

Matlab software for GNSS coordinate time series analysis

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Abstract - Determining of earth surface deformations is essential to understanding the mechanism of plate motions and its implication for geodetic processes. Global Navigation Satellite System (GNSS) is commonly used to monitor plate motion. For the reliable determination of any site's plate motions, coordinate time series analysis needs to be conducted. This manuscript introduces the software for coordinate time series analysis. The software was written in MATLAB programming language. MATLAB is one of the programming environments commonly used by scientists and engineers around the world. It consists of source codes (m files) and Graphical User Interface (GUI). The software performs rigorous computations for reliable coordinate time series analysis without the interference of users. The input of the software is the coordinate time series in Earth Centered Earth Fixed (ECEF) coordinates from repeated GNSS measurements and the outputs are three-dimensional velocities of a site and associated statistical results. The software handles the outliers and gaps in the coordinate time series. Users can modify the source codes according to their studies.

Key Words: GNSS, MATLAB, software, time series, velocity.

1. INTRODUCTION

The present-day velocities of the Earth's lithospheric plates are an important subject for many studies, including geology, geophysics and geodesy [1]. Precise information related to surface deformation of the earth is indispensable to analysing earthquakes, detecting local deformations, tectonic activities, landslides and establishing national geodetic datum [2; 3]. Geodetic datums can be classified as static, kinematic (dynamic), and semi-kinematic (semi-dynamic). A semi-kinematic datum is the one where complex deformation (plate tectonics and other deformation events) is modelled as an implicit component of the datum using velocities of the Earth's lithospheric plates, thus enabling kinematic coordinates acquired by Global Navigation Satellite System (GNSS) to be transformed consistently and accurately to a fixed reference epoch over time [4]. In this way, uncertainty in jurisdiction over cadastral information due to the changing coordinates through time by plate motion can be mitigated. GNSS has been developed since the late 1970s. Thanks to the improving accuracy and development of the receivers and antennas, GNSS is routinely used for monitoring tectonic motion with high accuracy. In order to determine accurate three-dimensional velocities of a site, at least 2.5-year time span of coordinate time series is needed [5]. With limited time span of coordinate time series (2-3 years) annual and semi-annual signals should be estimated simultaneously

with site velocities. Below 2.5 years, the uncertainty of velocities can become too large to intuitively determine tectonic motion. Coordinate time series analysis is prerequisite to obtain reliable velocities from the particular time span of coordinate time series. In this manuscript, coordinate time series analysis software written in MATLAB programming language is presented. The software consists of source codes (m files) and Graphical User Interface (GUI). The input data of the software is the coordinate time series obtained from continuous GNSS measurements. Coordinates should be collected as Earth Centered Earth Fixed [6] in order to consistently work using the software. Functional model coded in the software is given in Section 2. Section 3 and 4 describe the software's utilities and numerical example and the work is concluded in Section 5.

2. THE FUNCTIONAL MODEL OF THE COORDINATE TIME SERIES ANALYSIS

The functional model of the coordinate time series analysis can be written as follows [5];

$$x(t) = a + b(t) + c(i) * \sin(2 * \pi * f_i * t - \varphi) + d(i) * \cos(2 * \pi * f_i * t - \varphi) + \epsilon(t) \quad (1)$$

where $x(t)$ are the coordinates, a and b represent the linear trend and offset, $c(i)$ and $d(i)$ represent the trigonometric annual, semi-annual and seasonal amplitudes, f_i and φ represent the frequencies and the phase lag and ϵ represents the data noise. a , b , $c(i)$ and $d(i)$ coefficients can be computed by least-square adjustment. f_i frequencies are 1/365, 1/182.5 and 1/91.25 for annual, semi-annual and seasonal amplitudes, respectively. The software applies the statistical significance test for each estimated parameters after the adjustment. If any parameters are not statistically significant, these parameters are removed then adjustment starts again. The adjustment repeats until each parameter is statistically significant. The parameters can be computed with ordinary least-squares [7] and robust iterative least squares [8] adjustments using the software. Using robust iterative least squares, measurements can be weighted with respect to their residuals. In this way, outliers which could not be detected in outlier detection less affect the adjustment. Figure 1 shows the flowchart of the software.

