```
%%File: CV-CODE-Project-R2PT-ANALYSIS-2link_FL.mlx     :      Robot Arm (2-link) To PoinT (in 
% Trajectory Generation of the Equivalent End Effector _EE for a 2-link robot arm
% Source location: QRIS> C:\Users\USER-PC\QRIS\MATLAB Code
% ------------------------------------------------------------------------
% Notes:
% 1. Source file for angle DATA: Project-R2PT-LSQsampleCODE-2link.mlx
% 2. C:\Users\USER-PC\QRIS\MATLAB Code\DATA\LSQ_thetaDATA_2link.txt <---- path to angle data [2
% 3. Target trajectory of FL is displaced downwards by dltaY = 0.3577 [m] ==> ground contact le
% ------------------------------------------------------------------------
% ------------------------------------------------------------------------------------------------
clc;clf ; clear all;
clear global
% ------------------------------------------------------------------------
% CODE execution START:
% ------------------------------------------------------------------------
global numConfigs Ts
numConfigs = 300;
Ts = 1/300; % sample time rate [s]
% ------------------------------------------------------------------------
% C:\Users\USER-PC\QRIS\MATLAB Code\DATA   <---- DATA Folder to access
theta=[];
%MatrixDATA = dlmread('C:\Users\USER-PC\QRIS\MATLAB Code\DATA\LSQ_thetaDATA_2link.txt '); % the
MatrixDATA = dlmread('C:\Users\USER-PC\QRIS\MATLAB Code\DATA\LSQ_thetaDATA_2link_FL.txt '); % t
theta = MatrixDATA';% LSQ-optimised data [radians] <---> [300x2] <-- 2-link FL equivalent for C
[rws,cms] = size(MatrixDATA) ;
% ------------------------------------
% NOTE: angle order is [th1  th2 ]
% angle number         [ 1    2  ]
rws
```

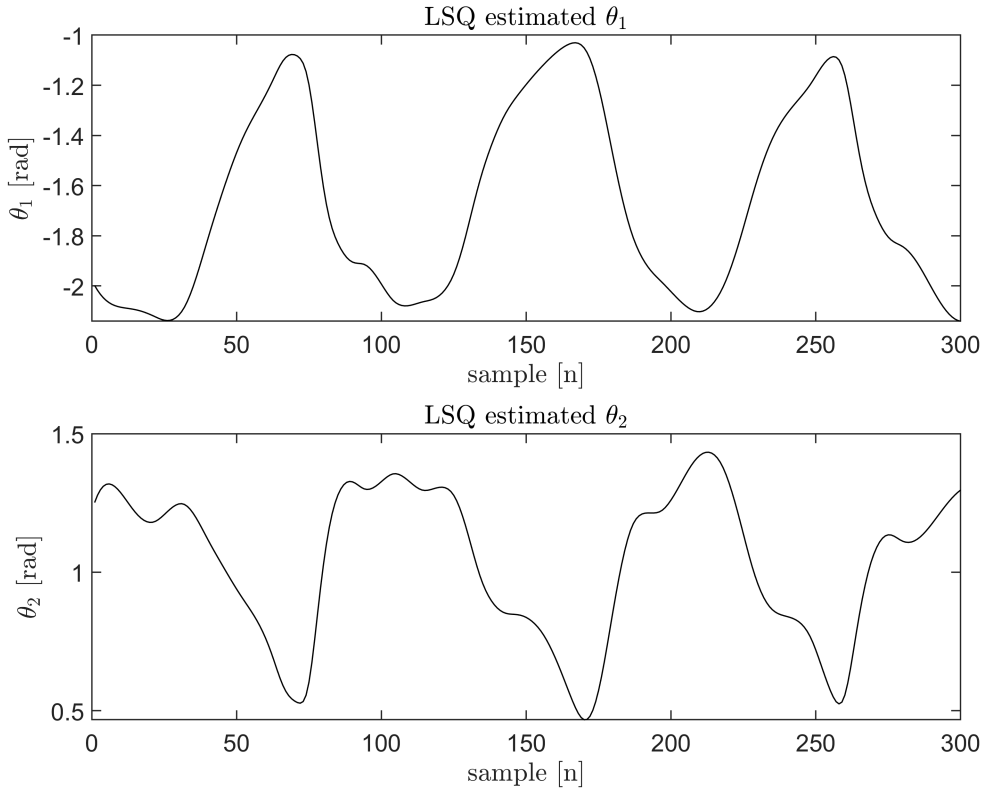
```
rws = 2
```

```
cms
```

```
cms = 300
```

```
th1 = theta(:,1);   % theta 1 LSQ data of 2-link front leg [300x1]
th2 = theta(:,2);   % theta 2 LSQ data of 2-link front leg [300x1]
% ------------------------------------------------------------------------------------------------
% ------------------------------------
% color CODE vectors ---->
cW = [1 1 1]; % white
