User Manual for Multiresolution Granger Causality Testing – MRCause GUI on Python

MRCause, developed by Saâdaoui et al. (2024), is a Python library designed for performing multiresolution Granger causality analysis between two time series using Variational Mode Decomposition (VMD). This manual guides users through the graphical user interface (GUI) for importing data, setting parameters, and interpreting results using the MRCause package.

1. Importing Data

1.1. Uploading the data file

1. **Data file**: Begin by uploading an Excel file containing your bivariate time series data. The file should consist of two columns, each representing one of the two time series (X and Y), which do not necessarily need to be stationary. If you wish to test causality in the opposite direction, simply switch the order of the columns in your Excel sheet.
2. **Upload process**:
    - The MRCause GUI will prompt you to upload your file. Click the upload button and select your Excel file containing the two columns.
    - The file will be processed, and a preview of the data will be displayed for verification.

1.2. Data preview

- **Displayed columns**: The first two columns from the Excel file are automatically selected as the time series for analysis.
- **Error handling**: If the column names do not match expectations, an error message will prompt you to verify the column names in the Excel file.

2. Setting Parameters

2.1. Number of modes

- **Input**: Enter the number of modes (Intrinsic Mode Functions, IMFs) you wish to extract using VMD.
- **Description**: This parameter determines how many frequency components the VMD will decompose the time series into.

2.2. Maximum lag for Granger causality test

- **Input**: Enter the maximum lag for the Granger causality test.

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- **Description**: This parameter defines the maximum number of lags to consider in the causality test, affecting the granularity of causality detection.

2.3. Alpha parameter for VMD

- **Fixed value**: The alpha parameter for VMD is set to a default value of 2000.
- **Description**: The trade-off parameter controls the balance between the smoothness of the decomposition and fidelity to the data. You can adjust this value if needed.

3. Performing Analysis

3.1. Variational mode decomposition

- **Execution**: `MRCause` performs VMD on the input time series data.
- **Output**: Decomposes each time series into multiple IMFs based on the number of modes specified.

3.2. Granger causality tests

- **Standard approach**: The software performs a Granger causality test on the differences of the original time series data (X and Y).
- **Multiresolution approach**: It also performs Granger causality tests on the IMFs obtained from VMD, excluding the first IMF and focusing on the remaining modes.

4. Interpreting Results

4.1. Granger causality test results

- **Standard approach**: The Granger causality test results include F-statistics and p-values for each lag up to the maximum specified. These statistics help determine if one time series Granger-causes the other. The null hypothesis (H_0) in this test is that the time series X does not Granger-cause Y. A low p-value (typically less than 0.05) suggests that we can reject the null hypothesis, indicating that X provides statistically significant information about future values of Y.
- **Multiresolution approach:** Similar results are provided for each Intrinsic Mode Function (IMF), with F-statistics and p-values calculated for each frequency component. The null hypothesis (H_0) remains the same, and the results reveal whether causality exists within specific frequency bands. This allows for a more granular understanding of the causal relationships at different scales or frequencies.

4.2. Data and IMF plots

- **Original data plots**: `MRCause` provides plots for the original time series data X and Y, showing the time series values over time.

- **VMD component plots**: Plots for each IMF are generated, displaying the amplitude of each component over time for both X and Y.

5. Example

5.1. Case study

This example illustrates the causality testing of the industrial production index (Industrial Production: Total Index, Index 2017=100, Monthly, Seasonally Adjusted) on oil prices (Global price of Brent Crude, U.S. Dollars per Barrel, Monthly, Not Seasonally Adjusted). The time series data are sourced from FRED (https://fred.stlouisfed.org/). Figure 1 displays the plotted time series, and the following subsections (5.2 – 5.5) provide screenshots detailing the entire process—from setting parameters and uploading data files to obtaining the results of the causality tests using both standard and multiresolution approaches (Figures 2—6).

