Estimating an accurate RMS velocity for locating a microseismic event

John C. Bancroft

ABSTRACT

The location and clock-time of a microseismic event (x_0, y_0, z_0, t_0) can be computed analytically using the Apollonius method that requires the first arrival clock-times at four known receiver locations. The velocity is assumed to be known and constant. If the velocity is not known, it can be estimated by using an iterative technique that minimizes the error of the traveltimes between the source and receiver. Improving the accuracy of the velocity improves the estimate of the source location.

The convergence to the correct solutions is dependent on the geometry of the source and receiver locations.

INTRODUCTION

The first arrival times of a microseismic event may be identified on seismic recordings from receivers in relatively close proximity to the event. Since the time of the event is not known, the times on the seismic records are defined as clock-times, and it is desired to identify the clock-time of the source. The traveltimes from the source location to the receivers are known as delta-times.

Given the correct velocity, the Apollonius method computes an analytic solution of a source from the clock-times at four receivers. Given accurate clock-times, the solution is accurate to the resolution capabilities of the computer. Errors in the measurement of the clock-times, or the velocity, introduce errors in the estimate. Error in the clock-time are discussed in a companion paper (Bancroft 2009). This paper addresses the errors in the velocity.

For modelled data, convergence to machine accuracy can be achieved in eight iterations, or to 0.1% accuracies in four iterations.

METHOD

The accuracy of estimating the location of a microseismic event depends on the accuracy of the assumed velocity. The following method computes an approximate location of the event using an initial estimate of the velocity. The velocity is refined, leading to an iterative solution.

The velocity is assumed to be constant, and the traveltimes from four receiver will only produce one analytic solution. That solution will be incorrect if the velocities are in error. However if we use the traveltimes from five receivers, we can use four receivers at a time, and compute different locations based on the five different combination, and get five different solutions.

Initially, the velocities were varied over a range from 0.7 to 1.3 of the actual velocities, and the errors of the raypaths computed. The clock-time of the event was arbitrarily set to minus two, t_0 = -2, and then the parameters estimated for the range of velocities. The parameters for the source location are:

```
Velocity = 1.0
x0 = 0.00, y0 = 0.20, z0 =-3.00 , Clock t0 =-2.00

x1 = 0.40, y1 = 0.10, z1 = 0.10 , Clock t1 = 1.13
x2 = 0.10, y2 = 0.60, z2 = 0.00 , Clock t2 = 1.03
x3 =-0.50, y3 =-0.10, z3 = 0.10 , Clock t3 = 1.15
x4 =-0.10, y4 =-0.50, z4 = 0.00 , Clock t4 = 1.08
x5 = 0.00, y5 = 0.00, z5 = 0.00 , Clock t5 = 1.01
```

Figure 1 displays the estimates for t_0 using the five different combinations.

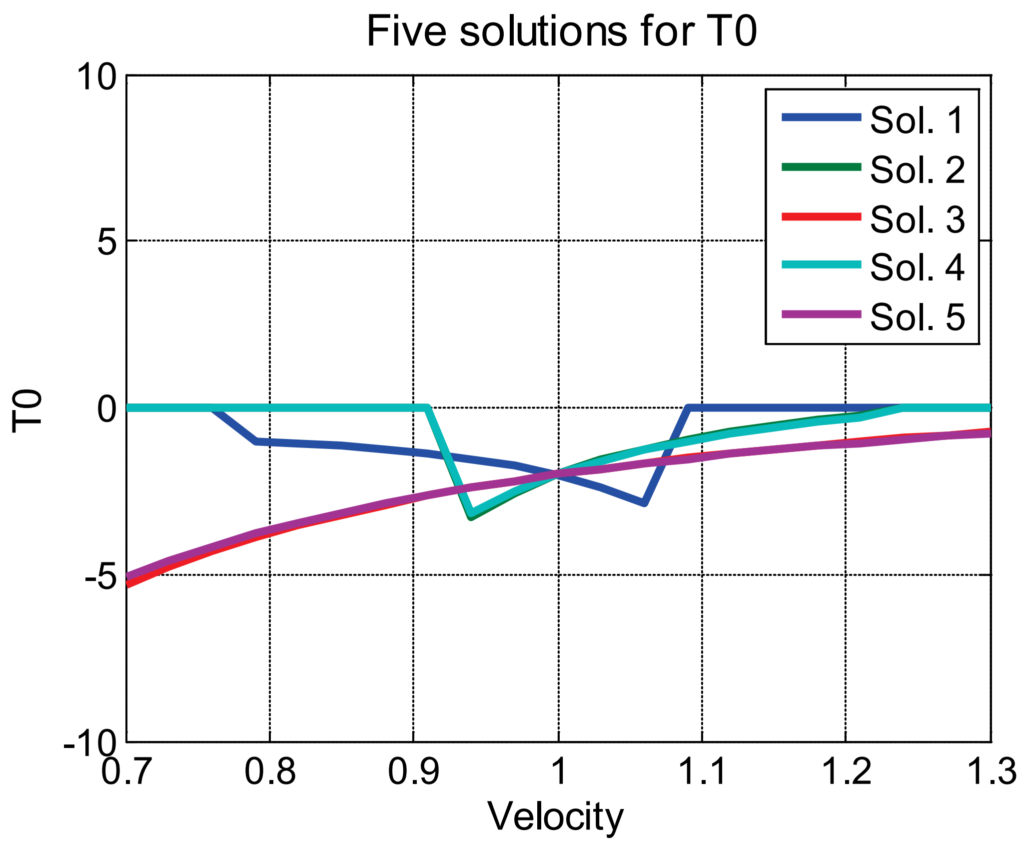
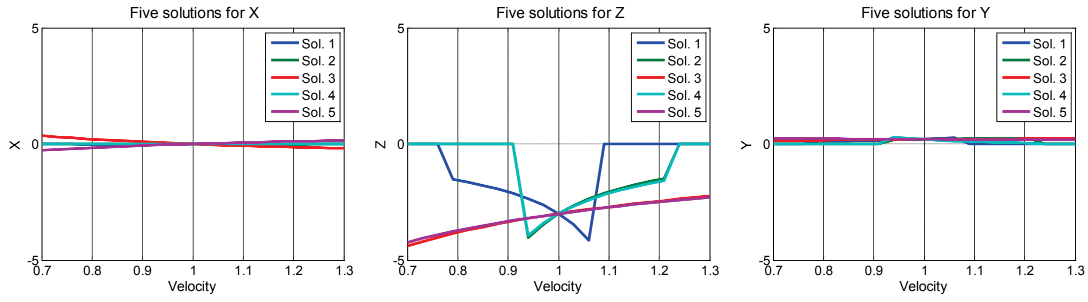