cA = [1 0 0]; % red
cB = [0 0 1]; % blue
cC = [0 1 1]; % cyan
cD = [1 0 1]; % magenta
cE = [1 1 0]; % yellow
cJ = [0 1 0]; % green
cK = [0 0 0]; % black
% --- hybrids ----------
cF = [0.75 0 0.99]; % purple
cG = [0 0.4 0.3]; % dark green
```

```
cH = [0.6 0.98 0]; % light green
cI = [0.99 0.5 0]; % orange
% ------------------------------------
% ----------------------------
figure
% ----------------------------
% set background colour
fig = gcf;
%fig.Color = [0 0 0]; % black = [0 0 0]
%colordef black
fig.Color = [1 1 1]; % white = [1 1 1]
colordef white
% ----------------------------

subplot(2,1,1),plot(th1,'Color', cK);
title('LSQ estimated $\theta_{1}$', 'Interpreter','latex')
xlabel('sample [n]', 'Interpreter','latex')
ylabel('$\theta_{1}$ [rad]', 'Interpreter','latex')

subplot(2,1,2),plot(th2,'Color', cK);
title('LSQ estimated $\theta_{2}$', 'Interpreter','latex')
xlabel('sample [n]', 'Interpreter','latex')
ylabel('$\theta_{2}$ [rad]', 'Interpreter','latex')
```

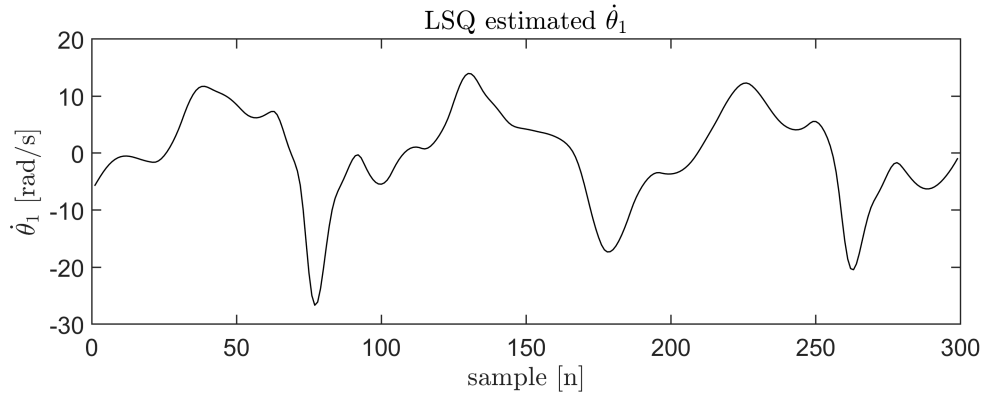


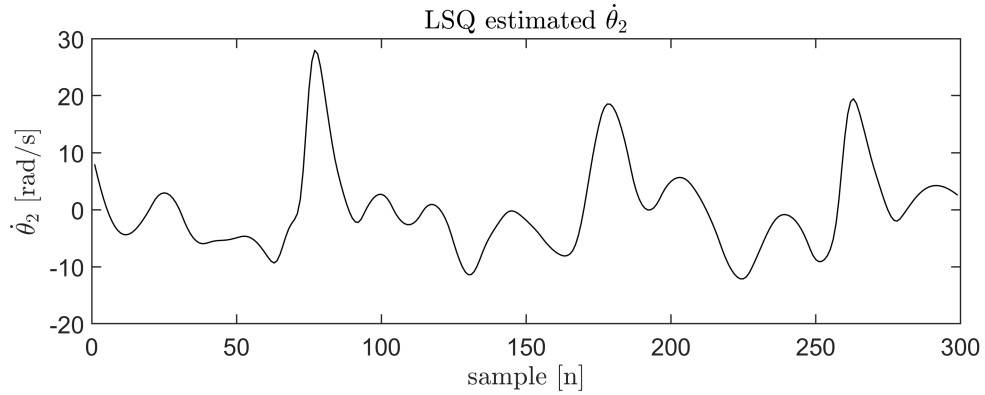

```
% ------------------------------------------------
% Compute the angular rates from the angle data ::::
Omega=[];
Omega = zeros((numConfigs-1),2); % store angular rate data for both FL angles and ALL configura
```

```
% ---- angular velocity data
% NOTE: angle order is [thD1 ; thD2 ]
% angle number         [ 1  ;  2  ]
for j=1:2 % 2 angles
for i=1:(numConfigs-1) % 299 angular velocity points for the 300 configurations
Omega(i,j) = ((theta(i+1,j)-theta(i,j))/Ts); % [rad/s]
end
end
Ts
```

```
Ts = 0.0033
```

```
Omega ; % raw thD data for FL [rad] [299 x 2]
thetaDtargetdata = Omega; % target angular velocity data  [rad/s]  [299 x 2]
% ------------------------------------------------------------
th1D = thetaDtargetdata(:,1);
th2D = thetaDtargetdata(:,2);

figure
subplot(2,1,1),plot(th1D,'Color', cK);
title('LSQ estimated $\dot\theta_{1}$', 'Interpreter','latex')
xlabel('sample [n]', 'Interpreter','latex')
ylabel('$\dot\theta_{1}$ [rad/s]', 'Interpreter','latex')