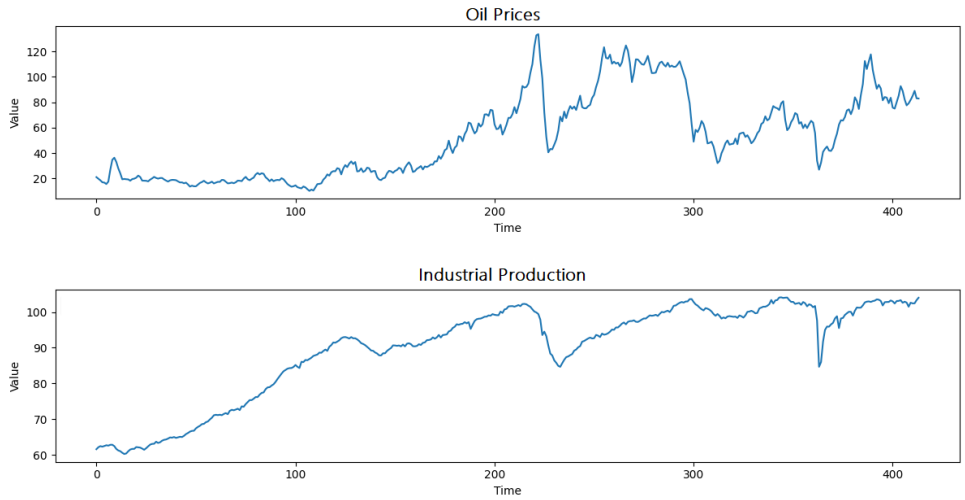


Figure 1. Time series plots of the global Brent crude oil price (U.S. Dollars per Barrel) and the industrial production index (2017=100). The data spans monthly observations from January 1990 to June 2024.

5.2. Parameter input screen

```
Requirement already satisfied: vmdpy in /usr/local/lib/python3.10/dist-packages (0.2)
Requirement already satisfied: numpy in /usr/local/lib/python3.10/dist-packages (from vmdpy) (1.26.4)
Enter the number of modes (IMFs) to extract:
```

Figure 2. Screenshot showing the input interface for selecting the number of IMFs (VMD levels).

```
Requirement already satisfied: vmdpy in /usr/local/lib/python3.10/dist-packages (0.2)
Requirement already satisfied: numpy in /usr/local/lib/python3.10/dist-packages (from vmdpy) (1.26.4
Enter the number of modes (IMFs) to extract: 3
Enter the maximum lag for Granger causality test:
```

Figure 3. Screenshot showing the input interface for specifying the maximum lag in the Granger causality test.

5.3. Data upload screen

```
Requirement already satisfied: vmdpy in /usr/local/lib/python3.10/dist-packages (0.2)
Requirement already satisfied: numpy in /usr/local/lib/python3.10/dist-packages (from vmdpy) (1.26.4)
Enter the number of modes (IMFs) to extract: 3
Enter the maximum lag for Granger causality test: 6
Sélect. fichiers  Aucun fichier choisi   Cancel upload
```

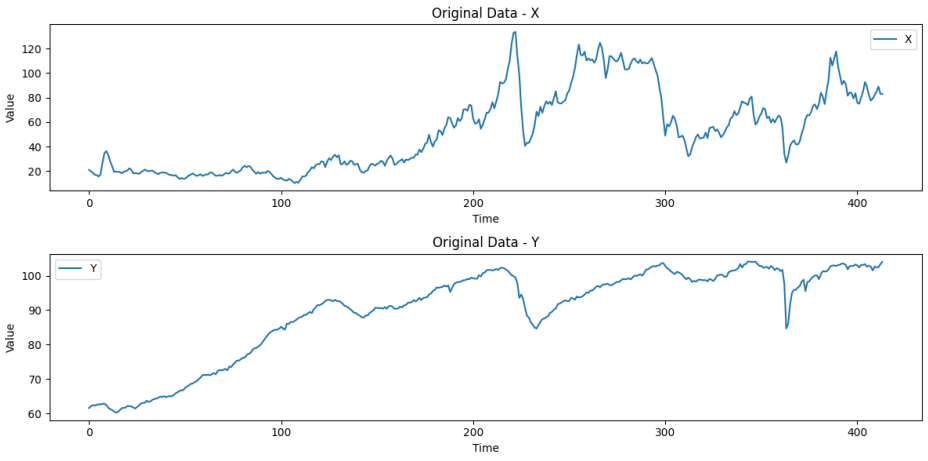
(a) The window where the user can browse and upload the sample data.

```
Requirement already satisfied: vmdpy in /usr/local/lib/python3.10/dist-packages (0.2)
Requirement already satisfied: numpy in /usr/local/lib/python3.10/dist-packages (from vmdpy) (1.26.4)
Enter the number of modes (IMFs) to extract: 3
Enter the maximum lag for Granger causality test: 6
Sélect. fichiers  IndusProdI...x-WTI.xlsx
• IndusProdIndex-WTI.xlsx(application/vnd.openxmlformats-officedocument.spreadsheetml.sheet) - 18762 bytes, last modified: 14/08/2024 - 100% done
Saving IndusProdIndex-WTI.xlsx to IndusProdIndex-WTI (1).xlsx
Data Preview:
   Global price of Brent  Industrial Production
0              20.989130                61.6352
1              19.702500                62.1951
2              18.465909                62.4916
3              16.926190                62.3511
4              16.671739                62.5353
```

(b) A portion of the sample is displayed, enabling the user to verify the accuracy of the procedure.

