Pseudo-3D seismic construction using tau-p transform interpolation

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Abstract. Three dimensional (3D) seismic imaging is very important in hydrocarbon exploration. However, 3D seismic data acquisition costs more expensive than 2D seismic data acquisition. Therefore, the explorations are mostly done with some 2D seismic lines and requiring some interpolation method to construct the 3D seismic model called Pseudo-3D Seismic. In other word, the 3D model depends much on the interpolation process for a more reliable result. There have been many interpolation methods used to construct the 3D seismic model. Tau-P Transform is one of the methods that can be used to construct a 3D seismic model. It has been used to reconstruct seismic data and fill the near-offset gap in marine seismic data for decades. In this research, the method is done by having the crossline of some 2D seismic lines and performing the transformation from t-x domain to the tau-p domain. After the transformation, by inverse-transformation from tau-p to t-x domain, we might perform interpolation along the line to construct more traces with regular and near spacing. This method can be performed to all crosslines and construct Pseudo-3D Seismic. The results show constructed crosslines with well-lineated layers. The crosslines show developed layers are like those of the inline implying that the interpolation successfully construct the layers based on the inline.

Keywords: Pseudo-3D seismic, tau-p transform, interpolation

1. Introduction

The seismic method is a geophysical method which is commonly used for oil and gas exploration. Seismic data is a robust method to map geological features related to oil and gas system and to estimate the reservoir and resource volume. Thus, seismic data needed in oil and gas exploration should be three-dimensional (3D) data. Yet, the 3D seismic data is expensive to obtain. The acquisition needs a lot of geophones and seismic source and needs to be repeated so many times to cover all the area. These all cost too much for the company to cover.

Encountering this problem, most of the companies conduct sparsely distributed 2D seismic acquisitions to cover the area. On the other hands, there are also problems such as the dysfunction of the geophones and some noisy traces recorded by the geophones. These result in non-uniformly seismic data. Thus, it is needed to do interpolation to cover all the area using a reliable method [1].

Some interpolation methods are introduced for seismic data. Some are used to fill the gap between traces in 2D seismic [2]. Others are used to construct pseudo-3D seismic [3, 4]. One of the algorithms used for interpolation is the tau-p transformation or also known as slant-stacking.
Tau-p transformation is mostly known for noise removal [5], yet this method is ever been used to interpolate near-offset gap marine seismic [2]. The methods will perform tau-p transformation to a seismic line from t-x to a tau-p domain, then interpolating more traces while inversely transforming the data from tau-p to t-x domain. This method can be used to construct 3D marine seismic from 2D seismic lines by performing tau-p transform to the crosslines and interpolate for more regular and near-spaced traces.

By implementing the method to sparsely distributed data, the pseudo-3D seismic might be constructed well from some 2D seismic lines.

2. Tau-p transform interpolation

Radon transform was a transformation established by Xu et al. [2]. This transform has been widely used in seismic processing (e.g. multiple attenuation, data interpolation and velocity analyses). There are three types of Radon transform which are linear Radon transform, parabolic Radon transform, and hyperbolic Radon transform. Linear Radon transform is well known as Tau-P transform or slant-stacking.

Tau-P transform will transform data from t-x domain to the tau-p domain. Seismic data is recorded in the t-x domain where t is the travel time of the signal and x is the offset of the receiver. The transformation is based on the formula [6]:

$$\tau = t - px$$  

where $p$ is the ray parameter or slowness, $x$ is the offset, $t$ is the two-way travel time, and $\tau$ is the linearly moved out time or time intercept. The transformation is conducted by stacking the amplitude values from the traces which confirm with the formulae and put the value into a coordinate of ($p$, $\tau$) (figure 1) [3]. For a set value $\tau$ and $p$, amplitudes from traces with different offsets at time $t$ based on the equation 1 will be summed and become a value at the new coordinate ($p$, $\tau$). The process is then repeated for a range of $p$ and $\tau$ value and thus giving the data in the $\tau$-p domain.

The $\tau$-p domain data could be inversely transformed to form original t-x domain data by this equation:

$$t = \tau + px$$

with a value of $t$ and $x$, amplitudes from traces with different $p$ values at time intercept $\tau$ will be stacked to be an amplitude at ($t$, $x$) coordinate. In another word, while transforming it back from ($p$, $\tau$) to ($x$, $t$) domain, the offset might be spaced more regularly and making it better to be interpolated.

