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Lindu Software: An Open Source Seismological Data Processing Using Python Framework To Relocate Hypocenter (Preliminary Software)

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Abstract. Recorded seismogram of an earthquake data contains the earth structure information. Researchers developed the method to extract the information and derives it into the program codes. However, generally, the program codes developed only for specific function and work on only specific scale. Almost the existing programs have a limitation, for example, they work on command-line based and less user-friendly. Lindu software is developed to solve these problems. In this paper, we show the preliminary results of Lindu software, a GUI – based software which is open source and developed in python platform. This software integrates the common procedure of routine data processing in earthquake seismology and works in local and regional scale. It is designed to read multi-component data on multi-station. To identify events automatically, we employ SL Kurt's method and use the results as guided auto–picking. However, the picked time also can be changed manually. Furthermore, we employ Joint Hypocenter Determination (JHD) algorithm to locate the hypocenter of earthquake events and update the 1D velocity model simultaneously. Then the events can be relocated by employing the double-difference method. The software was tested on the available data from IRIS and BMKG and shows the acceptable and reliable results.

1. Introduction

Earthquake can be described as the release of strain energy suddenly during the movement caused by tectonic, volcanic activity or rock-fall. Seismic waves generated by an earthquake propagate on the subsurface and recorded by the seismometer. Due to recorded data contains physical information of subsurface, many researchers develop the method to extract the information and derive it into the program codes, however, generally, program codes developed only for specific function and works on only specific scale and has a limitation, for example, they 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 imaging, and works in local and regional scale.

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 auto – picking feature which employs S/L Kurt algorithm[1]. The second is the feature to determine hypocenter location which uses Geiger's Adaptive Damping approach. The third is the feature to relocate the earthquake hypocenter. In the last feature, we employ the double-difference method[3] with a simple modified Fortran engine for python. For visualization, we use matplotlib and basemap module. The software is for educational purposed, so it will be an open source software and student or researcher can joint on this project to develop Lindu much better.

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2. Methods

2.1. *S/L Kurt*

The principle of S/L Kurt method is calculating a ratio between short-term kurtosis(STK) and long-term kurtosis(LTK) to determine of Gaussian distribution of the data. In this method, we found the problem about estimate window function of the kurtosis value at time sample[2]. The STK and LTK windows are computed as below:

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

where, $\sigma_i^2 = \frac{1}{(ls-1)} \sum_{j=i-ls}^{i} (X_j - \bar{X}_i)^2$

and

$$LTK_i = \frac{1}{(ll-1)\sigma_i^4} \sum_{j=i-ll}^{i} \left(X_j - \bar{X}_i\right)^4 \quad (2)$$

where, $\sigma_i^2 = \frac{1}{(ll-1)} \sum_{j=i-ws}^{i} (X_j - \bar{X}_i)^2$

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:

$$SL\,Kurt_i = ratio_i = \frac{STK_i}{LTK_i + \varepsilon} \quad (3)$$

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

2.2. *Geiger's Adaptive Dumping (GAD)*

Geiger 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. Solution algorithm uses the least squared methods. The following algorithm is shown at below,

$$res_j = \Delta T + \frac{\Delta TT_j}{\partial X}\Delta X + \frac{\Delta TT_j}{\partial Y}\Delta Y + \frac{\Delta TT_j}{\partial Z}\Delta Z \quad (4)$$

where res is residual between arrival times observation and calculation and $\Delta X, \Delta Y, \Delta Z, \Delta T$ are perturbation of event coordinate and original time, respectively[1].

2.3. *Joint Hypocenter Determination (JHD)*

Joint hypocenter determination is a method that simultaneously updating both of event (hypocenter) location and 1D velocity model[3]. The solution to this problem can be written as

$$w_{ij} r_{ij} = w_{ij} \left(\frac{\partial t}{\partial x^j}\Delta x^j + \frac{\partial t}{\partial y^j}\Delta y^j + \frac{\partial t}{\partial z^j}\Delta z^j + \Delta\tau^j + \Delta s^j \right) \quad (5)$$

where w_{ij} is data weighting, r_{ij} is residual of traveltime and original time. Index *i* and *j* are earthquake and station, respectively. To update model, $\Delta x, \Delta y, \Delta z, \Delta\tau$ and Δs are used as coordinate, arrival time, and slowness (inversely proportional with velocity) difference, respectively.

