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The preliminary results of Lindu software: a free seismological data processing using python framework

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The preliminary results of Lindu software: a free seismological data processing using python framework

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Abstract. LINDU software is developed to solve integrated earthquake data processing. It is GUI based software that fulfil the needed for user friendly type of software. The Python framework is used for computation and visualization and integrates the common programs for earthquake data processing, such as GAD.exe, JHD.exe, and HypoDD.exe. It is also integrates the common procedure of routine data processing in earthquake seismology and works in local and regional scale. In this paper, we shows the preliminary results of LINDU software for several functions. To identify arrival time of P-wave we employ Akaike Information Criterion (AIC), MER (Modified Energy Ratio) and S/L Kurt's method. The results of these method will be considered as guided – auto picking. However, the results also can be treated as reference for picking manually with Seisgram2k.jar. Geiger's method is employed to locate the event location. The events can be relocated and 1D velocity can be updated by employing Joint Hypocenter Determination (JHD). The next method to relocate the event location is Double Difference (DD) algorithm. The precision result of Lindu software has been tested using IRIS and real data available which run seamlessly.

1. Introduction

Seismic wave of an earthquake caused by tectonic, volcanic activity or rock-fall will propagate through the subsurface and then recorded by seismometer. Since the data contains physical information of subsurface, many researchers develop the method to extract the information and then derive it into the program codes. However, generally, the program codes was developed only for specific function, not integrated in one program, and work on command-line based and less user-friendly. We developed Lindu software which provides the solution to overcome the problem. The software integrates the common procedure of routine data processing in earthquake seismology, from automatic event identification to 3D seismic velocity tomography inversion, and works for local and regional scale. Figure 1 shows the general feature and procedure of LINDU software.

Lindu is a Graphical User Interface (GUI) based software and running on Windows environment. In this paper we show the preliminary result of Lindu software that has several features. The first is guided

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auto – picking feature which offers several approach: (1) Akaike Information Criterion (AIC) [1,2], (2) Modified Energy Ratio (MER) [3,4] and (3) S/L Kurt algorithm [5]. The next feature is hypocenter determination which employs Geiger's Adaptive Damping approach [6] and is widely used to determine earthquake event location [7,8,9]. The third is the feature to relocate the earthquake hypocenter. In this feature we employ Joint Hypocenter Determination method [8,9,10] after a simple modified Fortran engine for python. For visualization we added matplotlib and basemap module.
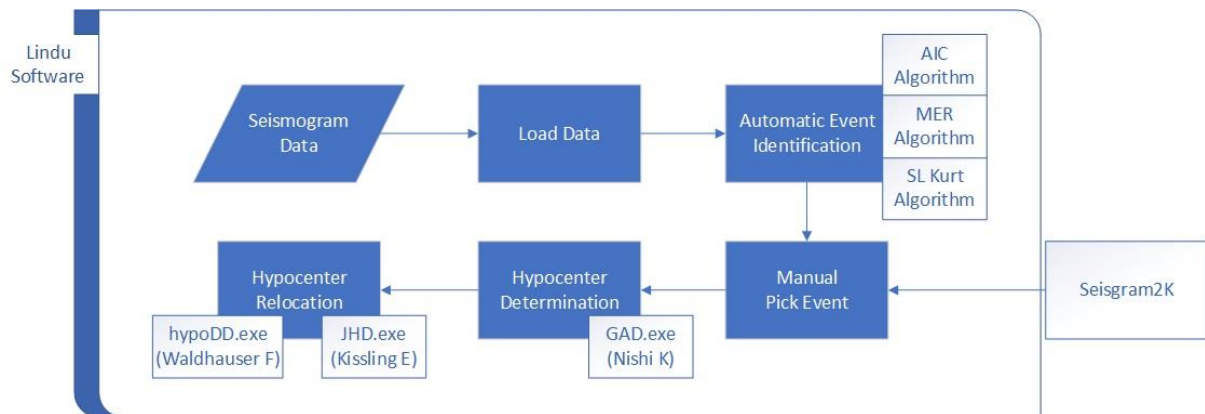
Figure 1. General feature of Lindu Software for seismological data processing

2. Methods

2.1 Akaike Information Criterion (AIC)
AIC assumes the signal as an autoregressive process (AR) that can be devided into locally stationary segments and the intervals before and after onset are two different stationary processes. Based on it, autoregressive Akaike information criterion (AR-AIC) can be written as follow [1],

$$AIC(k) = k \log\big(var(x[1,k])\big) + (N - k - 1)\log(var(x[k+1, N]))$$
(1)

where k is range of time series, x is current time series and N is length of time series.