subplot(2,1,2),plot(th2D,'Color', cK);
title('LSQ estimated $\dot\theta_{2}$', 'Interpreter','latex')
xlabel('sample [n]', 'Interpreter','latex')
ylabel('$\dot\theta_{2}$ [rad/s]', 'Interpreter','latex')
```






```
% ------------------------------------------------
xo = 0; yo = 0; % fixed reference joint coordinates
%dltaY = -0.3577;
%xo = 0; yo = 0 + dltaY; % fixed reference joint coordinates <---- adjusted yo ==> trajectory c

%r1 = 0.59; r2 = 0.711; % link lengths of 2-link
r1 = 0.6375; r2 = 0.85; % link lengths of 2-link

sum_r1r2 = r1+r2;
r1
```

```
r1 = 0.6375
```

```
r2
```

```
r2 = 0.8500
```

```
sum_r1r2
```

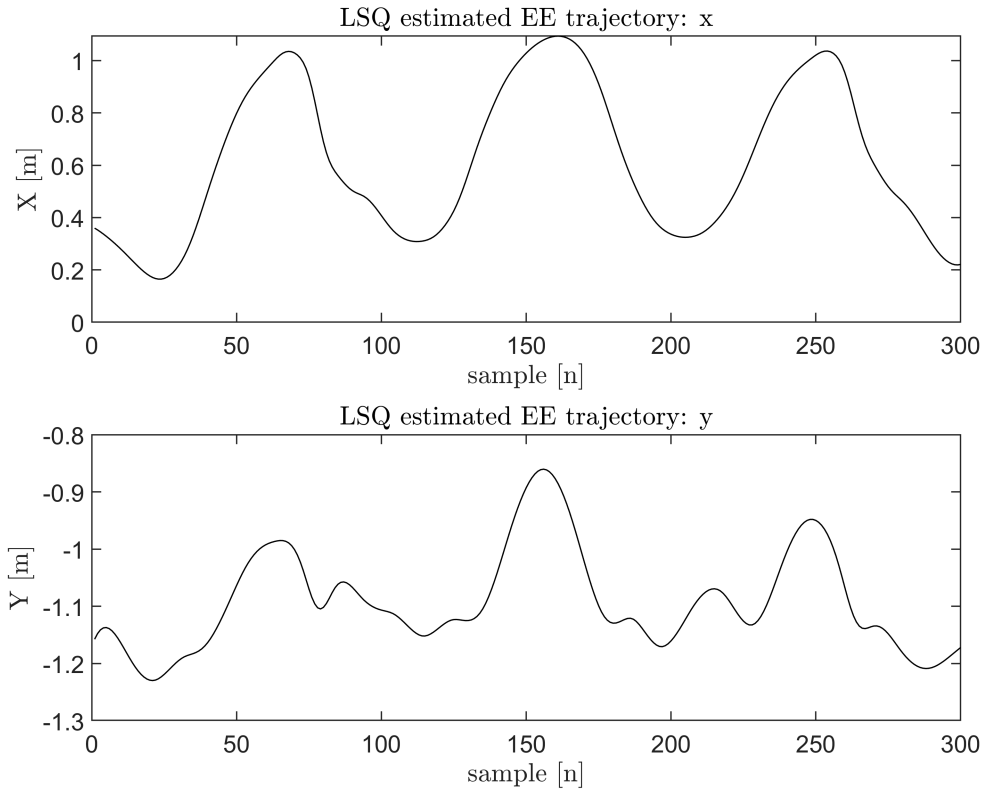
```
sum_r1r2 = 1.4875
```

```
% ------------------------------------------------------
% EE coordinates 2D ------------------------->
% ------------------------------------------------------
xEEplane = xo + r1*cos(th1) + r2*cos(th1 + th2); % [300x1]
yEEplane = yo + r1*sin(th1) + r2*sin(th1 + th2); % [300x1]
% ------------------------------------------------------
```

```
% ---------------------------------------------------------
% 299 Cartesian velocity points for the 300 data points
Ts
```

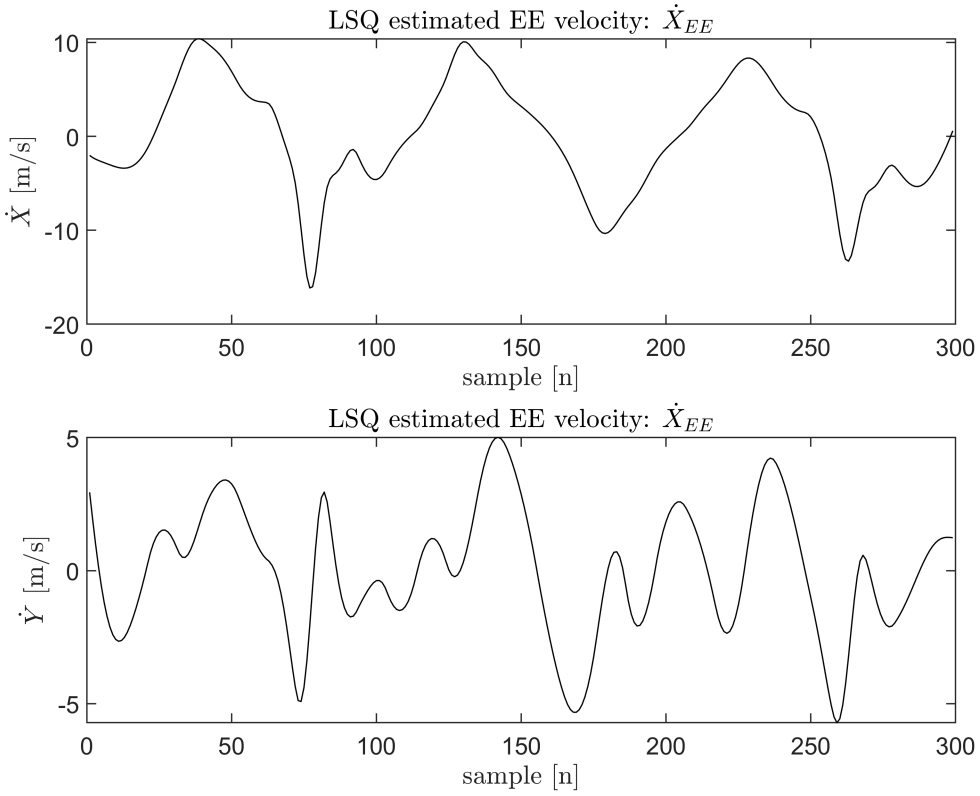
```
Ts = 0.0033
```

```
EExd = zeros((numConfigs-1),1); % stores x velocity points of EE
EEyd = zeros((numConfigs-1),1); % stores y velocity points of EE
for i=1:(numConfigs-1)
 EExd(i) = ((xEEplane(i+1)-xEEplane(i))/Ts); % [m/s]
 EEyd(i) = ((yEEplane(i+1)-yEEplane(i))/Ts); % [m/s]
end
% ------------------------------------------------------------------------------------------
figure
subplot(2,1,1),plot(xEEplane,'Color', cK);
title('LSQ estimated EE trajectory: x', 'Interpreter','latex')
xlabel('sample [n]', 'Interpreter','latex')
ylabel('X [m]', 'Interpreter','latex')

subplot(2,1,2),plot(yEEplane,'Color', cK);
title('LSQ estimated EE trajectory: y', 'Interpreter','latex')
xlabel('sample [n]', 'Interpreter','latex')
ylabel('Y [m]', 'Interpreter','latex')
```



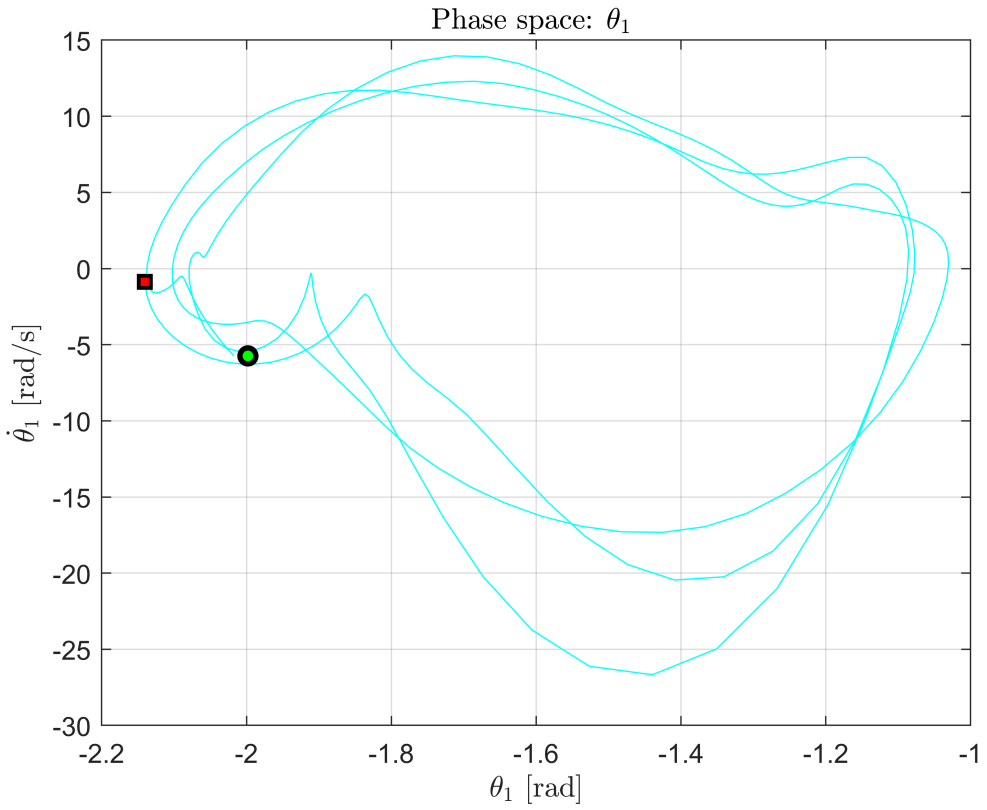

```
