Optimalization of ultrasonic tomography method using robotic instrument

Tedy Setiawan, Fatkhan, Fernando Lawrens and Albertus Ariel Rahadi
Geophysical Engineering of Study Program, Faculty of Mining and Petroleum Engineering, Institut Teknologi Bandung, Indonesia
*E-mail: fatkhan@yahoo.com

Abstract Ultrasonic tomography is one of many non-destructive methods to image a rock by measuring wave velocities (P or S-wave). Some applications of ultrasonic tomography include research for seismic anisotropy, rock physics, shale gas etc. The objective of this study is to assess the ability of the robotic instrument to measure rock samples using ultrasonic tomography method. As we know that a conventional method are still employed to measure wave velocities in ultrasonic tomography. The conventional method measures a rock manually that it is often difficult and sometime takes quite long time. One of alternatives to cope with the problem is to design a robotic instrument. The robotic instrument is made of microcontroller and stepper motor. The microcontroller and stepper motor control the position of ultrasonic transducers while measuring the rock sample. The robotic instrument is not only able to measure but also have feedback controls. As a result, measured data can be more accurate and precise than those of the conventional method. Several rock samples are used for testing measurements using a MSIRT (Modified Simultaneous Iterative Reconstruction Technique) method. Results show that using the robotic instrument can enhance quality of data and reduce error up to 50%.

1. Introduction
Ultrasonic tomography is one of the most rapidly growing methods[1]. The method utilizes specimens of laboratory scale cores. In practice, the core measurement by ultrasonic tomography still uses conventional means that are not practical and require much time. This conventional method can give different results from one researcher to another, due to the lack of uniformity and high degree of subjectivity during manual measurements.

The purpose of this research is to assess the ability of the robotic instrument to measure rock samples using ultrasonic tomography method. Therefore, it is necessary to have an instrument that is able to optimize performances of credible and relevant ultrasonic tomography measurements[2]. Using the latest technology, robotics instrument can be one solution to get better acquiring data[3][4]. Robotics instrument with a programming base from a computer can be arranged and modified during acquisition in such a way that it will get faster and precision results.

2. Method And Instrument Design
This research was conducted by designing robotic instruments in order to measure core samples. The core measurements were made with 16 data points. The measurement system consist of Transducer V103RM (wave P) and V153RM (wave S), pulser receiver 5072PR, preamplifier 5676, and digital oscilloscope NI-PCI 5911. Frequency of transducer used is of 1MHz. The measurement result is travel time of P wave on iron medium with reference of ultrasonic wave velocity of 5920 meter/second. Iron
is assumed to be homogeny medium and have good respond first break amplitudes. Picking travel times were conducted every first break for each waveform. P-wave velocity was obtained by calculating distance between transmitter and receiver divided by first break of picking travel time.

The distance from the transmitter to the receiver is assumed to be the same for manual calculations and with robotic instrument. Distance calculations were obtained by using the MATLAB program operation for a cylindrical sample model with a diameter of 4.5 cm divided into 16 measurement points. The sample consisted of 3 (three) different layers of resin-iron-resin. Measurements with the robotic instrument were conducted on the iron medium. Iron is located in the middle of the sample having a reference velocity. It ultimately has a good wave velocity response, making it easier for picking and analysis of the next step. To reconstruct a tomographic image, measurements of travel time are made at various angles from transmitter (T) to receiver (R). The measurement scheme is shown in Figure 1 below.

![Figure 1. Ultrasonic tomography measurement scheme](image)

2.1 Design of Robotic Instrument

For purpose of precise and accurate retrieval data, this research designs robotics instrument that is used as measurement tools. The prototype design is able to collect retrieval data [5]. More over a set of computers is utilized as a controller and recorder measurement. The prototype design of the robotic instrument can be seen in Figure 2. Dimensions of the robotic instrument are a height of 22 cm and a diameter of 10 cm.
2.2 Robotic instrument

Robotic instrument is used to improve precision and also to reduce measuring time. The main component used is one robotics instrument consisting of stepper motor 28BYJ-48 5V, Arduino UNO microcontroller, and ULN2003A motor driver[6][7]. Figure 3 illustrates the robotics instrument design assembly scheme.

