CHAPTER 1

Introduction

For last two decades, seismic imaging technology has been developed to obtain better imaging of subsurface of the area of prospective interest. Many seismic imaging techniques, such as migration algorithms have been invented and applied to solve imaging problems in area of the complex geology. The estimated subsurface velocity model is important for both the time and depth domains of current seismic migration and imaging technologies. Since better estimated velocity models are required, several methodologies, such as migration velocity analysis and travel time tomography have been used and developed. However, one of the most advance tools for estimating subsurface velocity model is full waveform inversion (FWI).

FWI is a method that where the subsurface velocity is estimated by minimising the difference between observed data and generated data. The generated data is created based on the initial model and estimates a new model that reduces the magnitude of the difference between 2 datasets towards zero.

1.1 Research objectives

- To modify and develop code for acoustic full waveform inversion
- To obtain high resolution velocity model for subsurface imaging

1.2 Literature review

The ultimate goal of exploration seismology is to quantitatively estimate accurate models of the subsurface from measured seismic data. In general, this requires solving an inverse problem governed by a forward operator. Seismic migration is used to extract and locate reflectivity of the subsurface by producing a structural image (Claerbout, 1985). However, a structural image alone cannot supply sufficient information to fully interpret properties of the model of the subsurface.

Forward modelling consists in computing the wave field at a given time and position by solving wave equation. Depending on the characteristics of the medium, the presence of source, etc., the formulation of this equation might differ. The methods for solving the wave equation can be generalised as one of the following:

- Ray theory (ray tracing, etc.)
- Numerical methods (finite difference, etc.)

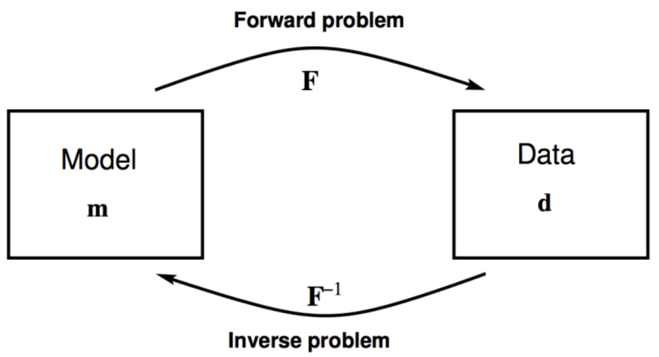

Figure 1.1 Simple sketch showing a relationship between forward modeling and inverse problem (Chabert, 2007)

In ray theory, the wave equation is solved by asymptotic, high frequency approximation (Cerveny et al., 1977). Ray tracing theory looks at wave propagation as rays following the normal component of wavefront. When the medium’s velocity is constant, the ray path will be straight, but if the velocity is increasing or decreasing, the ray path will curve. The rays will be reflected and/or transmitted at the interfaces in a layered medium. Since the ray theory is a high frequency approximation it requires the wavelengths to be smaller than the velocity variations in the medium (Hovem, 2007).

Numerical methods include finite difference, finite element, finite volume and spectral element methods. The numerical methods seek the solution of differential equations by making approximations and simplifications for easy computing. Generally, these methods divide the spacing into a mesh, where calculations of node values contribute to the complete wave field. This gives many, but simple, calculations. Numerical methods are well suited to find solution to the wave equation for complex and inhomogeneous media, but the calculations can be time consuming, especially in large 3D dataset.

The seismic inversion problems relate to finding a set of model parameters that predict the observed seismic data (Pratt et al., 1998). A forward modelling routine computes a set of data base on a current estimation of the model parameters. The residual between the observed data and computed data should be as small as possible, and the model parameters can be updated to reduce this misfit.

Full waveform inversion (FWI) is a method for deriving a velocity model from seismic datasets. The velocities are estimated by solving the inverse problem where the whole wave field forms the dataset. The results exhibit the features of the true model at sub-wavelength scale and account for many of the details in the data's observed arrival. The method was first introduced in 1986 by Albert Tarantola (Tarantola, 1986) in the time domain, and was extended to the frequency domain by R.G. Pratt in 1990 (Pratt et al., 1990). In time domain, the computational cost of inversion depends on number of sources used but in frequencies domain, the computational cost is only proportional to the number of the frequency used in the inversion, not the number of sources (Pratt et al., 1990).

