity estimation has performed well in the test cases presented. The estimate is robust when applied in areas of reasonable data quality. In these areas there is enough information available for the median stacking routine to eliminate poor data points, and gently smoothing the estimate in time gives a good estimate of velocity. In poor data quality areas, or at early times with little offset information, the estimate is not as reliable and tends to be unstable. Although the estimate is not always exact in these areas, it does provide a decent starting estimate of velocity without velocity spectra analysis or manual picking.

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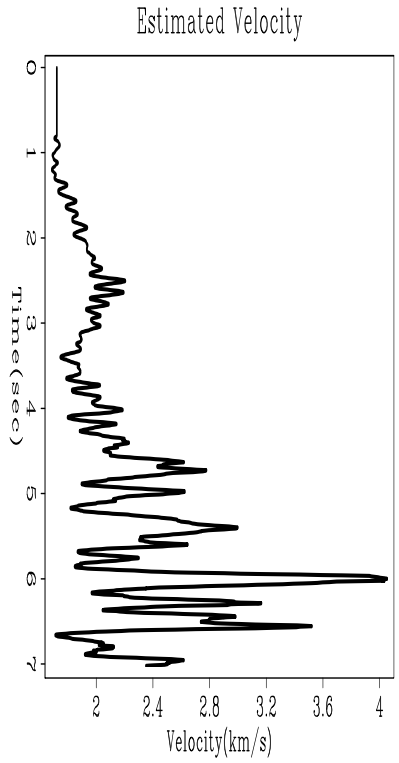

Figure 8: Estimated RMS velocity profile for the data in Figure 7.

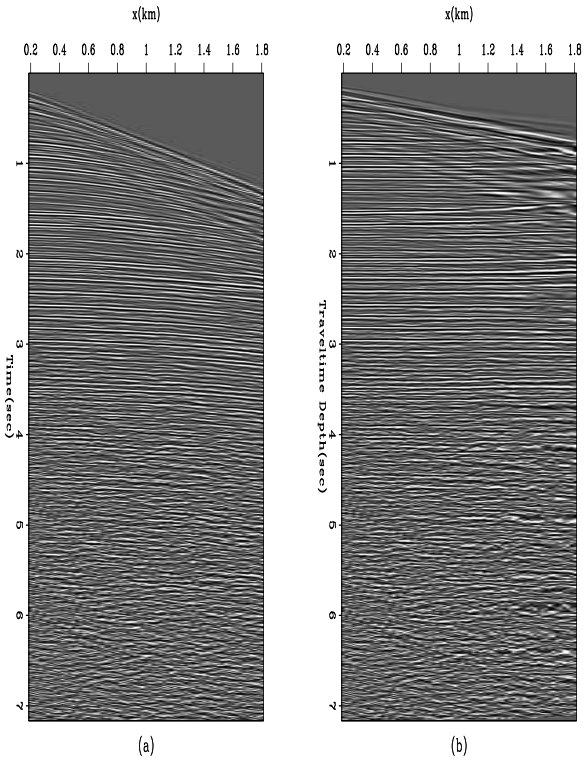

Figure 9: (a) Shot gather 27 with AGC, (b) results of the NMO corection on shot 27 using the estimated RMS velocity in Figure 8.