% ------------------------------------------------
% ------------------------------------------------------------------------------------------
figure
subplot(2,1,1),plot(EExd,'Color', cK);
```

```
title('LSQ estimated EE velocity: ${{\dot{X}}}_{{EE}}$', 'Interpreter','latex')
xlabel('sample [n]', 'Interpreter','latex')
ylabel(' ${{\dot{X}}}$ [m/s]', 'Interpreter','latex')

subplot(2,1,2),plot(EEyd,'Color', cK);
%title('LSQ estimated EE trajectory: y', 'Interpreter','latex')
title('LSQ estimated EE velocity: ${{\dot{X}}}_{{EE}}$', 'Interpreter','latex')
xlabel('sample [n]', 'Interpreter','latex')
ylabel(' ${{\dot{Y}}}$ [m/s]', 'Interpreter','latex')
```

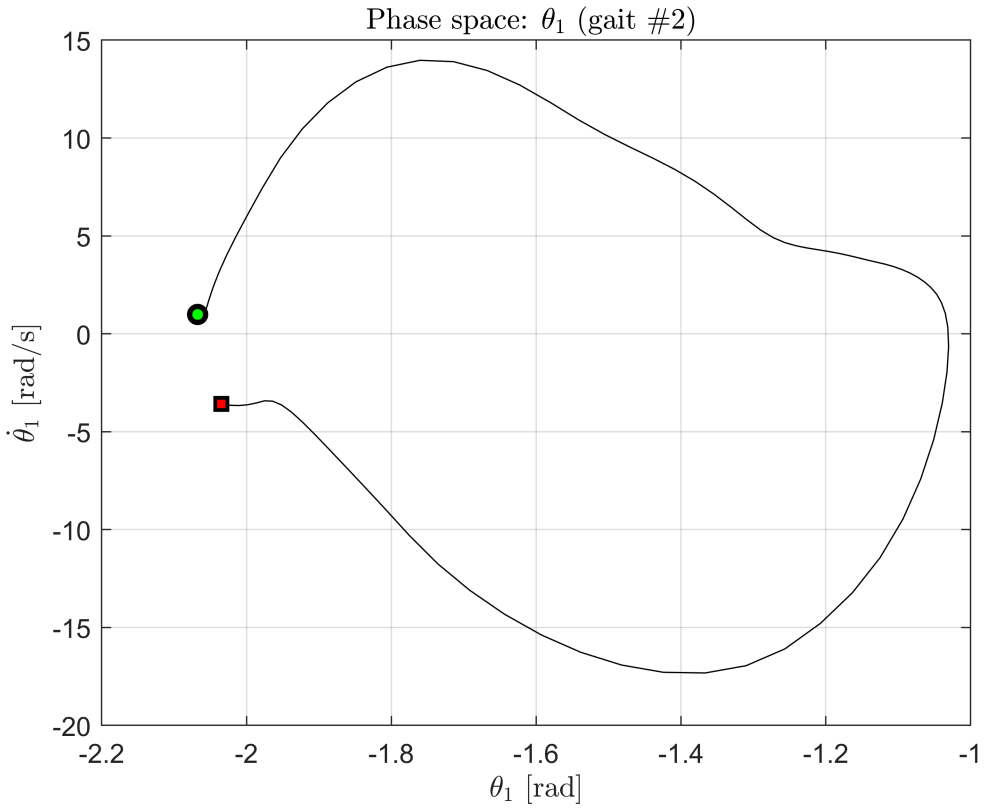



```
% ------------------------------------------------
% ------------------------------------------------------------------------------------
% PHASE SPACE Trajectories
% ------------------------------------------------------------------------------------
% ----------------------------
% set background colour
figure
fig = gcf;
fig.Color = [1 1 1]; % white = [1 1 1]
colordef white
% ----------------------------
plot(th1(2:end),th1D,'cyan')
hold on
plot(th1(1),th1D(1),'o', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','g') % startin
plot(th1(end),th1D(end),'s', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','r') % end
hold off
title('Phase space: $\theta_{1}$ ', 'Interpreter','latex')
xlabel('$\theta_{1}$ [rad]', 'Interpreter','latex')
```

```
ylabel('$\dot\theta_{1}$ [rad/s]', 'Interpreter','latex')
grid on
```

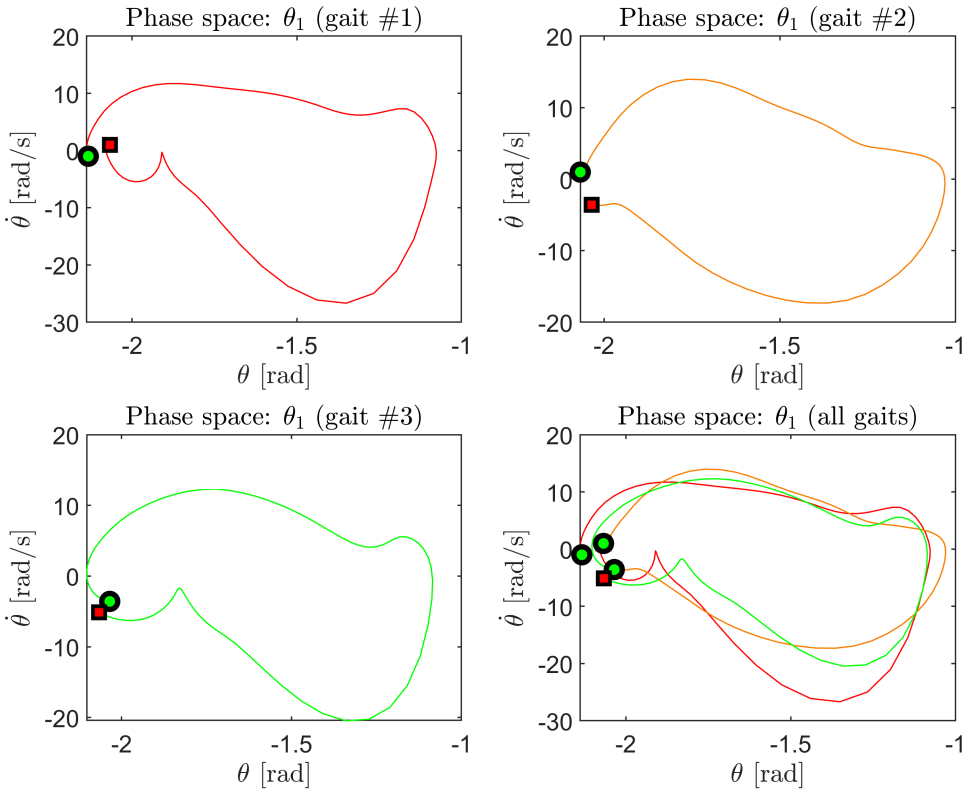



```
% ------------------------------------------------------------------
% ------------------------------------------------------------------
% GAIT 2 only : Config#113--->Config#201
% ----------------------------
% set background colour
fig = gcf;
fig.Color = [1 1 1]; % white = [1 1 1]
colordef white
% ----------------------------
plot(th1(113:201),th1D(113:201),'k')
hold on
plot(th1(113),th1D(113),'o', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','g') % sta