In this research the Mamousi model is geometrically based on a profile through the North Quenguela trough in the Cuanza basin (Angola) (Brougois et al., 1990). The geometry and the velocity model were created to produce complex seismic data, which require advanced processing techniques to obtain a correct earth image.

The original Marmousi model was created in 1988 at the Institute Francais du Petrole (IFP) to re-sample and model the overall continental drift geological setting in the Cuanza basin (Figure 1.2). Numerous large normal faults were created as a result of drift. The model contains many steep dip reflectors, and strong velocity variations in both lateral and vertical direction.

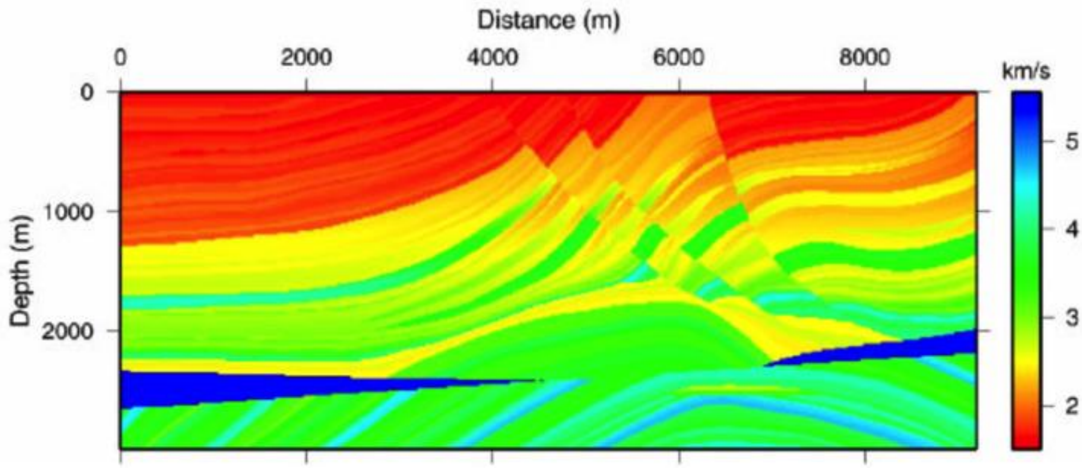

Figure 1.2 Marmousi model of P-wave velocity (Marmousi model).

1.3 FWI challenges

While FWI can produce a reasonable model, there are still some major obstacles to be considered when applying FWI for exploration seismology.

1.3.1 High computational cost

Performing FWI for velocity updating requires a huge amount of the computer power for simulation the seismic wave field. The computational cost for the FWI in time domain is a proportional to a number of shots. For large seismic survey this cost maybe prohibitive. (Yong Ma, 2010)

FWI also requires multiple iterations to minimise the data misfit, and the computational cost is proportional to the number of the iterations required.

1.3.2 Non unique solution

Most of the geophysical problems are non-linear, therefore the modelling solutions are non-unique. Many different models could yield synthetic data that match with the recorded data within a reasonable data misfit. Solving the inverse problem with the gradient method, the presence of the local minima in the data misfit function also result in non-uniqueness. The iterative inversion methods may converge to the global minimum if the initial model is close to the true model. If the initial model is far from the true model, iterative methods can converge to the local minimum, Figure 1.3.

The cycle-skipping also causes non-unique solution for FWI. It occurs if the phase difference between synthetic and observed data is larger than half of the dominant wavelet. Figure 1.4 illustrates the cycle skip problem in FWI. Two synthetic monochromatic seismogram with period T in (a) and (c) are compared with the seismogram in (b). The synthetic seismogram in (a) has a time delay larger than half of the period and in this case FWI will update the model such that the (n+1) cycle in (a) match with the n cycle in (b). Therefore FWI produces an inaccurate model. Consider the seismogram in (c) which has a delay time less than half a period of (b), and in this case FWI will update the model such the nth cycle in (c) match with the nth cycle in (b), produce an accurate model. This particular problem occurs because it difficult to obtain a sufficient initial model that consists of low frequency component. (Yong Ma, 2010)

1.4 Thesis overview

The objective of this thesis is to modify and develop a MATLAB code for performing FWI to obtain a higher resolution of the velocity model.

