Comparing between KM and RTM Algorithms to Pre-Stack Migrate Seismic Data

Shms Aldeen S. Al-Duri*1 and Amel H .Abbas*2

1- Mustansiriyah University, Baghdad, Iraq. Email: shms.aldeen@tu.edu.iq
2- Mustansiriyah University, Baghdad, Iraq. Email: de.amelhussein2017@uomustansiriyah.edu.iq

Abstract

Creating a clear seismic section to explore the underground is the primary goal of seismic surveys. The seismic section is created by processing the data obtained from the seismic survey. Migration is an important seismic data process, as it puts reflections in place. In this research, the Kirchhoff Migration (KM) algorithm and the Reverse Time Migration (RTM) algorithm were applied using MatlabR2019 software on two industrial models, comparing the results by calculating the brightness on the resulting image and after calculating the contrast and adjusting the seismic section. The results showed that the use of the RTM algorithm gives more clear results than the results obtained when applying the KM algorithm.

1 Introduction.

A seismic survey is a scientific method for determining the geological formation under the surface of the earth, which depends on detonating a small freight of explosives close to the surface. This results in mechanical shock, tremor, or seismic waves. [1] These waves return to the surface after being reflected from the sides between the layers of different natural properties. [2] Reflections of the waves are recorded by sensors that are responsive to the movement of the Earth called Geophones, which are spread on the ground with a specific formation that defines the dimensions of the seismic survey and is placed on specific dimensions from the detonation point to receive reflected sound waves and record them on the Seismograph device as shown in figure 1-a. A seismic survey can also be performed in the seas as in figure 1-b by replacing the explosives with an electric spark which has a high voltage that may reach ten thousand volts to be discharged underwater to produce an auditory pulse at short consecutive periods to conduct the seismic survey at depths between 100 - 400. [3]
The speed of the sound waves depends on the density of the medium through which they pass, as the reflections of these waves are recorded on the geophones set at specific places on the surface of the earth. As is well known that sound waves propagate in all directions, but we cannot record all of them, so we are satisfied with recording those waves that reach us on the surface. The seismic survey method is characterized by its ability to determine the shapes of layers from which it was reflected or refracted, and thus to know the details of the geological structure in which it spread.

Seismic survey process includes the following three stages: The first is the stage of obtaining seismic data, which includes fieldwork, where some field controls, detonation sites, wave receiver, and distances between them and the method of work are set by field surveys, as devices are usually used Evolving digital for seismic data collection and transfer over a narrow channel and stored for processing. The second is the seismic data processing, which involves the use of many mathematical techniques of digital signage and digital image processing techniques, whose goal is to record seismic information in the form of documents that are easy to interpret to improve the signal-to-noise ratio, and the computer is used to facilitate processing work. The last is the interpretation of the seismic data and means the study of seismic documents that are obtained in the depth of treatment in which all geological information such as the structure, layers, and properties of rocks are extracted.

There are many scientific articles in the field of seismic data processing, including, submit a suggestion about using the empirical wavelet transform (EWT) to do the seismic time-frequency analysis. This method first estimates the components of the frequency appearing in the seismic signal, then it determines the limits and finally extracts the vibrational components of the signal depending on the calculated limits. This method was tried on two-dimensional and three-dimensional seismic data and the results showed that EWT can provide much higher accuracy than traditional continuous wavelet transforms, this suggestion was made by [7]. Another researcher suggested a technique that performs a spiking deconvolution process on prestack time migration (PSTM) which is a stage of seismic data processing, to test the effect of the process length and prewhitening ratio in spiking deconvolutory and apply them sequentially, and the result was when the coefficient of length was 5 ms, 10 ms, 15 ms when the prewhitening ratio is 0% while when the prewhitening ratio is 1% the length of the factor is 60 ms, 40 ms, and the results show that the shorter the coefficient and
the prewhitening rate 0% gives a better result, but it is better to use a longer length coefficient when the prewhitening value is greater. From 0%, this technique was suggested by [8]. Also, a study was presented on the use of 3D seismic reflection data as a pre-consideration phase for the eastern Baghdad oilfield, which is located in central Iraq and within the boundaries of the administrative city of Baghdad. The study is based on the use and utilization of HRS-9 software by analyzing and changing the capacity of field data. The study included the operations of (AVO) Amplitude Versus Offset Offset or Angle (data processing, making seismic models and analyzing the capacity change data with the displacement based on the change of the capacity with the change of displacement and its relationship to rock properties and fluids) which utilizing which he was able to determine the type of oil tank, this technique proposed by [9].

