Contents

1 FIGURE 9 – BACCALA ET AL. (2016) DTF: UNIFIED ASYMPTOTIC THEORY

DESCRIPTION:

Routine **figure9_example3_idtf_ns2000.m** publish

Linear five-dimensional VAR(2) model

LA Baccala, DY Takahashi, K Sameshima (2016) Directed Transfer Function: Unified Asymptotic Theory and Some of its Implications. *IEEE Transactions on Biomedical Engineering* **PP**.

```
http://dx.doi.org/10.1109/TBME.2016.2550199
```

Example 3: Asymptotic DTF: Example 3 5-VAR model - open / closed loop.

```
                     x1 ==> x2 ==> x3 ==> x4 <==> x5
                      ^-------------------------/
```

```
                      *This is the close loop model.*
```

Contents

- Generating data set for analysis
- Equation (11)
- Connectivity diagram
- DTF estimation
- Figure depicted in the article Baccala et al (2016)
- Some remarks:

Generating data set for analysis

```
clear; clc; format compact
flgPlotStyle = 'Print'; % or 'Screen' mode
flgRandomize = 0;  % Generate the specific data set used in Fig. 9.
ns = 2000;         % number of sample points
nDiscard = 20000;  % number of points discarded at beginning of simulation
p = 2;             % model order

if (exist('figure9_example3_idtf_ns2000.mat') == 2) & is_octave & ~flgRandomize
   ,
   load figure9_example3_idtf_ns2000
else
   [u] = fbaccala2016_example3( ns, nDiscard, flgRandomize );
   if ~is_octave & ~flgRandomize,
```

```
      save figure9_example3_idtf_ns2000 u
   end;
end;

chLabels = [];    % Using default labeling schema for channel identification
```

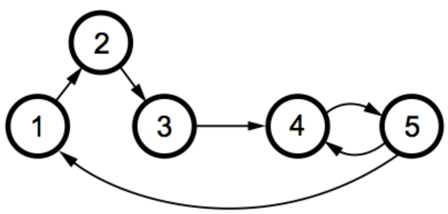
```
======================================================================
   Asymptotic DTF:  Example 3 5-VAR model - open / closed loop.
                 x1 ==> x2 ==> x3 ==> x4 <==> x5
                  ^-------------------------/
                   This is the close loop model.
======================================================================
```

Equation (11)

$$
\begin{aligned}
x_1(n) &= 0.25\sqrt{2}x_1(n-1) + 0.25\sqrt{2}x_2(n-1) + w_1(n) \\
x_2(n) &= -0.25\sqrt{2}x_1(n-1) + 0.25\sqrt{2}x_2(n-1) + w_2(n) \\
x_3(n) &= 0.5x_2(n-1) + w_3(n) \qquad (12)
\end{aligned}
$$

Equation (11) from Baccala et al. *IEEE Trans Biomed Engin.*, 2016.

Connectivity diagram



Example 3 loop connectivity structure following (11). Signals from any structure reach all other structures. from Baccala et al. *IEEE Trans Biomed Engin.*, 2016.

Data pre-processing: detrending and normalization options

```
flgDetrend = 1;      % Detrending the data set
flgStandardize = 0; % No standardization
[nChannels,nSegLength] = size(u);
if nChannels > nSegLength, u = u.';
   [nChannels,nSegLength] = size(u);
end;
if flgDetrend,
   for i=1:nChannels, u(i,:) = detrend(u(i,:)); end;
   disp('Time series were detrended.');
end;
if flgStandardize,
   for i=1:nChannels, u(i,:) = u(i,:)/std(u(i,:)); end;
   disp('Time series were scale-standardized.');
end;
```

```
        Time series were detrended.
```