Chapter 02 introduces the general theory of FWI based on a gradient method which can be used for solving a non-linear problem such as a geophysical problem.

Chapter 03 describes the methodology and workflow of the FWI performed in this study including the calculation of the partial derivative wave field, gradient of misfit function and the estimation of scaling for calculated perturbation model.

Chapter 04 applies the FWI algorithm to a Marmousi synthetic dataset. A smoothed version of Marmousi model was assumed as the initial model, and then the FWI has been performed to recover an update of the velocity model. The result and some limitations of the FWI have been discussed later on this chapter.

Finally, in Chapter 05 the overall finding are summarised along with recommendations for future research.

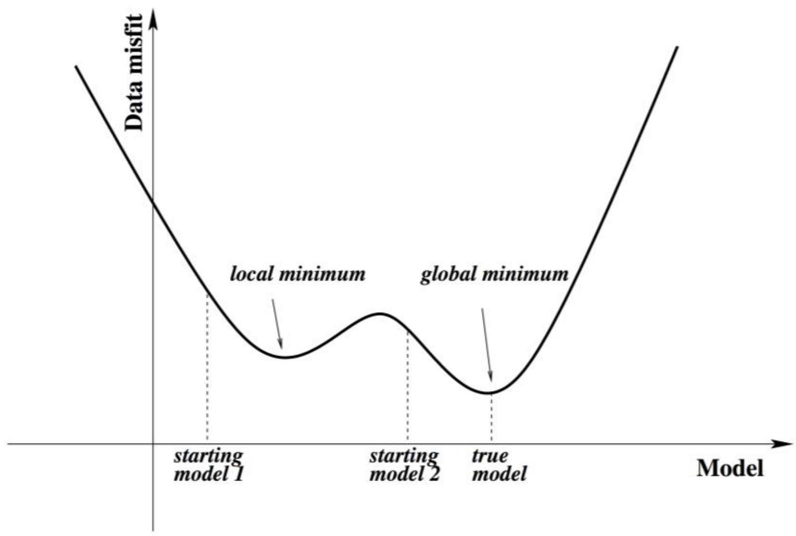

Figure 1.3 Schematic of the local minima problem for FWI. The misfit function has several local minimum because the non-linear in the forward modelling (Yong Ma, 2010).

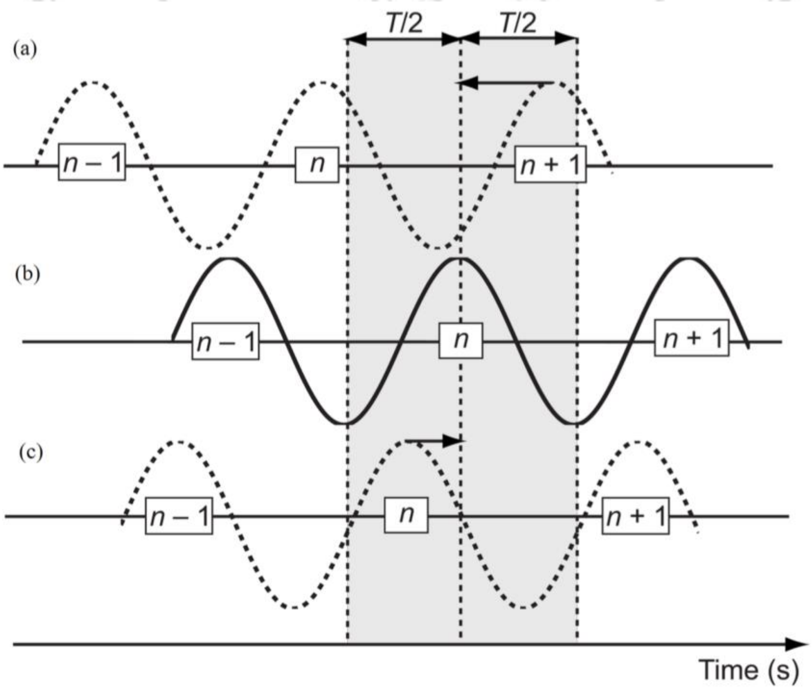

Figure 1.4 The synthetic monochromatic seismogram with time period T illustrates the cycle skip problem in FWI. (Virieux et al, 2009)