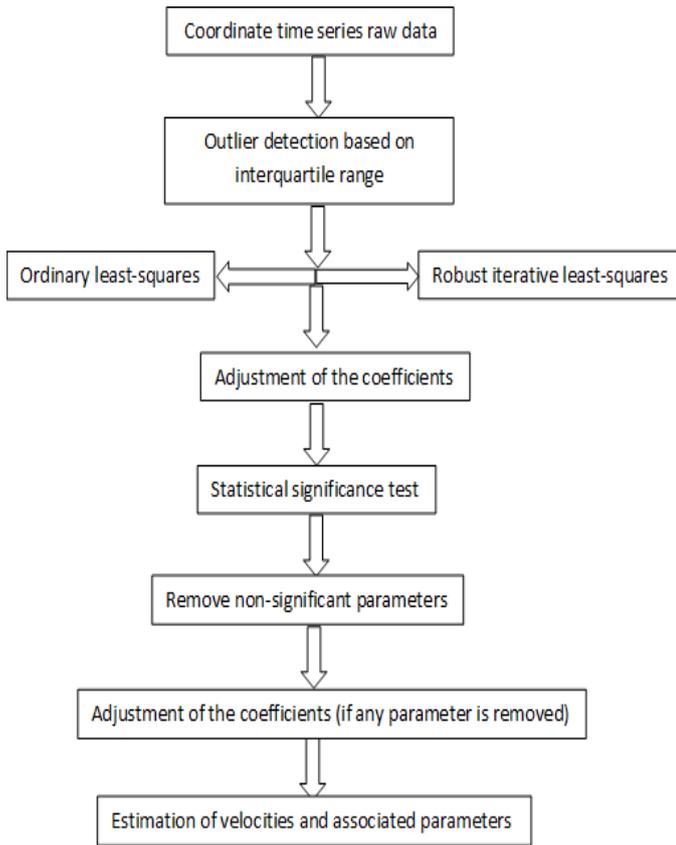


Figure 1. Flowchart of the software

Unlike the other available software, three-dimensional velocities are computed in ECEF and local topocentric coordinate frame (north, east, up), simultaneously. Besides the velocities, the software compute several parameters related to the coordinate time series. These parameters are correlation coefficients between the topocentric components [9], R^2 value for a measure of fit of the regression line for coordinates, de-trended standard deviation of ECEF and topocentric coordinates and significance test of the estimated parameters. Since the stochastic model mainly affects the uncertainties of velocity, the stochastic part is excluded in the software therefore, estimated velocity uncertainties from the software are generally underestimated [10; 11; 12; 13].

3. INTRODUCTION OF THE SOFTWARE

There are four push-button and five radio-button included in the software. First push-button is for inputting the reference coordinates, users can read the excel file includes the coordinate time series using push-button 2, third push-button is for saving the topocentric coordinates in the text file and fourth push button is for reset the computations. The radio buttons are used for choosing the adjustment type (ordinary least-squares or robust) and choosing the reference ellipsoid. Figure 2 shows the results screen after the adjustment.

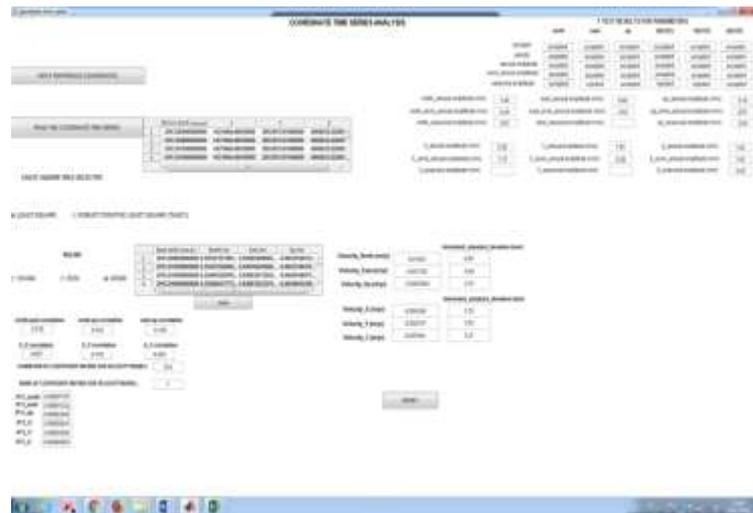
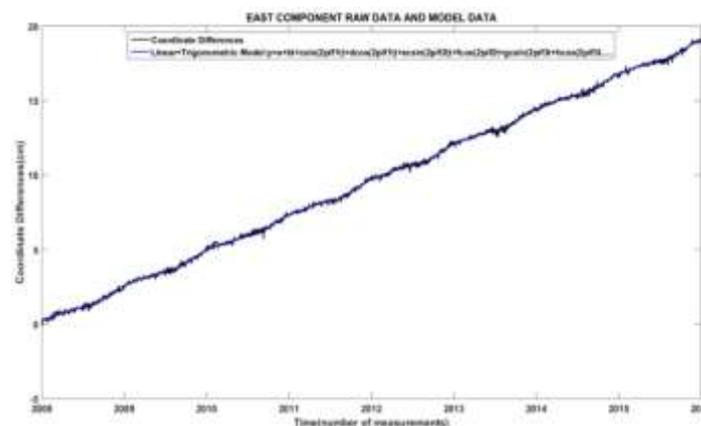
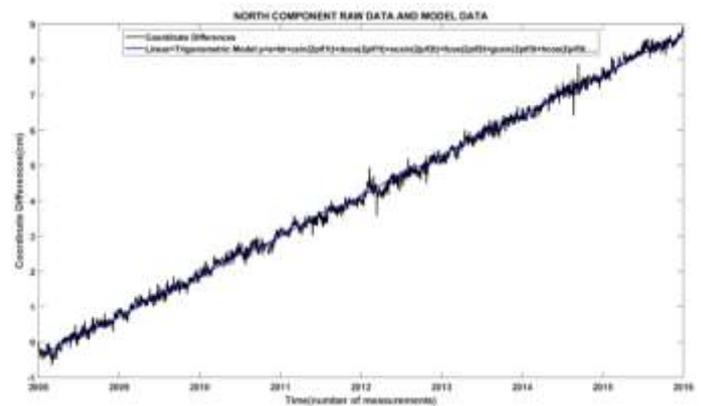