2.4. Double Difference (DD)
Double difference algorithm is a method to determine hypocenter locations which using residuals (dr_k^{ij}) between observed and theoretical travel-time differences by two events[4]. The residuals are defined as

$$dr_k^{ij} = \left(t_k^i - t_k^j\right)^{obs} - \left(t_k^i - t_k^j\right)^{cal} \quad (6)$$

where t_k^i and t_k^j are arrival time of event i and j to station k. Generally, updating location of hypocenter is generated by differential of time equation based on space and velocity. Double difference is compared differential on two event so that can be taked a residuals. The compared can be writted as

$$\frac{\partial t_k^i}{\partial x}\Delta x^i + \frac{\partial t_k^i}{\partial y}\Delta y^i + \frac{\partial t_k^i}{\partial z}\Delta z^i + \Delta\tau^i - \frac{\partial t_k^j}{\partial x}\Delta x^j - \frac{\partial t_k^j}{\partial y}\Delta y^j - \frac{\partial t_k^j}{\partial z}\Delta z^j - \Delta\tau^j = dr_k^{ij} \quad (7)$$

where $\Delta x, \Delta y, \Delta z, \Delta\tau$ are model difference to update event location and arrival time, respectively. To solve this equation, least squared methods and singular value decompoosition metodes are used

3. Result and Discussions
3.1. Graphic User Interface
Lindu is software for routine seismograms data processing such as reading and visualization data seismogram, picking travel time data in seismogram with guidance tool (auto picking), and determining hypocenter. In the routine earthquake data processing procedure, some algorithms are used such as S/L-Kurt algorithm for guiding data picking, JHD and double-difference algorithm to locate and relocate the earthquake events, respectively. In this software, six main tabs are readily used for the processing. There are getting started, datasets, visualization, locate (GAD), relocate (JHD), and relocate (DD). The first tab, getting started, is used for the main view of this software and quick access button such as load data. The second tab, datasets, is used for viewing and managing seismogram data and then in this tab also the status information of every seismogram data(s) is shown. The third tab, visualization, is used for graph viewing of seismogram data. The fourth, fifth and the last tabs, locate (GAD), relocate (JHD) and relocate (DD) respectively, are used for determining hypocenter of every earthquake event. Figure 1 shows us the flowchart of Lindu software.