**Figure 1.** By summing up $u(x, t)$ along the line $t = \tau + px$, the slant stack $\psi(p, \tau)$ could be obtained at any point ($p$, $\tau$). While the $\psi$ at the intersected lines of $u$ could be obtained by the interpolation method.
This method can be applied to the crosslines of some 2D seismic lines to produce a pseudo-3D seismic. Supposedly there have been a set of 2D seismic lines with the same orientation North-South. By taking a crossline perpendicular to the lines, some set of seismic traces will be obtained from different seismic lines. With the obtained traces, the tau-p transformation will be conducted to get data at \( \tau - p \) domain. Then, the data is being transformed back to a t-x domain with a more regular offset value. Thus, an interpolated t-x section is obtained. By moving out the crosslines along the seismic lines, the 3D seismic data can be constructed from the interpolation process of crosslines.

3. Results and discussion

The interpolation method is applied to 12 2D seismic lines. Before the interpolation process, the coordinates of the data are rotated to adjust the lines as a horizontal seismic line (figure 2). This would make the crosslines to become easier to be interpolated.

The crosslines of the 12 2D seismic lines are made vertically. The crosslines are made as far as the seismic lines coverage. The distance between two traces within one seismic line is about 6 meters. The distance is very close to seismic data. Thus, the crosslines are made by binning the traces along the seismic lines.

The interpolation of a crossline can be done if only there are at least 2 traces within the crossline. So, each crossline that could be interpolated might have 2 up to 12 traces. The more traces obtained for crossline, the more reliable the interpolation process other than the \( \tau \) and \( p \) parameter itself. The interpolation from 2-12 traces within one crossline is processed by transforming it into the \( \tau - p \) domain.

The transformation is performed within a range of \( p \) and \( \tau \) value. The \( p \)-value is ranged for 200 regularly-spaced values. While the \( \tau \) value is ranged by the sampling interval for as many as the sampled seismic data. Then, the crossline is then transformed into the \( \tau - p \) domain.

After having transformed into \( \tau - p \) domain, this \( \tau - p \) domain data is transformed back to t-x domain. The inverse transform is conducted to made 100 regularly-spaced traces. So, a crossline which consists of about 2–12 traces is being interpolated to make 100 regularly-spaced traces.

![Figure 2](image)

**Figure 2.** 2D seismic lines in this study, (a) 2D seismic lines at real coordinates, and (b) after rotation.
Interpolation using τ-p transform shall produce an optimum result by setting the τ-p parameter accordingly with the offset of the data. The value for τ can be adjusted the same with the value of t in the t-x domain. While the value for p should be adjusted with the range of the offset and the time to perform optimum interpolation result. Different range of the two parameters will result in the interpolation with different resolution (figure 3).

The interpolation results show the optimum imaging than the others (figure 3b). The left one is the result by using a lower value of p, the imaging shows more flatty structures (figure 3a). While the right one is the result of a higher value of p, showing many discontinuous structures (figure 3c). Meanwhile the middle figure shows wavy structures indicating better result than others p range (figure 3b).

The parameter used to interpolate all other crosslines is derived from the same value as used in figure 3b. The interpolation is applied to all the crosslines along with the seismic line coverage. The interpolation results for adjacent crosslines should show slightly different structures since space is narrow. Thus, the interpolation is done with good parameter.

Consecutive crosslines were then obtained from the interpolation process with only slightly different imaging result (figure 4). The 3 crosslines show slightly different structures from each other in the lower part. Since the crosslines are only 6 meters far from each other, the structure is more likely to be similar. If the adjacent crosslines show very distinctive structures from each other, then the interpolation process might not be well conducted. Thus, having 3 crosslines with similar structures show the interpolation process is well conducted to the data and success in constructing pseudo-3D seismic data along with the inline, crossline, and time (x, y, t).

The interpolation with 12 2D seismic lines gives a result of pseudo-3D seismic coverage (figure 5). As there are 2 traces in the crosslines, the interpolation can be conducted. The coordinates are then rotated back to original coordinates (figure 5b). This shows a coverage area that can be modelled from 12 2D seismic lines. The tau-p transform interpolation successfully constructs pseudo-3D seismic data from 2D seismic lines which might help to reduce the acquisition cost other than having the 3D seismic acquisition.

![Figure 3](image-url)  
Figure 3. Interpolation results from various range of p, (a) Flatty structures resulted by interpolation using a too low range of p, (b) well-developed structures resulted from an optimum range of p, and (c) discontinuous structures resulted from the higher range of p.
4. Conclusion
Pseudo-3D seismic has been well constructed using tau-p transform from 12 2D seismic lines. The tau-p transform is used to interpolate 2D seismic lines by the inverse transform into more nearly-spaced offset. The optimum result is set with some specific range of p and tau. The range of p depends on the offset of the offset and the time range of the data. The result shows that the tau-p transform is applicable to interpolate 2D seismic lines and to construct pseudo-3D seismic. With the interpolation result shows structures relevant to the structures of the seismic inline, the interpolation is reliable to construct pseudo-3D seismic from 2D seismic.
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