2.2 Modified Energy Ratio (MER)
MER is a method that modifying equation of basic energy ratio attribute. The basic energy attribute can be written as the following equation [3],

$$er(i) = \sum_{i=i}^{i+L} grm(j)^2 \Big/ \sum_{i=i-L}^{i} grm(j)^2$$
(2)

where i is current index, L is the length of the energy collection windows preceding and following the current, and grm(j) is the seismogram value at index j. To improve event detection, energy ratio was modified as below,

$$mer(i) = [er(i) * abs(grm(i)]^3$$
(3)

2.3 S/L Kurt
The principle of S/L Kurt method is calculating a ratio of short-term kurtosis (STK) and long-term kurtosis (LTK). The STK and LTK windows are computed as the following equation [5]:

$$STK_i = \frac{1}{(ls-1)\sigma_i^4} \sum_{j=i-ls}^{i} \big(X_j - \bar{X}_i\big)^4$$
(4)

where,

$$\sigma_i^2 = \frac{1}{(ls-1)} \sum\nolimits_{j=i-ls}^{i} \left(X_j - \bar{X}_i\right)^2$$

$$\tag{5}$$

and

$$LTK_i = \frac{1}{(ll-1)\sigma_i^4} \sum\nolimits_{j=i-ll}^{i} \left(X_j - \bar{X}_i\right)^4$$

$$\tag{6}$$

where,

$$\sigma_i^2 = \frac{1}{(ll-1)} \sum\nolimits_{j=i-ll}^{i} \left(X_j - \bar{X}_i\right)^2$$

$$\tag{7}$$

where σ_i^2 is standard deviation, X_j is j-th sample, $\bar{X}_i$ is mean of data, ls and ll is length of short and long-term window. Finally, the formula become:

$$S/L\,Kurt_i = ratio_i = \frac{STK_i}{LTK_i + \varepsilon}$$

$$\tag{8}$$

where ε is a constants added to avoid from zero division.

2.4 Geiger's Adaptive Dumping (GAD)

Geiger's Adaptive Dumping is one of hypocenter determination methods within a relatively close between source and station. The method assumes that earth is flat so that it is only solved at local earthquake problem. Inversion solution algorithm uses least squared methods. The following algorithm is shown at below,

$$res_j = \Delta T + \frac{\Delta TT_j}{\partial x}\Delta X + \frac{\Delta TT_j}{\partial y}\Delta Y + \frac{\Delta TT_j}{\partial z}\Delta Z$$

$$\tag{9}$$

where res_j is residual between arrival times observation and calculation and ΔX, ΔY, ΔZ, ΔT are perturbation of event coordinate and original time, respectively [6].

2.5 Joint Hypocenter Determination (JHD)

Joint hypocenter determination is a method that simultaneously updating both of event (hypocenter) location and 1D velocity model [10]. The solution of this problem can be written as

$$w_{ij}r_{ij} = w_{ij}\left(\frac{\partial t}{\partial x^j}\Delta x^j + \frac{\partial t}{\partial y^j}\Delta y^j \frac{\partial t}{\partial z^j}\Delta z^j + \Delta \tau^j + \Delta s^j\right)$$

$$\tag{10}$$

where wij is data weighting, rij is residual of traveltime and original time. Index i and j are earthquake and station, respectively. To update model, Δx, Δy, Δz, $\Delta \tau$ and Δs are used as coordinate, arrival time, and slowness (inversely proportional with velocity) difference, respectively.

3. Result and Discussions

3.1 Graphic User Interface

Lindu is a software for routine seismological data processing. It has capability to load and visualization seismogram data in various format, manually picking arrival time data in seismogram with automatic event identification results as reference, determining and relocating events hypocenter. Figure 2 shows splash screen, getting started tab, and datasets tab on this software.

