A GUI based automatic detection of seismic P-wave arrivals by using Short Term Average/Long Term Average (STA/LTA) method

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Abstract. Automatic detection of P wave very important to speed up the data analysis rather than manual. One of the methods used for P wave detection is Short Term Average/Long Term Average (STA/LTA). The P wave is detected automatically by STA/LTA when the STA/LTA ratio exceed from the given threshold value. This algorithm has been displayed in the form of Graphical User Interface (GUI) for make it easy to use. We have experimented the GUI to an earthquake on December 24, 2014 that recorded by ACEHSEIS network. We use four vertical components from different seismic stations and one of it has a noisy waveform. The P-wave was obtained when the STA/LTA ratio exceeded the threshold value at 0.35. We also determine the P wave with the manual detection and Pphase Picker as the comparison to our GUI of STA/LTA. The result shows that, our GUI of STA/LTA method can be used determine P wave arrivals although the waveform is noisy but the program cannot be used to determine the relatively minor phase of P wave arrivals. While the results of Pphase Picker is opposite of STA/LTA.

1. Introduction
Generally, two types of body-seismic wave are P wave (primer) and S wave (secondary). P wave is a longitudinal wave with small potential of damage while S wave is transversal wave with larger potential of damage to the population. The velocity of P wave is faster than S wave [1]. Therefore, in a seismometer phase of P wave is arrived earlier and observed more clearly in vertical component. Identification of P wave very important in seismology to estimate the location of an earthquake and subsequently to determine the magnitude and mechanism of the earthquake [2].

The P wave detection manually is easy but it is very time consuming when the number of earthquakes are large. Moreover, an earthquake is recorded by a large number of seismic stations so that the number of hand-detection could increase significantly. We propose to use automatic detection method for determine P wave arrivals so that the method could reduce the pre-processing time. One of the method of the automatic detection of P wave arrivals is called Short Term Average/Long Term Average (STA/LTA). In this paper, we introduce and describe the design of a user friendly Graphical User Interface (GUI) of the STA/LTA method to determine P wave arrivals easily. The algorithm of STA/LTA in this paper will be compared with manual detection (conducted by Aulia Khalqillah) and Pphase Picker algorithm introduced by Erol Kalkan in 2016.
2. STA/LTA Method

Short Term Average/Long Term Average introduced by Allen (1978) is one of the methods automatic detection of P wave in seismology. This algorithm has good performance on many waveform data [3]. The STA/LTA is the most extensively used algorithm in weak motion. The algorithm has two moving window, that is STA window and LTA window. For the process, we calculate the sum of absolute value of STA and LTA amplitudes. Next, the STA/LTA ratio is calculated. The phase of P wave is considered to arrive if the STA/LTA ratio exceeds threshold value and the P wave arrival is detected [4]. The calculation of STA/LTA ratio can be written as follows:

$$\varepsilon = \frac{STA_j}{LTA_j} = \frac{\sum_{i=1}^{n} D_i |u(t_i)|^2}{\sum_{i=1}^{n} C_i |u(t_i)|^2}$$  \hspace{1cm} (1)

Where $u(t_i)$ is the earthquake time series data, $D_i$ and $C_i$ is the exponential form amplitude decay of STA and LTA, respectively. The form of $D_i$ and $C_i$ can be expressed by:

$$D_i = D_0 \exp \left[ -\alpha_2 (n - i) \right]$$  \hspace{1cm} (2)

$$C_i = C_0 \exp \left[ -\alpha_1 (n - i) \right]$$  \hspace{1cm} (3)

Where $\alpha_1$ and $\alpha_2$ is the decay coefficient which should be adjusted based on types of the general form of earthquake data, where $\alpha_1 << \alpha_2$ and $D_0$ and $C_0$ are constants, $n$ is length of time series data and $i$ is the inde of earthquake data [5].

3. Methodology

3.1. Waveforms Data

In this paper, the earthquake data was obtained from the ACEHSEIS network that was installed in 2014 – 2015 in Central Aceh, Indonesia. The waveform of an earthquake recorded by four stations that were used to test the algorithm. Because the P-waves are longitudinal propagation, the algorithm was applied to the vertical components of the seismic waveforms. We use the earthquake data on 24 December 2014 at 17:34 WIB.