plot(th1(201),th1D(201),'s', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','r') % end
hold off
title('Phase space: $\theta_{1}$ (gait $\#$2) ', 'Interpreter','latex')
xlabel('$\theta_{1}$ [rad]', 'Interpreter','latex')
ylabel('$\dot\theta_{1}$ [rad/s]', 'Interpreter','latex')
grid on
```

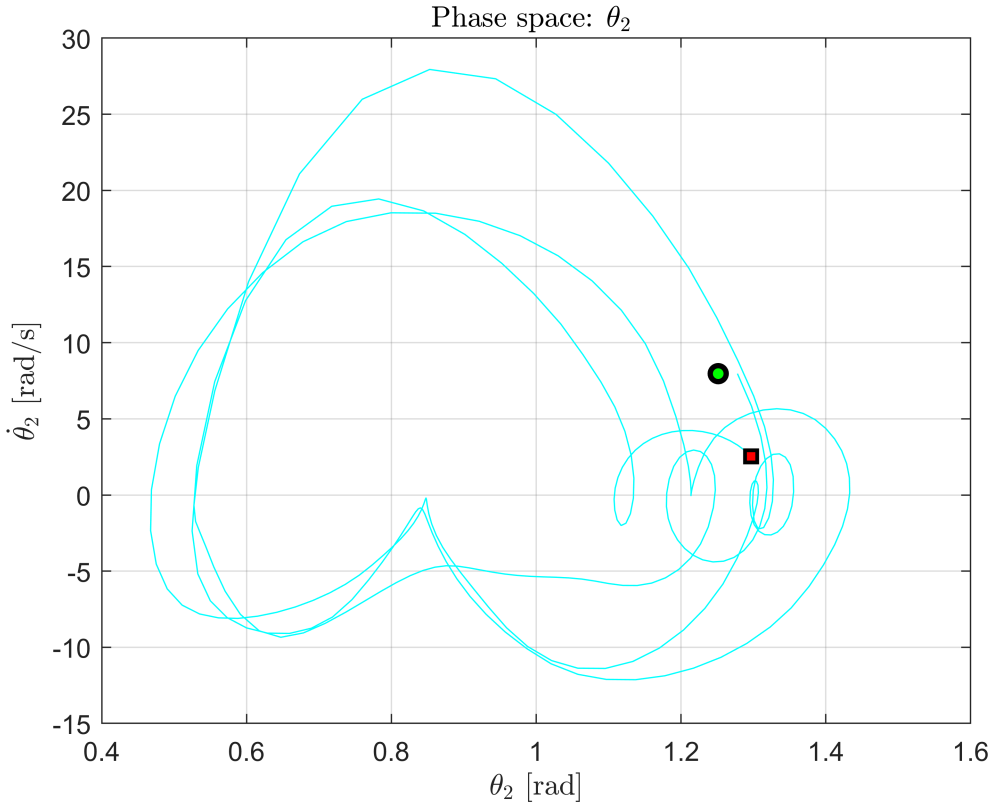



```
% ------------------------------------------------------------------------------
% ------------------------------------------------------------------------------
figure
fig = gcf;
fig.Color = [1 1 1]; % white = [1 1 1]
colordef white
% ----------------------------
cI = [0.99 0.5 0]; % orange--->....'Color',cI
thEE = th1;
thdEEpython = th1D;
% gait #1
subplot(2,2,1),plot(thEE(24:113),thdEEpython(24:113),'red')
hold on
plot(thEE(24),thdEEpython(24),'o', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','g')
plot(thEE(113),thdEEpython(113),'s', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','r
title('Phase space: $\theta_{1}$ (gait $\#$1)', 'Interpreter','latex')
xlabel('$\theta$ [rad]', 'Interpreter','latex')
ylabel('$\dot{\theta}$ [rad/s]', 'Interpreter','latex')
hold off
% gait #2
subplot(2,2,2),plot(thEE(113:201),thdEEpython(113:201),'Color',cI)
hold on
plot(thEE(113),thdEEpython(113),'o', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','g
plot(thEE(201),thdEEpython(201),'s', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','r
hold off
title('Phase space: $\theta_{1}$ (gait $\#$2)', 'Interpreter','latex')
xlabel('$\theta$ [rad]', 'Interpreter','latex')
```

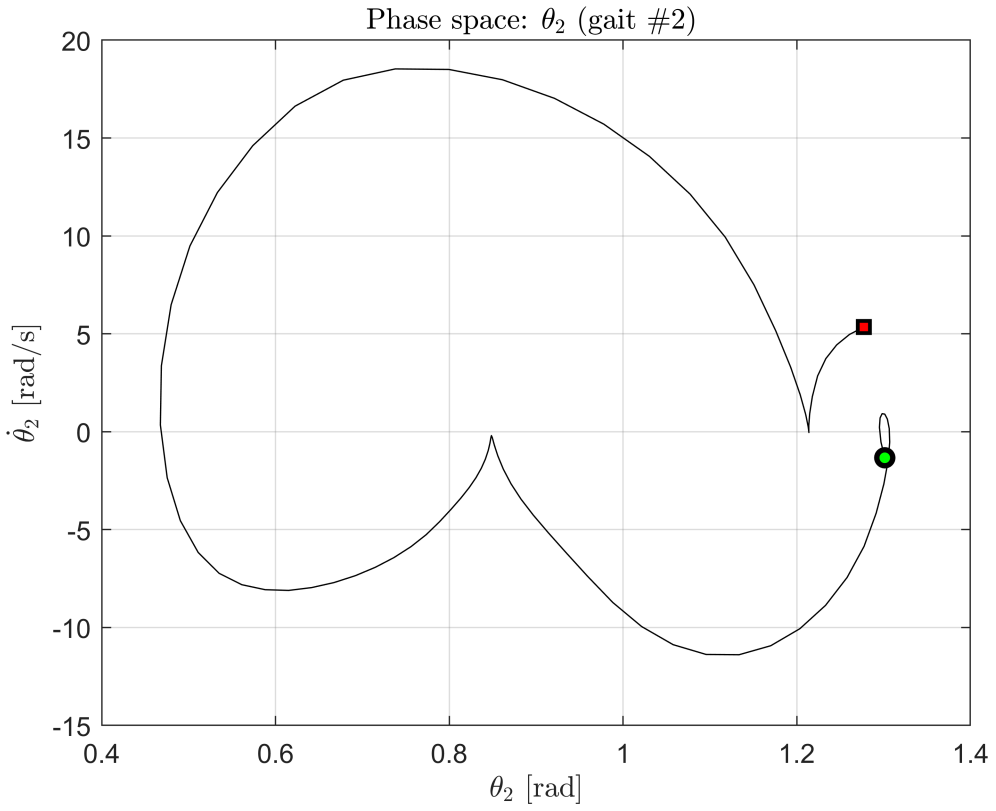
```
ylabel('$\dot{\theta}$ [rad/s]', 'Interpreter','latex')
% gait #3
subplot(2,2,3),plot(thEE(201:293),thdEEpython(201:293),'green')
hold on
plot(thEE(201),thdEEpython(201),'o', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','g
plot(thEE(293),thdEEpython(293),'s', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','r
hold off
title('Phase space: $\theta_{1}$ (gait $\#$3)', 'Interpreter','latex')
xlabel('$\theta$ [rad]', 'Interpreter','latex')