Figure 2. GUI of the software

After the adjustment, 38 windows for visualizing the results are opened. These are consist of the linear trend, de-trended model and the power-spectrum analysis. Fast Fourier Transformation (FFT) is applied for computing time interval of periodic movement with respect to each coordinate components [11]. Figure 3 shows the raw coordinates and coordinates obtained from the model (trend and seasonal) of ISTA International GNSS Service (IGS) station from 2008 to 2016 after inputting raw coordinate time series to the software.



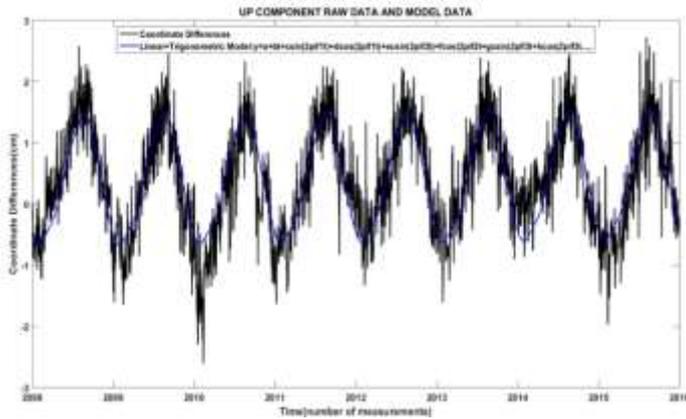


Figure 3. Raw coordinates and model coordinates of ISTA IGS station

As it is seen from Figure 3, horizontal movements of the station follow a linear trend whereas vertical movement of the station follows a non-linear trigonometric trend.

4. NUMERICAL EXAMPLE

Three IGS stations (ISTA, NICO and GENO) were chosen to test the software. The assumed true three-dimensional velocities were taken from Jet Propulsion Laboratory (JPL) Global Positioning System (GPS) Time Series (<https://sideshow.jpl.nasa.gov/post/series.html>). Any offset in GNSS time series can severely degrade the accuracy of estimated velocities [14; 15]. In order to obtain reliable velocities, offsets should be determined in advance of the processing. Figure 4 shows the GPS time series of the ISTA (located in Turkey), NICO (located in Cyprus) and GENO (located in Italy) IGS stations for latitude, longitude and height components.