Figure 4. Screenshot of the interface for importing the data file from the device.

5.4. Plots of the VMD



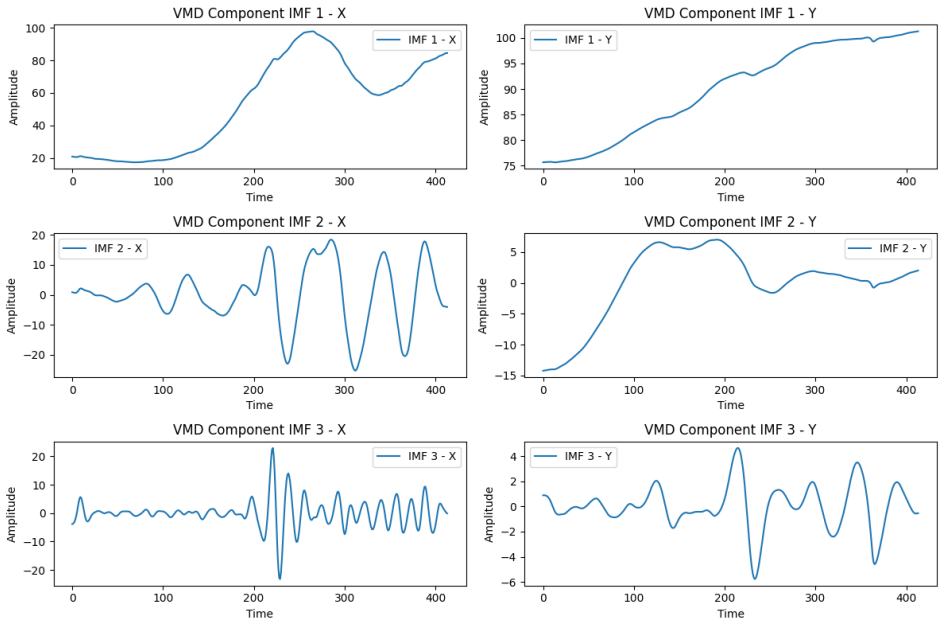


Figure 5. Plots of the Intrinsic Mode Functions (IMFs) obtained from Variational Mode Decomposition (VMD) with a preliminary setting of 3 levels.

5.5. Results display

```
H0: Column 2 does not Granger-cause Column 1

Granger Causality Test on Differenced Data:
Lag 1: F-statistic = 0.1281, p-value = 0.7206, Recommendation: Fail to Reject H0
Lag 2: F-statistic = 0.0108, p-value = 0.9893, Recommendation: Fail to Reject H0
Lag 3: F-statistic = 0.6223, p-value = 0.6009, Recommendation: Fail to Reject H0
Lag 4: F-statistic = 0.7973, p-value = 0.5274, Recommendation: Fail to Reject H0
Lag 5: F-statistic = 0.9802, p-value = 0.4296, Recommendation: Fail to Reject H0

Granger Causality Test for IMF 2 on Raw Data:
Lag 1: F-statistic = 0.1337, p-value = 0.7148, Recommendation: Fail to Reject H0
Lag 2: F-statistic = 1.1309, p-value = 0.3238, Recommendation: Fail to Reject H0
Lag 3: F-statistic = 2.9340, p-value = 0.0333, Recommendation: Reject H0
Lag 4: F-statistic = 1.6239, p-value = 0.1673, Recommendation: Fail to Reject H0
Lag 5: F-statistic = 0.6764, p-value = 0.6416, Recommendation: Fail to Reject H0

Granger Causality Test for IMF 3 on Raw Data:
Lag 1: F-statistic = 0.0023, p-value = 0.9621, Recommendation: Fail to Reject H0
Lag 2: F-statistic = 3.3799, p-value = 0.0350, Recommendation: Reject H0
Lag 3: F-statistic = 2.3391, p-value = 0.0730, Recommendation: Fail to Reject H0
Lag 4: F-statistic = 3.7466, p-value = 0.0052, Recommendation: Reject H0
Lag 5: F-statistic = 2.2929, p-value = 0.0450, Recommendation: Reject H0
```

Figure 6. Causality testing of the null hypothesis asserting no causality of industrial production on oil prices. While this claim is accepted using the standard Granger method, it is rejected at certain VMD scales.

6. Support and Citation

For any issues or questions, please contact support (foued.saadaoui@isgs.rnu.tn). If you use `MRCause` in your research, please cite the following:

Citation: Saâdaoui, F., Herch, H., & Rabbouch, H. (2024). *Multiresolution Granger causality testing grounded in Variational Mode Decomposition: A Python library*. Submitted to *Journal of Applied Statistics*.