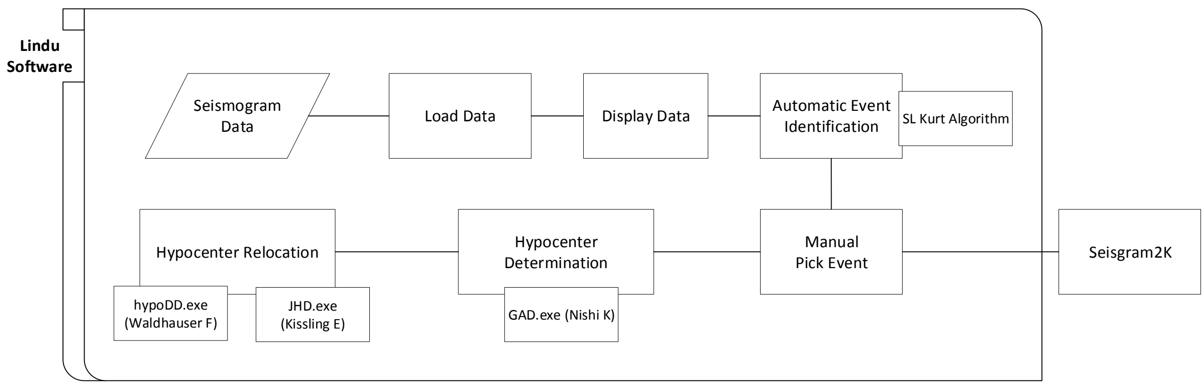

Figure 1. Flowchart of Lindu

3.2. Picking Seismogram Data

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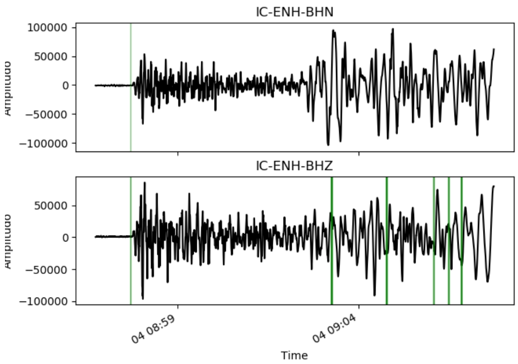
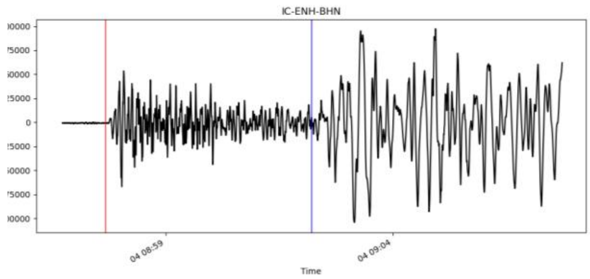
On datasets tab, the users can select single or several data and plotting them to visualization tab so that the users can start picking seismogram data. Visualization tab also provides guided auto-pick as first break P and/or S wave approaching to facilitate the users to identify the event by clicking get guide button (Figure 2 (a)). Currently, the guided auto-pick feature is limited to use because of trouble with window estimation value (*ls* and *ll*) of S/L Kurt algorithm that can give bad result in event identification. Then, to start picking arrival time, we must choose pick-p or pick-s button firstly (Figure 2 (b)). Picking data results will appear on the table picking automatically that appropriate with picking options. The data on the table picking contains station, channel, date event, time pick-p, and time pick-s. this table also can be exported as (*.pick) file that can be used for next earthquake processing.



(a)



(b)

Figure 2. (a). Result of guided picking; (b) Result of arrival time pick-p(red) and pick-s(blue)

3.3. Hypocenter Determination

In this software, the hypocenter determination consists of two steps, the first is locating and the last is relocating based on locating results. To locate hypocenter, we employ Geiger adaptive damping (GAD) method and then we use joint hypocenter determination (JHD) and double difference (DD) to relocate the events. The GAD, at the fourth tab, only needs some input data to operate it, such as station, velocity, and arrival-time data file and those files are in *.dat format file. Station file is used to get information of each station such as coordinate and elevation. Velocity file is used to get information depth and value on each Vp and Vs. Last, arrival file is used to catch information about the arrival time of each station on the following event. Output file that used *.dat extension contains information about hypocenter location and probably errors on each event. Figure 3 shows the result of determining hypocenter by GAD that is shown at view tab.

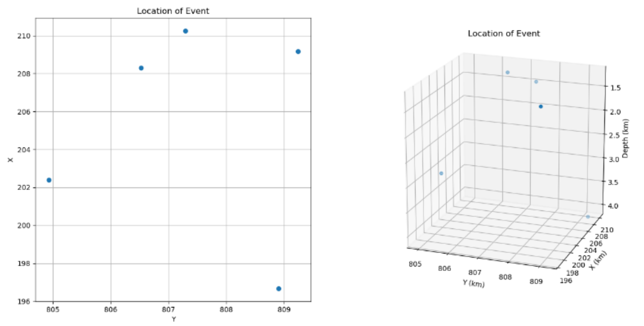


Figure 3. 2D view (left) and 3D view for result data (*.dat) (right) at tab view in 'Locate (GAD)' tab

To relocate hypocenter, this software use hypocenter determination (JHD) and double difference (DD) algorithm. Input or output file at both algorithms on this software is compatible with VELEST and hypoDD, respectively. JHD, at the fourth tab, needs some importantly input data to operate it, such as model file (*.mod), station file (*.sta), and earthquake data (*.cnv) and some optional data for single event mode such as region names, region coordinates, and seismo-file for magnitude calculation. The model file is a file that contains the velocity model (Vp and Vs). Station file contains information and status on each station that used to locate hypocenter. Earthquake data contain information about events and travel time from the hypocenter to each recording station.
Some parameter is used for processing JHD in this software. After the parameter fields were filled and path of input and output file are determined, locating hypocenter can be operated. Visualization of this software consists of 2 subviews. The first is 2D view with basemap and the second is a 3D view of the earthquake events. The visualization can be seen in Figure 4.