ylabel('$\dot{\theta}$ [rad/s]', 'Interpreter','latex')
% ------Composite
% gait #1
subplot(2,2,4),plot(thEE(24:113),thdEEpython(24:113),'red')
hold on
plot(thEE(24),thdEEpython(24),'o', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','g')
plot(thEE(113),thdEEpython(113),'s', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','r
% gait #2
plot(thEE(113:201),thdEEpython(113:201),'Color',cI)
plot(thEE(113),thdEEpython(113),'o', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','g
plot(thEE(201),thdEEpython(201),'s', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','r
% gait #3
plot(thEE(201:293),thdEEpython(201:293),'green')
plot(thEE(201),thdEEpython(201),'o', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','g
plot(thEE(293),thdEEpython(293),'s', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','r
hold off
title('Phase space: $\theta_{1}$ (all gaits)', 'Interpreter','latex')
xlabel('$\theta$ [rad]', 'Interpreter','latex')
ylabel('$\dot{\theta}$ [rad/s]', 'Interpreter','latex')
```




```
% ------------------------------------------------------------------------------
% ----------------------------
% set background colour
figure
fig = gcf;
fig.Color = [1 1 1]; % white = [1 1 1]
colordef white
% ----------------------------
plot(th2(2:end),th2D,'cyan')
hold on
plot(th2(1),th2D(1),'o', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','g') % startin
plot(th2(end),th2D(end),'s', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','r') % end
hold off
title('Phase space: $\theta_{2}$ ', 'Interpreter','latex')
xlabel('$\theta_{2}$ [rad]', 'Interpreter','latex')
ylabel('$\dot\theta_{2}$ [rad/s]', 'Interpreter','latex')
grid on
```

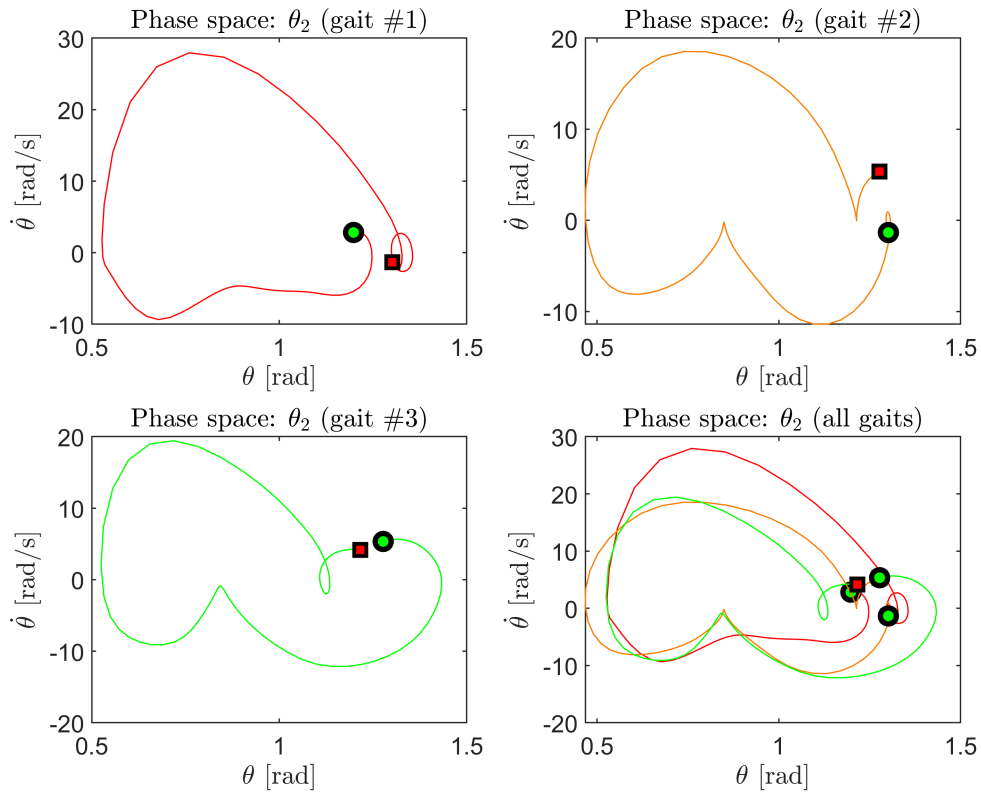



```
% ------------------------------------------------------------------
% ------------------------------------------------------------------
% GAIT 2 only : Config#113--->Config#201
% ----------------------------
% set background colour
fig = gcf;
fig.Color = [1 1 1]; % white = [1 1 1]
colordef white