1.2 Seismic waves

Seismic waves are waves or sound energy that propagate into the rocky solid media as a result of vibrations in rock particles. These waves differ in speed, shape, and length depending on the medium through which they appear and appear on receivers geophones as a winding line and are divided into two types [10]

1- body waves: They are sound waves that cause the movement of the media through which it passes forward and backward, where the movement of the medium towards the wave’s path is causing it to stretch or compress and permeate the medium. This type is usually used in seismic exploration.[3]

These waves are divided into two types

A- Primary waves: The fastest waves reach the receivers, their speed ranges between 5.5-13.8 Km/s and increases as the depth increases. It leads to the oscillation of the medium that penetrates it in the direction of its flow. As shown in figure 2 and is rapidly spreading and is transmitted through the solid, liquid, and gaseous materials, called p-wave and sometimes towards wave propagation. The velocity of these waves is calculated from the following formula:

\[ v_p = \sqrt{\frac{k + 3/4\mu}{p}} \]  

Whereas: \( p \) is the density of the medium, \( k \) is the volumetric coefficient of matter, and \( \mu \) is the shear modulus.[3]

B - Secondary waves: After the primary waves, they reach the receivers, and their speed ranges between 3.2 and 7.4 Km/s, and increases as the depth increase. The particles move vertically along the wave propagation line (as shown in figure 2), and they spread only in solid media. The velocity of these waves is calculated from the following formula:

\[ v_s = \sqrt{\frac{\mu}{p}} \] ...

whereas: \( \mu \) is the shear modulus, and \( p \) is the density of the medium. [4]
2- Surface waves: waves propagating only on the surface of the Earth. The velocity of the surface wave is large on the surface and decreases as the depth increases to weaken and fade, and also with a lower frequency than the body waves. It is divided into:[4,10]

A- Rayleigh Waves: The Earth moves as a result of the spread of these waves in which there is a movement similar to the waves on the surface of the water. As shown in figure 2, which is slower than the secondary waves s, where its velocity is 90% of the wave’s s speed, its speed depends on the frequency and wavelength. These waves are up, down, and side to side in the same direction the wave is moving. It was discovered by Lord Ripley in 1885 AD. [4, 7]

B- Love Waves: The spread of these waves is limited to the surface of the earth's crust. These waves propagate horizontally to the surface layer of the Earth (as shown in figure 2) and cause the Earth to move from side to side towards the direction of the wave. The mathematical model of this wave was the scientist Augustus Love in 1911 AD. [3,11,12]

Figure 2: The types of seismic waves are shown in the (left part), Phantom (simplified) seismic recording in (right part). These are illustrated by [12]

2 Seismic data Processing

Field records obtained from field operations, are converted into seismic sections through the processing of these records, and to obtain a final image to depict the correct location of the depth of the seismic section we apply the migration process to the seismic section, which should be ideal, that is, it does not contain noise, multiples, and some unwanted waveforms before migrating.

• Migration: A process applied to seismic data to restore reflections to their true geological locations in depth, and also improves final image quality and hides
distortions in the seismic section. If migration is applied to seismic data after a stacking process, it is called post-stack migration, and migration can also be applied to data before the stacking process, called pre-stacked migration. A great effort must be made to obtain a good velocity model because the accuracy of the carried-off seismic section depends on the input velocity model. Kirchhoff migration and reverse time migration algorithms that perform the migration process. [14,13,4,5]

• Kirchhoff Migration: The algorithm of placing energy reflected from the dispersed medium to its correct location in a migrated trace. The Kirchhoff Migration process can be expressed using equation (3) to produce a migrated seismic section. This algorithm needs to calculate the travel time of the wave (the time taken for the wave from the point of detonation until it is received in the geophone), and shots gather which produce after seismic survey. The Travel Time can be calculated from equation (4), equation (5), and Shot gather records from equation (6).

\[ M(r, z, s) = u(x, s, t(s, x, z)) \quad \ldots (3) \]

Where \( M \) indicates the output of the migration process, \( u \) indicates the wave field, \( x \) and \( z \) indicate an image of a point in the depth of the velocity model, \( t \) is the travel time and \( s \) the source number.

\[ t_k = \frac{\sqrt{(k-1)x^2 + 4L^2}}{v}, \quad \ldots (4) \]

Where \( k \) is the number of receivers, \( v \) indicates the speed, \( x \) the distance between the source and receivers, and \( L \) indicates the depth of the reflector. If the value of \( x \) (the distance between the source and the receiver) equals zero, then travel time can be calculated using the following formula:

\[ t_k = \frac{2L}{v} \quad \ldots (5) \]

\[ u(a, b, t + \Delta t) = \left[ 2 - \frac{5c\Delta t}{\Delta z} \right] u(a, b, t) - u(a, b, t - \Delta t) \]

\[ + \left[ \frac{4c\Delta t^2}{3\Delta z} \right] u\left( (a + 1, b, t) + u(a - 1, b, t) + u(a, b - 1, t) \right) \]

\[ - \left[ \frac{c\Delta t^2}{12\Delta z} \right] u\left( (a + 2, b, t) + u(a - 2, b, t) \right) \]

\[ + u(a, b_2, t)u(a, b - 2, t) \quad \ldots (6) \]