3.2 Picking Seismogram Data

Users can select single or several seismogram data and plotting them to start picking arrival time of P-wave and S-wave manually. The arrival time data will be stored automatically in memory and then can be saved in ASCII data. Figure 3 demonstrates the results of AIC, MER, and S/L-Kurt algorithm respectively to real seismogram data of a Banda Sea earthquake on 24 September 2017 which was recorded at station KAPI.
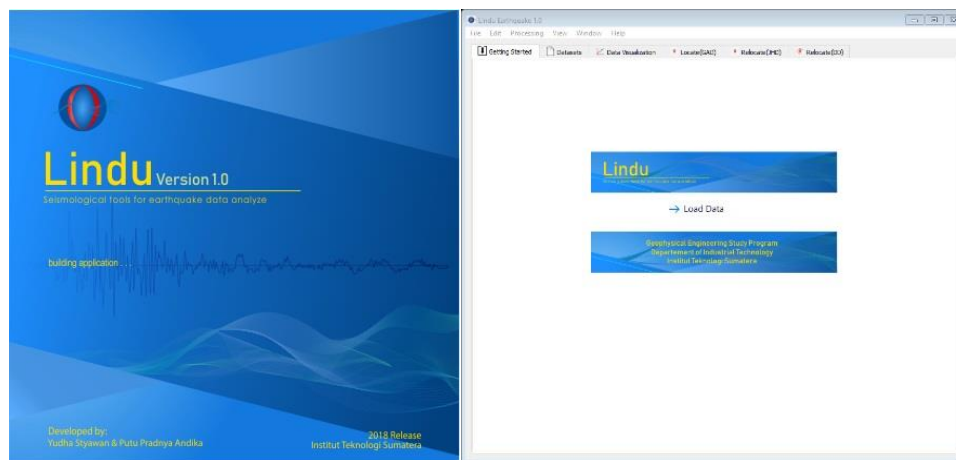
(a)   (b)

Figure 2. (a) Splash screen; (b) Getting started tab
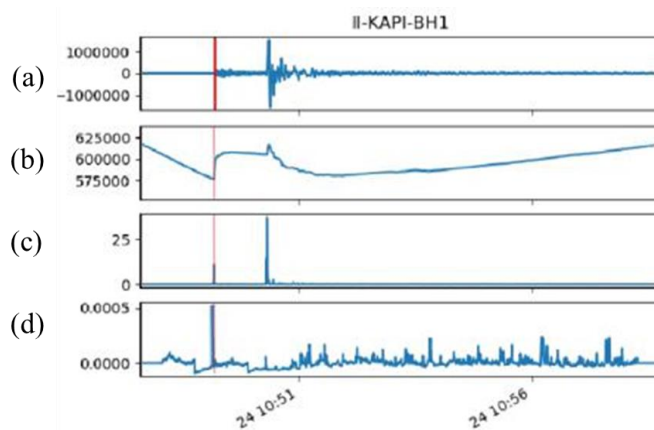
Figure 3. (a) Earthquake seismogram and its characteristic function consists of (b) AIC (c) MER and (d) S/L-Kurt.
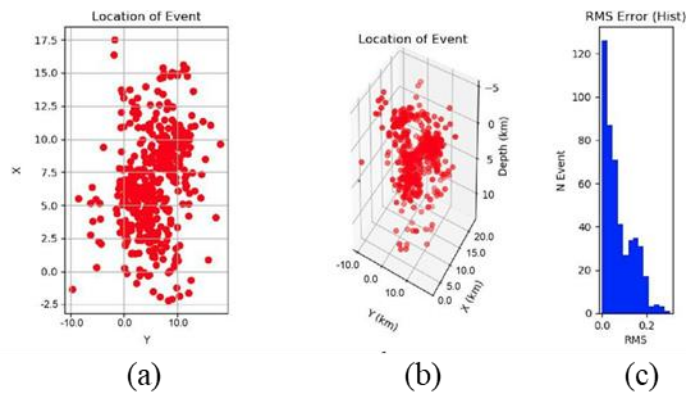
3.3 Hypocenter Determination