% ----------------------------
plot(th2(113:201),th2D(113:201),'k')
hold on
plot(th2(113),th2D(113),'o', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','g') % sta
plot(th2(201),th2D(201),'s', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','r') % end
hold off
title('Phase space: $\theta_{2}$ (gait $\#$2) ', 'Interpreter','latex')
xlabel('$\theta_{2}$ [rad]', 'Interpreter','latex')
ylabel('$\dot\theta_{2}$ [rad/s]', 'Interpreter','latex')
grid on
```

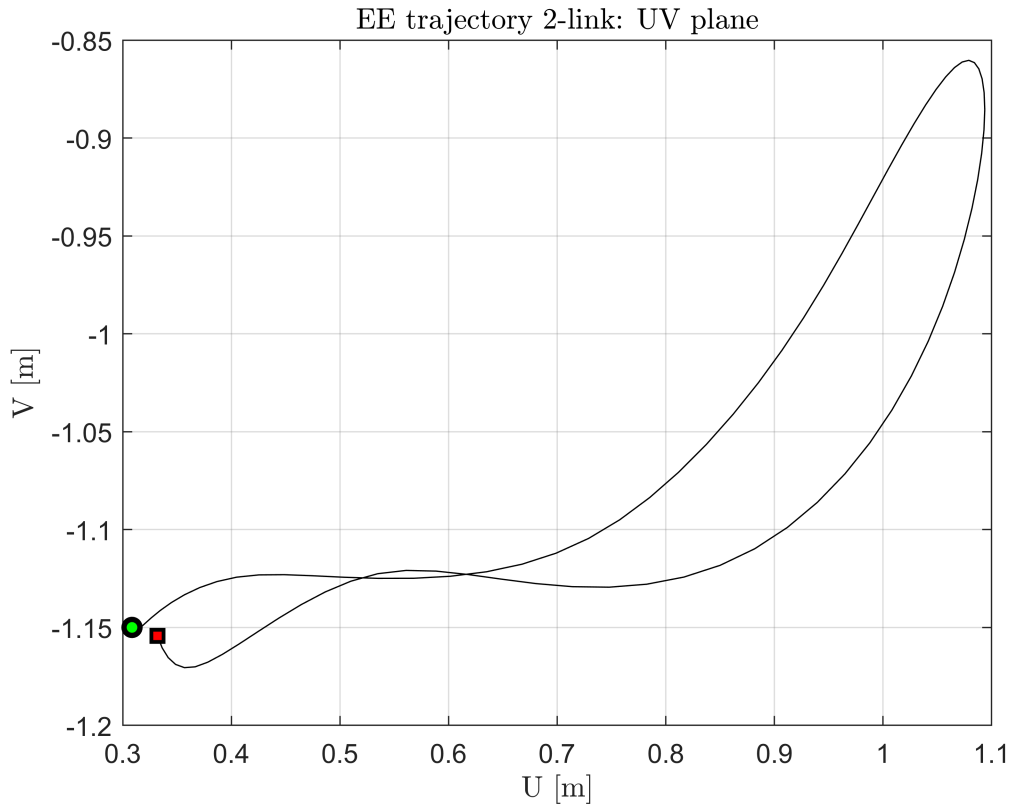



```
% ------------------------------------------------------------------------------
% ------------------------------------------------------------------------------
figure
fig = gcf;
fig.Color = [1 1 1]; % white = [1 1 1]
colordef white
% ----------------------------
cI = [0.99 0.5 0]; % orange--->....'Color',cI
thEE = th2;
thdEEpython = th2D;
% gait #1
subplot(2,2,1),plot(thEE(24:113),thdEEpython(24:113),'red')
hold on
plot(thEE(24),thdEEpython(24),'o', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','g'
plot(thEE(113),thdEEpython(113),'s', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','
title('Phase space: $\theta_{2}$ (gait $\#$1)', 'Interpreter','latex')
xlabel('$\theta$ [rad]', 'Interpreter','latex')
ylabel('$\dot{\theta}$ [rad/s]', 'Interpreter','latex')
hold off
% gait #2
subplot(2,2,2),plot(thEE(113:201),thdEEpython(113:201),'Color',cI)
hold on
plot(thEE(113),thdEEpython(113),'o', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','
plot(thEE(201),thdEEpython(201),'s', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','
hold off
title('Phase space: $\theta_{2}$ (gait $\#$2)', 'Interpreter','latex')
xlabel('$\theta$ [rad]', 'Interpreter','latex')
```

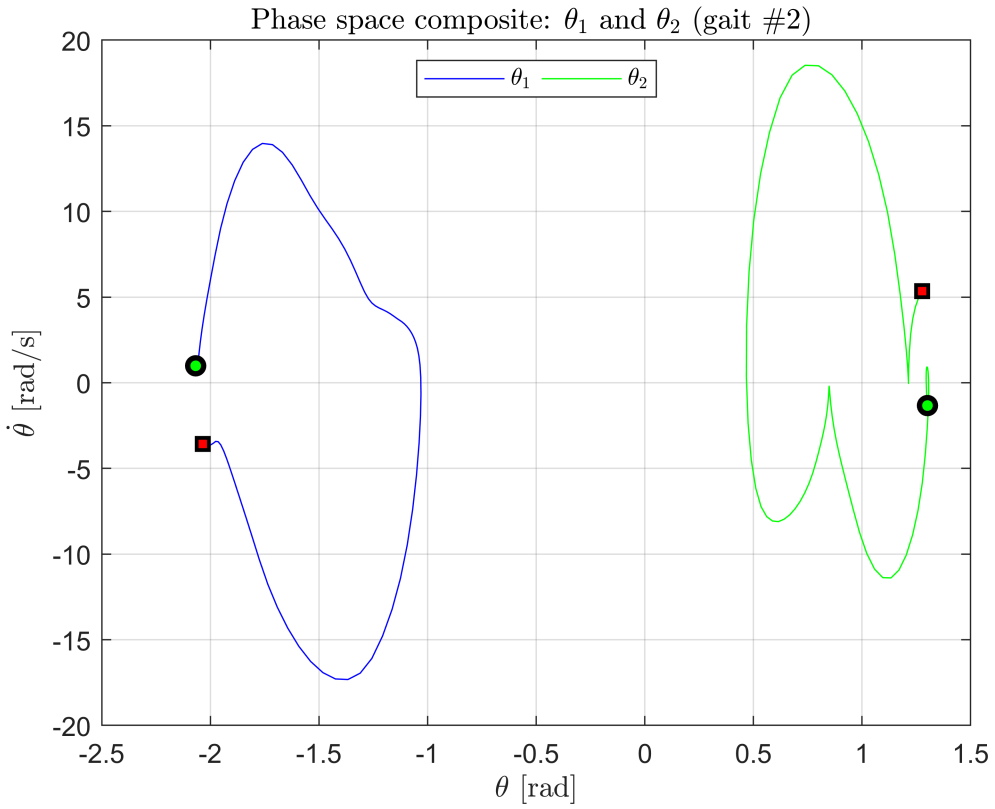
```
ylabel('$\dot{\theta}$ [rad/s]', 'Interpreter','latex')
% gait #3
subplot(2,2,3),plot(thEE(201:293),thdEEpython(201:293),'green')
hold on
plot(thEE(201),thdEEpython(201),'o', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','g
plot(thEE(293),thdEEpython(293),'s', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','r