Since \( u \) indicates the strength of the source, \( c \) represents the velocity at the location \( (a, b) \), \( t \) represents time and \( \Delta t \) indicates the increase in time. [15,4,10]

• Reverse time migration (RTM): An algorithm used to make migrate seismic sections. It relies on reversing the time-receiving traces as a source - time in each geophone. In other words, it is an algorithm that depends on the temporal reflection characteristic of the wave equation. That is, the wave becomes two independent fields, the first is for recorded data (wave reflections) on receivers and is called the receiver wave filed and the second is set up by considering the geophone as a source of vibration and is called source wave filed. The process of creating two fields remains along the time axis, where the source wave filed is created forward in time,
while the receiver wave filed is created by reversing the time. (This is why it is called reverse time). The stacked image consists of linking these two fields. The Reverse Time Migration algorithm can be expressed using equation (7). [17, 16, 15, 5]

\[ I(x, z) = \sum_k \sum_t U_k(x, z, t)D_k(x, z, t) \quad \ldots (7) \]

Where I denote the resulting image from RTM, U denotes source wave filed, D denotes receiver wave filed at a location (x, z) at time t, and k indicates the source number.

3 Datasets

In this work two models industrial of data are used, its depth and distance which is one kilometer. These models are derived from the data used in the book "Seismic Interferometry" [16]. The first model contains reflections of the ground layers, as in figure 3. And the second model contains salt flank and reflections of the layers as shown in figure 4.

![Figure 3: The first data model.](image)

![Figure 4: The second data model.](image)

4 Methodology

Diagram 1 shows the sequence of work steps proposed in this search. As the first step includes reading the data (the industrial models shown above in figure 3 and 4), and
the second step prepared a simulation process for a seismic survey on the input models (the first stage in the seismic survey is the stage of obtaining seismic data), where we suggested the presence of 10 geophones the distance between them 100 meters to record the reflected waves. It was created as a simulation of 20 Hz sound waves by applying Equation 6. Each Shot consisting of a traces group was saved. Each trace was created by Ricker wavelet. Then we applied Equation 5 to create forward travel time.

Upon completion of the above two steps, the Kirchhoff Migration algorithm implemented by applying Equation 3 for each shot and forward travel time and stacking the result. Then saved the final output of the stacked image algorithm which is called the seismic section. To implement the Reverse Time Migration algorithm must calculate reverse travel time first by implementing equation 6 for each shot. Then implemented the RTM algorithm by applying equation 7 and stacking the result. Then saved the final output of the stacked image (seismic section) algorithm.

Finally, calculated the quality of image (seismic section) quality resulting from the KM and RTM algorithms by calculating the brightness, contrast, and adjustment for them.

Diagram 1: Explains the steps of the practical part of the research.
5 Experimental Results

BY using the Matlab R2019a software to apply the code that is created to implement the research methodology to produce the seismic section. figures 5 and 6 show the result of the Generate and Save shots gather step on the entered data. And figures 7 and 8 appear as a result of the implementation of the Generate and Save Forward Travel Time step on the entered data.

**Figure 5:** Shows the shape of some shots gather for the first industrial model: (a) the shot No. 11 (b) for the shot No. 30 (c) for the shot No. 70 (d) for the shot No. 95.

**Figure 6:** Shows the shape of some shots gather for the second industrial model: (a) shot No. 5 (b) for shot No. 40 (c) for shot No. 77 (d) for shot No. 95.
After getting the shots and travel time from the previous step, then the Kirchhoff Migration (KM) algorithm is implemented on each shot to produce the final seismic section and be the result of adding the migration result for each shot. Figure 9 shows the result of applying the KM algorithm to the shots gather (No. 11, 30, 70, 95) for the first model. Figure 10 shows the result of applying the KM algorithm to shot gather No. (100) and the result of collecting the result of the KM algorithm on each shot gather for the first data model.

The result of implementing the KM algorithm to the second model is shown in figure 11 on the shots gather (5, 40, 77, 95). Figure 12 shows the result of the KM algorithm on the 100 shots gather, the final result of the algorithm on the second data model.
Next, according to diagram 1, calculated the reverse travel time for shots gathers of each of the input models separately, as a previous step to complete the requirements of implementing the RTM algorithm. Figure 13 shows the result of the implementation of the RTM algorithm on the numbered (15,65,85) shots gather. The result of applying the algorithm to the shots gather (20,60,89) for the second model is shown in figure 14.