Figure 1. The location of seismic of the ACEHSEIS network and the distribution of earthquake in Central Aceh, Indonesia [5]
3.2. STA/LTA Algorithm
The P wave arrivals were automatically detected by using equation 5 to 7 for processing in this algorithm. The window length of the seismic waveforms is 30 s with sampling time 0.01 s which means that we have 3000 data to be processed in 30 s time series. The parameters already set such as length of STA window is 1 s and length of LTA window is 30 s. Furthermore, for decay coefficient $\alpha_1$ is 0.01 and $\alpha_2$ is 0.1. First, the user should define threshold value as the initial estimation for P wave arrival. When the STA/LTA ratio exceeds initial estimation of the threshold value given by a user, it means the P-wave is detected.

4. Result and Discussion
4.1. Graphical User Interface Design
The program can only read the miniSEED data format consisting of three components including vertical component, east-west or horizontal component, north-south/ horizontal component. Graphical User Interface for this algorithm has been designed and the GUI has worked in MatlabR2015b (Figure 2) properly. The GUI-based P wave automatic detection allows the user to determine the phase of P wave more easily. The GUI displays three components of waveforms of an earthquake of each station.

![Figure 2](image.png)

**Figure 2.** The standard display of GUI-based STA/LTA method consisting of three sub-figure to view a three component waveform

4.2. P Wave Determination Results
To P wave detection by GUI of STA/LTA, we must set the initial threshold value as estimation. First, we set the initial threshold value was 0.3 to estimation the P wave arrival. When the process was done, the P wave was not detected. Furthermore, we set again the new initial threshold value was 0.32. It is the same as before, the P wave was not detected improperly. The proper threshold values was 0.35 and the P wave was detected properly (Figure 3). The P wave was detected when the STA/LTA ratio exceeds the proper threshold value and we get the threshold value for each station are 0.3536, 0.3562, 0.3511 for station 662, 848, and 852, respectively.
Figure 3. Picking results of an earthquake data is obtained when STA/LTA ratio ≥ 0.35

The P-waves arrivals (travel times from the origin time) calculated by STA/LTA are shown in Table 1.

| Station | Arrival times of P-wave from the origin time (STA/LTA method) |
|---------|-------------------------------------------------------------|
| 662     | 65.33                                                       |
| 848     | 64.65                                                       |
| 852     | 63.71                                                       |

4.3. Algorithm Analysis

The result of P wave detection that recorded by the station 662, 848 and 852 shows that the amplitude $D_i$ for STA (red line) decays more sharply than amplitude $C_i$ for LTA (blue line) as shown in Figure 4. It means that when the P wave arrived, the response of the STA segment more sensitive than the LTA segment. It is understandable because $C_i$ is the amplitude summation of much longer data series compare to $D_i$. 
Figure 4. The $D_i$ amplitude (STA) decay more significantly than $C_i$ amplitude (LTA).

Figure 5. The mispicks of seismic arrival time of waveforms recorded the three station when $\alpha_1 \ll \alpha_2$.

The decay of the amplitude depends on the decay coefficient $\alpha$, where $\alpha_2 \gg \alpha_1$. In this algorithm, we set the decay coefficient $\alpha_2 = 0.1$ and $\alpha_1 = 0.01$. If the $\alpha_2$ is much smaller than $\alpha_1$ ($\alpha_2 \ll \alpha_1$) (e.g. $\alpha_2 = 0.01$ and $\alpha_1 = 0.1$) the algorithm could not detect the P arrivals no matter what threshold value given by user (Figure 5). The STA segment increases significantly and the LTA segment increases slowly until both meet at the peak, then the arrival time of P wave was obtained (Figure 6).
Figure 6. Arrival time of P wave is obtained when STA segment and LTA segment meet each other at the peak

The three data of P wave arrivals were detected shown in Figure 7 when the STA/LTA ratio exceeds the given threshold value that are 0.3536 for the station 662, 0.3562 for the station 848, and 0.3511 for the station 852.