FIG. 1 The estimated time t0 for each of the five different combinations of receivers over the velocity range

When the velocity is correct at 1.0, all the estimated times converge to the correct solution, elsewhere they are in error. Plots of the x, y, and z locations are displayed on the next figure.



a) b) c)

FIG. 2 The estimated locations a) x, b) y, and c) z

Note the convergence of *x*, *y*, and *z* to the defined values at the correct velocity. Also notice the range of some of the estimates, and how they do not all converge toward the defined values for the whole range of velocities. For this configuration of receivers and source location the parameters will only converge between the velocity range of 0.95 to 1.05. Other configuration may have a greater or smaller range of convergence.

Another test iterated the parameters to the correct solution. The defined parameters and iteration values follow. The velocity started at 0.9 and converged to less than 1% percent in 5 iterations, and less than 0.00001% error in8 iterations.

```
Defined source values t0 = 2
x0 =  0     y0 =  0.2   z0 = -3
x1 =  0.4   y1 =  0.1   z1 =  0.1
x2 =  0.1   y2 =  0.6   z2 =  0
x3 = -0.5   y3 = -0.1   z3 =  0.1
x4 = -0.1   y4 = -0.5   z4 =  0

Ivel = 1  V = 0.9     %V = -10%            error  = -21.8108%
Ivel = 2  V = 0.909   %V = -9.1%           error  = -20.5277%
Ivel = 3  V = 1.053   %V = 5.299%          error  =  24.1346%
Ivel = 4  V = 0.97518 %V = -2.4819%        error  =  -7.3763%
Ivel = 5  V = 0.9934  %V = -0.6605%        error  =  -2.1419%
Ivel = 6  V = 1.0008  %V = 0.084839%       error  =   0.28565%
Ivel = 7  V = 0.99997 %V = -0.0028635%     error  =  -0.0095983%
Ivel = 8  V = 1       %V = -1.2377e-005%   error  =  -4.1492e-005%
Ivel = 9  V = 1       %V = 1.8059e-009%    error  =   6.0554e-009%
Ivel = 10 V = 1       %V = -4.2188e-013%   error  =   5.7339e-014%
Ivel = 11 V = 1       %V = -4.4409e-013%   error  =   5.7339e-014%
```

COMMENT AND CONCLUSIONS

Two methods were presented to estimate the correct velocity when locating a microseismic event. The first displayed a range of velocities, and the second iterated to the correct solution. If the starting point was too large, the solution would diverge. A combination of both methods may provide an optimum solution.

ACKNOWLEDGEMENTS

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REFERENCES

Bancroft, J.C., 2009, Sensitivity measurements for locating microseismic events, CREWES Research Report.

SOFTWARE

MATLAB was used for the tests in this report

```
\2009-Matlab\TraveltimeMicroseismic\
TestVelToMinLocationErrorUsing5Pts.m
TestVelToMinTimeError.m
```