This software use GAD.exe that adapted from Geiger algorithm with adaptive damping to determine hypocenter. This feature was tested to both synthetic and real data from a geothermal field in Indonesia, this software can do this task showed by Figure 4 and 5.
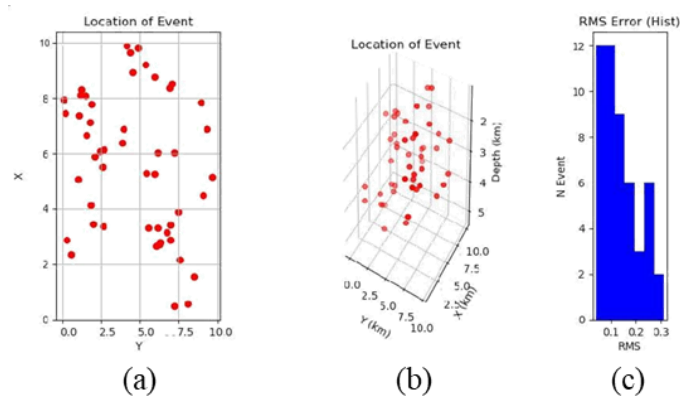
Figure 4. Hypocenter determination of synthetic data of 50 events (a) Epicenter, (b) Hypocenter location, and (c) RMS Error

Figure 4 shows the distribution of hypocenter determination from synthetic data using GAD. Root-mean-squares (RMS) histogram explains the result could be accepted by having value less than 0.3 for

every single events in synthetic data. In addition, Figure 5 describes the distribution of hypocenter determination using real data moreover the algorithm gives acceptable result shown in RMS histogram by less than 0.3. Hence, Lindu software can be evidence to determine hypocenter for field data case.

Figure 5. Hypocenter determination of a real data set. (a) Epicenter, (b) Hypocenter location, and (c) RMS Error

3.4 Hypocenter Relocation
To relocate hypocenter, we employ JHD algorithm which solve velocity and hypocenter determination simultaneously. This feature is tested to example data from Velest and run seamlessly. 1D velocity updated also resulted from JHD is shown in Figure 6.
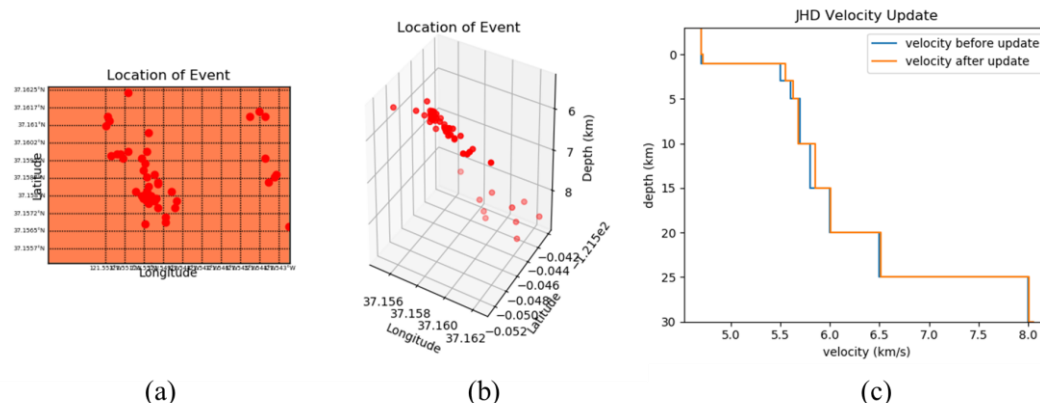
Figure 6. Hypocenter relocation from 63 events by Velest data example; (a) Epicenter, (b) Hypocenter by JHD engine for relocating, and (c) 1D velocity model.

Additionally, this software can facilitates user to view location of source by surface model (2D) and volume model (3D) as in determining or relocating hypocenter. Besides, in JHD module, user may extract 1D velocity update in the output file for displaying as Figure 6c.

4. Conclusion
In this preliminary results we successfully develop LINDU software which integrates common procedure in seismological data processing and implement the procedure into several features, they are automatic P-arrival time picking, hypocenter determination, and hypocenter relocation. However, for hypocenter determination and relocation we use existing program with some simple modification in order to be called by our software and the results can be viewed directly without any other software for visualization. For further purposes, we will continue to enhance the feature by including 3D seismic velocity tomography.

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