The final result (final seismic section) for applying the Reverse Time Migration algorithm to all shots gather for each input model is shown in Figure 15.
Figure 15: shows Reverse Time Migration on (a) the first industrial model
(b) the second industrial model.

The results of the Migration algorithms were compared by calculating the brightness of the final image (seismic section) resulting from the application of the KM and RTM algorithms and after calculating the contrast and adjusting of this image. Charts (1) and (2), show the brightness results of the images resulting from the two algorithms after calculating the values of the above criteria on them. As shown in the results on the original seismic section, the application of the RTM algorithm to the input models is the value of brightness higher than the brightness when applying the KM algorithm to the two input models, and also the value of brightness remains higher concerning the seismic section resulting from the RTM algorithm after calculating the contrast and adjusting it from The brightness value of the resulting section when applying KM and calculating the contrast and adjusting it. The reason for the high brightness value of the images generated by the RTM algorithm from that produced by the KM algorithm is the forward travel time and reverse travel time calculation in carrying out the migration of the one shot. Also, figure 15-b shows that the Reverse Time Migration algorithm shows the final seismic section which contains the complex structures for the second model more clearly than the final seismic section to implement the Kirchhoff migration algorithm as in figure 12 which represents the final result of the second model. The final result of the algorithm of KM on the first model, which contains a model of the layers without complex structures, appears clearly but slightly less than the final result of applying RTM to the same model as in figures 15 and 10.
6 Conclusion

In this research, two algorithms of the Migration process are applied, Kirchhoff Migration (KM) algorithm and Reverse Time Migration (RTM) algorithm. Through the results, Reverse Time Migration provides more straightforward results. Therefore, recommend that researchers use the RTM method because in the case in which KM and RTM give different results in clarity, especially in the data that contains complex Earth structures, this leads to the conclusion that KM, despite its speed of implementation, is less clear in imaging such as these models are in contrast to RTM, whose result is better to show these structures because it takes into account reverse time.

References

1- Zhou H.-W.,(2014), Practical Seismic Data Analysis, Cambridge University Press, ISBN: 9780521199100.
2- Khalid Sh.,(2019), Seismic Processing for Oil and Gas, Bookstore for Printing, Publishing and Translating
3- Khazi A., Mhana M., (2018), Principles Of Geophysical Methods In Geological Exploration, House of Books and Documents in Baghdad.
4- Enwenode O.,(2014), Seismic Data Analysis Techniques In Hydrocarbon Exploration, Elsevier.
5- Yilmaz, Ö. (2001) Seismic Data Analysis: Processing, Inversion, and Interpretation of Seismic Data, no. 10 in Investigations in Geophysics, Society of Exploration Geophysicists, Tulsa, OK.
6- Abdullatif A., Saleh A., Wail A.,(2017), Seismic Data Interpretation using Digital Image Processing, 1st edn, JohnWiley & Sons Ltd.
7- Wei L., Siyuan C., and Yangkang Ch.,(2015), Seismic Time– Frequency Analysis via Empirical Wavelet Transform, IEEE Geoscience and Remote Sensing Letters , DOI: 10.1109/LGRS.2015.2493198.
8- Mohamed M., Feng X., and Xu C.,(2015), Parameters effects on spiking deconvolution of land seismic data, Global Geology, 18(4) : 226-231.

9- Khalid S., Anwar A.,(2015), Processing and interpretation of 3D seismic data of an oil field in central of Iraq using AVO techniques, Iraqi Journal of Science, Vol 56, No.2C, pp: 1728-1738.

10- Mamdouh R. G., Ray F.,(2009), Exploration Geophysics, Springer, ISBN: 978-3-540-85159-2.

11- Datta, T. K,(2010), Seismic Analysis of Structures, John Wiley & Sons (Asia) Pte Ltd, 2 Clementi Loop, # 02-01, Singapore 129809.

12- Hoogenboezem, R.M.,(2010), Automatic classification of segmented seismic recordings at the Nevado del Ruiz volcano, Columbia, master thesis, [Online], Available: http://resolver.tudelft.nl/uuid:5de9543b-cda8-4397-b61a-4e5f17639d3f.

13- Jones IF (2010) An Introduction to: Velocity Model Building. EAGE Publications, Houten.

14- Bleistein, N., Cohen, J.K., Stockwell, John W. Jr,(2001), Mathematics of Multidimensional Seismic Imaging, Migration, and Inversion, Springer-Verlag New York, Interdisciplinary Applied Mathematics 13.

15- Celal B.,(2015), Investigation Of Seismic Surveys And Enhancement Of Seismic Images, Master Thesis : Texas A&M University.

16- Gerard T. S.,(2009), Seismic Interferometry, Cambridge University Press, ISBN 9780521871242.

17- Claerbout, J. F., (1985), Imaging the earth’s Interior, Blackwell Science Inc.