![Figure 3. The assembly scheme of the robotic instrument](image)

**Figure 2.** The prototype design of robotic instrument.
3. Reconstruction Data Recovery Technique
The measurement results are presented in the table containing the variable P wave velocity from the cross, quarter, and ¾ cross ranges. The measurement result is 5 (five) sets of data with each of 16 measurement points. Figures 4 a, b and c show to give illustrations for straight path measurements. Dimensions of a core sample are a height of 17 cm and a diameter of 5 cm.

3.1 Graph plots of Measurement Results
Figure 5 shows graph plots of measurement results. The blue curve is the measurement value using the tool, while the red curve is the conventional measurement value. Then, the reference plot is indicated by a green color curve located at a value of 5920 m/s. In general, measurements with robotic instrument (blue curves) have a more horizontal trend toward reference values, and are less volatile compared to manual measurements (red curves). The value of the obtained velocity is also close to the reference velocity, by a considerable distance with manual measurement data. This further reinforces the hypothesis that with robotic measurement tools for distance and point determination requiring more accuracy can provide more precise and accurate results.

Figure 4. Straight path measurement data (a) cross, (b) ¾ cross, (c) quarter.

Figure 5. Graph plots of cross measurement results.
3.2 Tomography

To further provide an overview of quality data, measurement experiments of ultrasonic tomography were conducted with 2 types of data. The first data is results of fully manual measurements, whilst the second data is a combination of manual measurements and the robotic instrument measurements at certain points. Tomographic result is calculated using MSIRT (Modified Simultaneous Iterative Reconstruction Technique) method developed by Sanny and Sassa [8]. Figure 6 shows ray path of ultrasonic tomography measurement data. Dimensions of a core sample are height of 17 cm and a diameter of 5 cm.

![Figure 6](image6.png)

**Figure 6.** Ray path of ultrasonic tomography measurement data.

![Figure 7](image7.png)

**Figure 7.** Results of ultrasonic tomography from combined measurement data.
When we examine carefully, it can be seen that on the outside circle of tomographic results there is improvement of data quality with relevant results (Figure 7). The outer cells originally green, yellow, or young orange become darker in color toward the orange. In accordance with color codes, orange color represents a value of approximately the reference velocity used 5920 meter/second. Results obtained have improved in terms of quality that making it more credible and relevant.

To provide a more detailed error description, Table 1 and Table 2 show error calculations for 3 (three) parts, i.e. cross, quarter, and ¼ cross. Calculation errors with least square method are conducted with 2 (two) types, that is by using with and without equation of line.

**Table 1.** Table comparison of errors with line equations

|                | With Equation | Manual |
|----------------|---------------|--------|
| Error Cross    | 0.488         | 0.387  |
| Error Quarter  | 2.230         | 10.006 |
| Error ¼ Cross  | 1.063         | 1.031  |

**Table 2.** Table comparison of errors without line equations.

|                | Without Equation | Manual |
|----------------|------------------|--------|
| Error Cross    | 0.490            | 0.382  |
| Error Quarter  | 2.229            | 9.938  |
| Error ¼ Cross  | 1.026            | 3.087  |

The table of calculation errors from both types of methods used to provide better results on quarter error calculations. This significant error reduction provides the fact that, measurements using robotic instrument can contribute positively to improve quality data. Better point placement will provide better travelt ime picking, so the calculation of the wave velocity will also close to the reference velocity.

4. **Future Research**

Future research regarding the prototype robotics instrument will be conducted to tackle several issues to achieve better measurements quantitatively and qualitatively. So far the prototype robotic instrument can conduct measurement maximum 3 hours. This is simply because the design is at the prototype stage. The obstacle often encountered in this preliminary study is stepper motor overheat due to heavy workload for small motor capacity. To improve the durability of the robotic instrument, further research can use stepper motor with torque and larger dimensions, making it more flexible for different loading types. With a larger stepper motor, the duration of measurement time can also be longer.

Another constraint is the existence of software errors that result in the robotic control system on the smartphone to stop functioning. To overcome these problems required further study of programming, so as to create software that is free from bugs. The use of computers in the placement will be more accurate and precise.
5. Conclusions

This paper has presented ultrasonic tomography measurements using the robotic instrument in which some findings can be drawn as follows:

- rock samples are used for testing measurements using a MSIRT (Modified Simultaneous Iterative Reconstruction Technique) method in which inversion tomographic result is quite good.
- the robotic instrument is not only able to measure but also have feedback controls. As a result, measured data can be more accurate and precise than those of the conventional method.
- the robotic instrument can set transducers automatically that can enhance quality of data and also reduce error by putting the transducers manually.

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