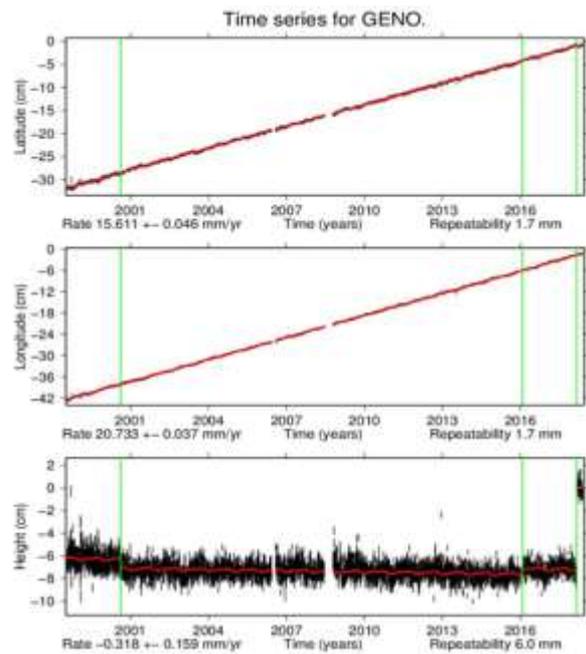
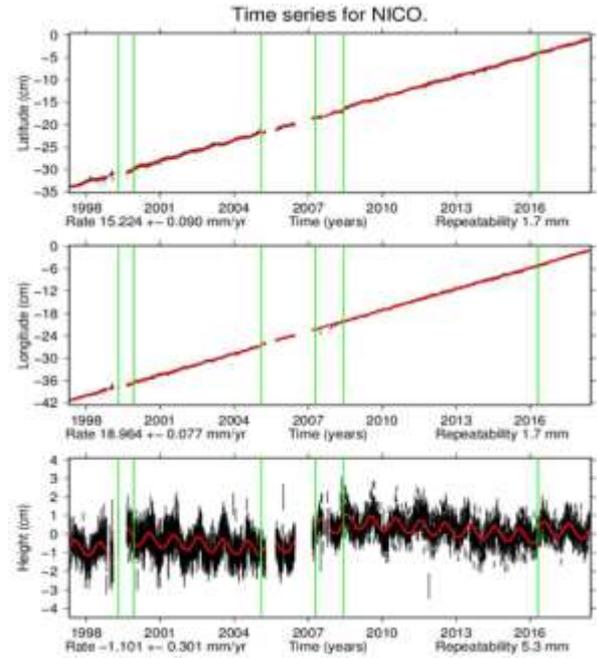
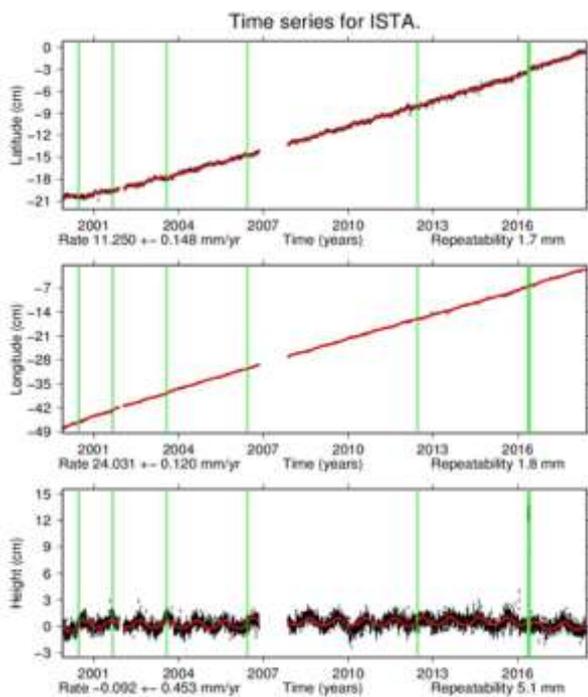


Figure 4. GPS time series of the IGS stations (<https://sideshow.jpl.nasa.gov/post/series.html>)



In order to avoid the offsets, 2008-2016 years interval were chosen for ISTA and NICO stations and 2001-2016 years interval were chosen for GENO station. JPL processed north, east, up topocentric coordinates were obtained

(<ftp://sideshow.jpl.nasa.gov/pub/usr/mbh/point/>) for the software input. Coordinate time series of each station were processed using the software with the ordinary least-squares adjustment. Estimated three-dimensional velocities and standard deviations using the software were compared to the results of JPL. Table 1 shows the velocities and standard deviation differences between the software and JPL.

Table -1: Velocity and standard deviation differences between JPL and the software (Units: millimeter/year)

Coordinate components	ISTA	NICO	GENO
North (Velocity/Standard Deviation) differences	0.20/0.10	0.20/0.40	0.00/0.10
East (Velocity/Standard Deviation) differences	0.40/0.20	0.03/0.00	0.01/0.10
Up (Velocity/Standard Deviation) differences	0.10/0.80	0.10/0.60	0.05/0.10

As it is seen from the Table 1, velocity and standard deviation differences between the software and JPL are in the order of sub-mm level. Since processing of JPL time series include the whole data sets, sub-mm level velocity differences between processing using the MATLAB software and JPL processing is observed. It is concluded that processing using the software is consistent enough to obtain reliable velocity and standard deviation.

5. CONCLUSION

GNSS is commonly used for monitoring surface deformation of the earth with high accuracy. In order to accurately determine the tectonic velocity of a site using GNSS technique, coordinate time series analysis need to be conducted. In this study, coordinate time series analysis software written in MATLAB programming language is introduced. This software implements GNSS coordinate time series processing in the raw three-dimensional coordinates obtained from continuous GNSS measurements. Users can access the results automatically without the need to intervene in intermediate computations. All computations include the statistical analysis can be conducted in single processing. The numerical results show that the results obtained using the software is highly consistent with JPL results. The source codes and GUI of the software can be accessed in <https://tinyurl.com/y8dxo536>. The author would like to have any comments, suggestions, and critiques sent to the author's mail address. Please refer to this manuscript should the software is used for any scientific paper.

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