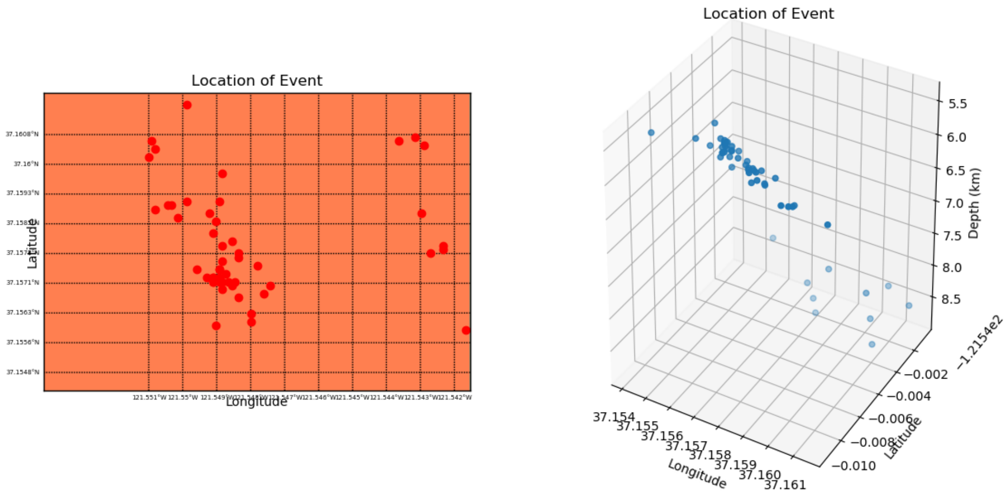


Figure 4. 2D view (left) and 3D view for earthquake data (*.cnv) (right) at tab view in 'Relocate (JHD)' tab

Besides JHD, another method that is used for relocating hypocenter is double-difference (DD) method and it can be found in relocate (DD) tab. To operate this method, some input data is needed such as cross-correlation difference time (optional), catalog travel time, initial hypocenter, station, and improved file for this software, velocity file. Some parameters, such as data type, phase type, the maximum distance between cluster and stations, weighting-reweighting and etc., are used to operate this module. Before and after relocating, format data *.loc and *.reloc respectively can be seen in Figure 5. This figure is the same within locating (JHD) tab. There are 2D view with basemap and 3D view to locate hypocenter.

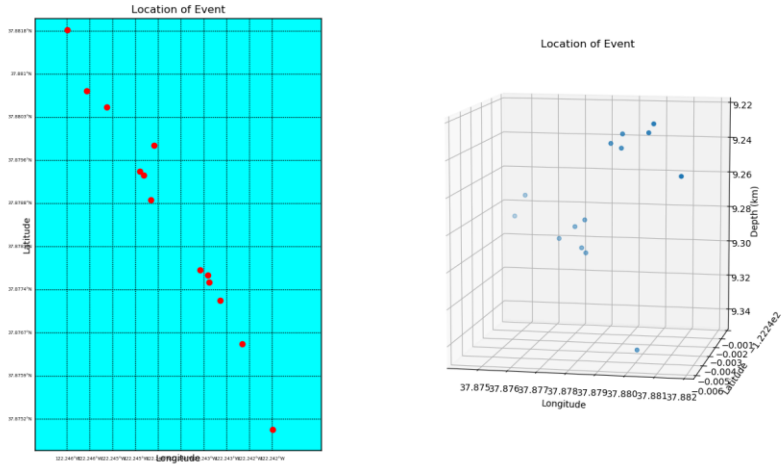


Figure 5. 2D view (left) and 3D view for output data (*.loc or *.reloc) (right) at tab view in ‘Relocate (DD)’ tab

4. Conclusions

This software is the preliminary result for routine seismogram data processing that contains visualization seismogram data, picking operation with guided auto picking used S/L-Kurt algorithm, and hypocenter determination that consist of two-step, locating and relocating hypocenter. Geiger Adaptive Damping (GAD) algorithm is used for locating and Joint Hypocenter Determination (JHD) with Double Difference (DD) algorithm are used for relocating. The result of JHD and DD can be seen on 2D (with basemap) and 3D graph. For the further developing, improving guided auto picking algorithm and tomography will be included in this software.

5. References

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