MVAR model estimation

```
maxIP = 30;         % maximum model order to consider.
alg = 1;            % 1: Nutall-Strand MVAR estimation algorithm
criterion = 1;      % 1: AIC, Akaike Information Criteria
disp('Running MVAR estimation and GCT analysis routines.')
[IP,pf,A,pb,B,ef,eb,vaic,Vaicv] = mvar(u,maxIP,alg,criterion);
disp(['Number of channels = ' int2str(nChannels) ' with ' ...
   int2str(nSegLength) ' data points; MAR model order = ' int2str(IP) '.']);
```

```
        Running MVAR estimation and GCT analysis routines.
maxOrder limited to 30
IP=1  vaic=79027.676838
IP=2  vaic=76136.019225
IP=3  vaic=76162.273276

Number of channels = 5 with 2000 data points; MAR model order = 2.
```

Testing for adequacy of MAR model fitting through Portmanteau test

```
h = 20; % testing lag
MVARadequacy_signif = 0.05; % VAR model estimation adequacy significance
                            % level
aValueMVAR = 1 - MVARadequacy_signif; % Confidence value for the testing
flgPrintResults = 1;
```

Granger causality test (GCT) and instantaneous GCT

```
gct_signif  = 0.01;  % Granger causality test significance level
igct_signif = 0.01;  % Instantaneous GCT significance level
flgPrintResults = 1;
[Tr_gct, pValue_gct, Tr_igct, pValue_igct] = gct_alg(u,A,pf,gct_signif, ...
                                              igct_signif,flgPrintResults);
```

```

---------------------------------------------------------------------
                         GRANGER CAUSALITY TEST
=====================================================================
Connectivity matrix:
          NaN             0             0             0          1.00
         1.00           NaN             0             0             0
            0          1.00           NaN             0             0
            0             0          1.00           NaN          1.00
            0             0             0          1.00           NaN
Granger causality test p-values:
          NaN          0.54          0.11          0.47             0
            0           NaN          0.27          0.59          0.97
         0.45             0           NaN          0.23          0.88
         0.13          0.89             0           NaN             0
         0.36          0.87          0.49             0           NaN
---------------------------------------------------------------------
                  INSTANTANEOUS GRANGER CAUSALITY TEST
=====================================================================
Instantaneous connectivity matrix:
          NaN             0             0             0             0
```

```
             0            NaN              0              0              0
             0              0            NaN              0              0
             0              0              0            NaN              0
             0              0              0              0            NaN
Instantaneous Granger causality test p-values:
           NaN           0.56           0.64           0.08           0.41
          0.56            NaN           0.94           0.33           0.28
          0.64           0.94            NaN           0.74           0.03
          0.08           0.33           0.74            NaN           0.71
          0.41           0.28           0.03           0.71            NaN
>>>> Instantaneous Granger causality NOT detected.
```

DTF estimation

DTF analysis results are saved in **c** structure. See asymp_dtf.m or issue >> help asymp_dtf command for more detail.

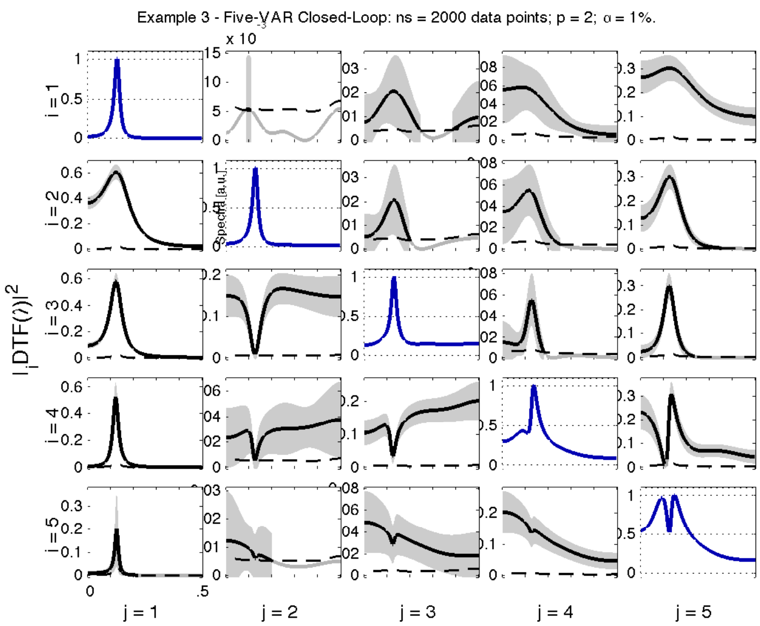
```
metric = 'info';  % euc  = original PDC or DTF;
                 % diag = generalized PDC (gPDC) or directed coherence (DC);
                 % info = information PDC (iPDC) or iDTF.

nFreqs = 128;
alpha = 0.01;

c = asymp_dtf(u,A,pf,nFreqs,metric,alpha);
```

```
        * Information DTF and asymptotic statistics
```