Figure 7. The STA/LTA ratio exceeds the threshold value (0.35, given by user)

4.4. Comparison Result between STA/LTA and USGS Pphase Picker
As the comparison, the result of automatic picking determined by the STA/LTA was compared with manual picking (conducted by Aulia Khalqillah) and the Pphase Picker algorithm introduced by Erol Kalkan in 2016. The Pphase Picker is another automatic detection for P wave. The Pphase Picker works to transform signal becomes oscillator domain response in Single Degree of Freedom (SDOF) with viscous damping and then track the loss damping energy changes which is associated with a seismic wave arrival. In general, Pphase Picker could determine the P phases without requiring a threshold value.
used [6]. Pphase Picker work in Matlab without display GUI. The result from three method picking is not much different (Figure 8).

According the result shown in Figure 8, at the station 662 Pphase Picker (green line) detected P wave earlier than the STA/LTA (black line). The misfit of the arrival times resulted by both methods is 0.33 second. At the station 848 and 852, the Pphase Picker has same result as the STA/LTA. The arrival time resulted by both methods are shown in Table 2.

Table 2. Comparison of P arrivals from origin time determined by manual picking, Pphase Picker and STA/LTA

| Name of station | Manual Picking (sec) | Pphase Picker USGS, (sec) | STA/LTA (sec) |
|-----------------|----------------------|--------------------------|---------------|
| 662             | 65.05                | 65                       | 65.33         |
| 848             | 64.6                 | 64.65                    | 64.65         |
| 852             | 63.7                 | 63.73                    | 63.71         |

The arrival time misfits between STA/LTA and Pphase Picker are large. When we tried to input the threshold value less than 0.35, the STA/LTA could not pick the P arrivals (Figure 9). It means that only with the threshold value larger than 0.35 the phase of P wave could be detected by STA/LTA. In case the first arrival is relatively weak compared to the second wiggle of waveform, the STA/LTA method could pick the second wiggle as the P arrival (Figure 10-a).
Figure 9. The arrival of the P phase was detected incorrectly by the STA/LTA (black line) when the threshold was set less than 0.35.

Figure 10. (a) The STA/LTA pick the second wiggle of the waveform recorded by the station 662 while (b) the station 848 and (c) 852 picked the arrivals correctly.
Figure 11. The difference pick times resulted from the STA/LTA and Pphase Picker

Furthermore, we compare result of P wave detection between STA/LTA, Pphase Picker and manual detection against station 851 that has a small noisy signal. There is big difference between the P wave arrivals determined by the STA/LTA and Pphase Picker (Figure 11). While the Pphase Picker (green line) detected some noise in data, our STA/LTA method (black line) detected the phase of P-wave correctly (manual detection almost approaching to STA/LTA detection).

Each automatic detection method of seismic wave arrivals has advantages and disadvantages. The STA/LTA can be used to determine P wave of earthquake although the waveforms are noisy but cannot be used to determine the P wave of a relatively small magnitude earthquakes. On the other hand, Pphase Picker can detection the P wave with small phase but cannot P wave detection while the phase has noisy signals.

5. Conclusion
The algorithm of automatic detection of P wave arrivals using STA/LTA method has been successfully designed with Graphical User Interface display and work improperly. The phase of P waves were obtained when the threshold value was at 0.35 including arrival time of all waveforms recorded by four seismic stations only vertical component. The result of STA/LTA ratio of each station obtained as follows: for the station 662 the ratio was at 0.3536, the station 848 was at 0.3562 and the station 852 was at 0.3511 with decay coefficient $\alpha_1 = 0.01$ and $\alpha_2 = 0.1$. When STA/LTA and Pphase Picker were compared to using station 851 that has noisy signals, STA/LTA can be used to determine P wave arrivals although the waveform is noisy but the program cannot be used to determine noisy P wave of a relatively small phase. The opposite, Pphase Picker can detection the P wave with small phase but cannot P wave detection while the phase has noisy signals.
Acknowledgments
The authors are grateful to Dr.rer.nat. Muksin and Dr. Muhammad Isa for direction, discussions and advice for completing this paper, to Tsunami Disaster and Mitigation Research Center (TDMRC), to my friends in Tsunami Disaster and Mitigation Research Center (TDMRC), Syiah Kuala University, Aceh, Indonesia for supporting me and for the last thanks to anonymous reviewers for many valuable comments for this paper.

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