$|_iDTF(\lambda)|^2$ Matrix Layout Plotting

```
switch lower(flgPlotStyle)
   case 'print'
      flgColor =[0];      % white background
      flgMax = 'TCI';
      flgSignifColor = 1; % black + gray
      flgScale = 3;       % [0 max(flgMax)]
   otherwise % 'screen'
      flgColor =[1];      % Colored background
      flgMax = 'TCI';
      flgSignifColor = 3; % red + green
      flgScale = 2;       % [0 1]/[0 .1]/[0 .01]
end;

% ---------------Plotting options flag setting-----------------------------
%            [1 2 3 4 5 6 7]
flgPrinting=[1 1 1 2 2 0 1];
%             | | | | | | 7 Spectra(0: w/o SS; 1: Linear; 2: log-scale)
%             | | | | | 6 Coherence
%             | | | | 5 Plot lower confidence limit (legacy)
%             | | | 4 Plot upper confidence limit
%             | | 3 Significant DTF(w) in red line  (legacy)
%             | 2 Patnaik threshold level in black dashed-line
%             1 plot DTF
%--------------------------------------------------------------------------

fs = 1;       % sampling frequency
```

```
w = fs*(0:(nFreqs-1))/2/nFreqs;
w_max = fs/2;

h=figure;
set(h,'NumberTitle','off','MenuBar','none', ...
      'Name','[Asymptotic DTF] Fig 9. Example 3 - iDTF, ns = 2000')

[hxlabel hylabel] = xplot(c,...
   flgPrinting,fs,w_max,chLabels,flgColor,flgScale,flgMax,flgSignifColor);

%xplot_title(alpha, metric, measure(c));

[ax,hT]=suplabel(['Example 3 - Five-VAR Closed-Loop: ns = ' ...
   int2str(ns) ' data points; p = ' int2str(c.p) '; \alpha = ' ...
   int2str(100*alpha) '%.'],'t');
set(hT,'FontSize',10); % Subtitle font size

drawnow
```



Uncomment the command line bellow to generate an eps output file

% print -depsc2 -painters Fig9_example3_idtf_ns2000.eps

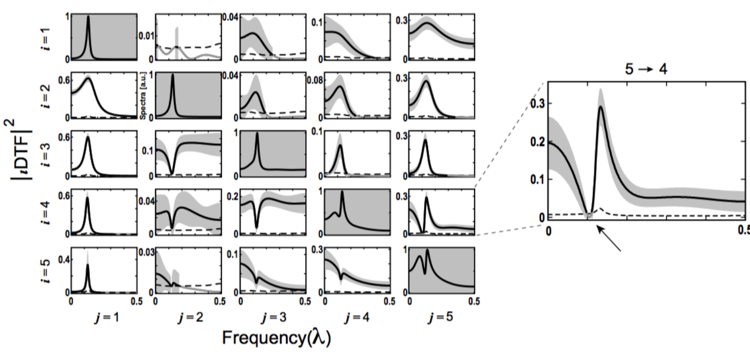
Figure depicted in the article Baccala et al (2016)

Figure 9, deproduced from article.

Some remarks:

1. As usual, figure 9 underwent some cosmetic edit and addition of a inlet graph

This completes the **Figure 9** generation (Baccala et al, 2016)'



|ıDTF|²
i = 1
i = 2
i = 3
i = 4
i = 5
j = 1
j = 2
j = 3
j = 4
j = 5
Spectra [a.u.]
Frequency(λ)
5 → 4