hold off
title('Phase space: $\theta_{2}$ (gait $\#$3)', 'Interpreter','latex')
xlabel('$\theta$ [rad]', 'Interpreter','latex')
ylabel('$\dot{\theta}$ [rad/s]', 'Interpreter','latex')
% ------Composite
% gait #1
subplot(2,2,4),plot(thEE(24:113),thdEEpython(24:113),'red')
hold on
plot(thEE(24),thdEEpython(24),'o', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','g')
plot(thEE(113),thdEEpython(113),'s', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','r
% gait #2
plot(thEE(113:201),thdEEpython(113:201),'Color',cI)
plot(thEE(113),thdEEpython(113),'o', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','g
plot(thEE(201),thdEEpython(201),'s', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','r
% gait #3
plot(thEE(201:293),thdEEpython(201:293),'green')
plot(thEE(201),thdEEpython(201),'o', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','g
plot(thEE(293),thdEEpython(293),'s', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','r
hold off
title('Phase space: $\theta_{2}$ (all gaits)', 'Interpreter','latex')
xlabel('$\theta$ [rad]', 'Interpreter','latex')
ylabel('$\dot{\theta}$ [rad/s]', 'Interpreter','latex')
```



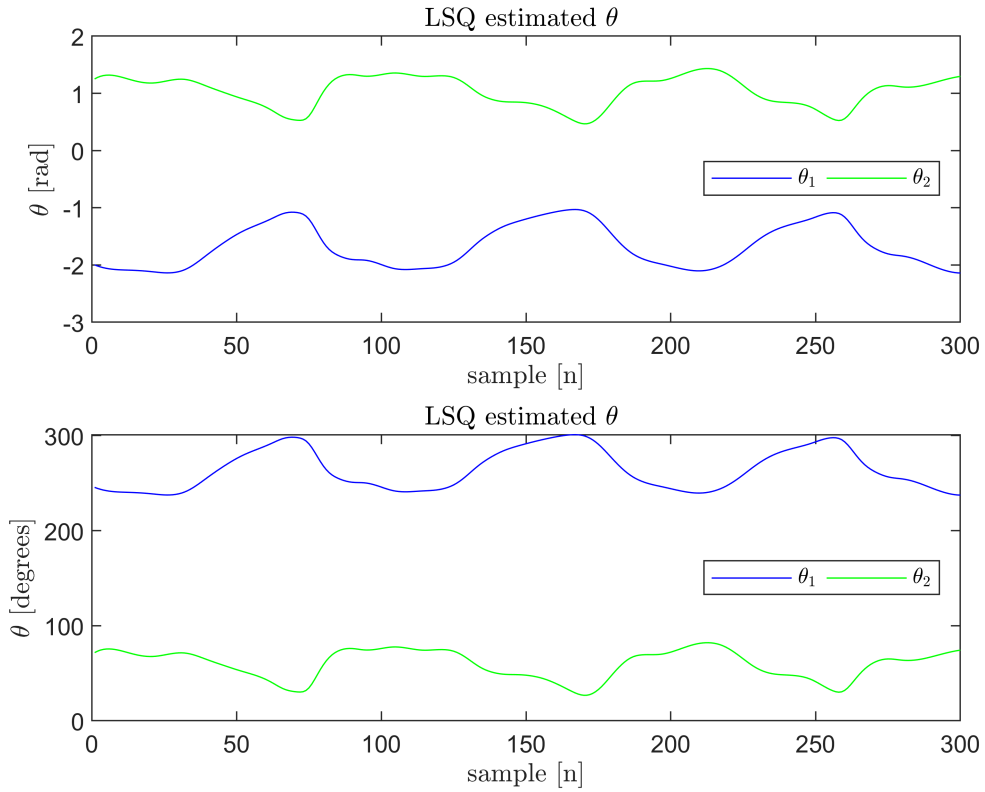

```
% ------------------------------------------------------------------------------
figure
xEE = xEEplane;
yEE = yEEplane;
xEEspace = xEEplane;
yEEspace = yEEplane;
plot(xEE(113:201),yEE(113:201),'Color', cK); % gait 2 range ---> (113:201)
hold on
plot(xEEspace(113),yEEspace(113),'o', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor',
plot(xEEspace(201),yEEspace(201),'s', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor',
hold off
grid on
title('EE trajectory 2-link: UV plane', 'Interpreter','latex')
xlabel('U [m]', 'Interpreter','latex')
ylabel('V [m]', 'Interpreter','latex')
% ------------------------------------------------------------------
% GAIT 2 only : Config#113--->Config#201
% ----------------------------
% set background colour
fig = gcf;
fig.Color = [1 1 1]; % white = [1 1 1]
```



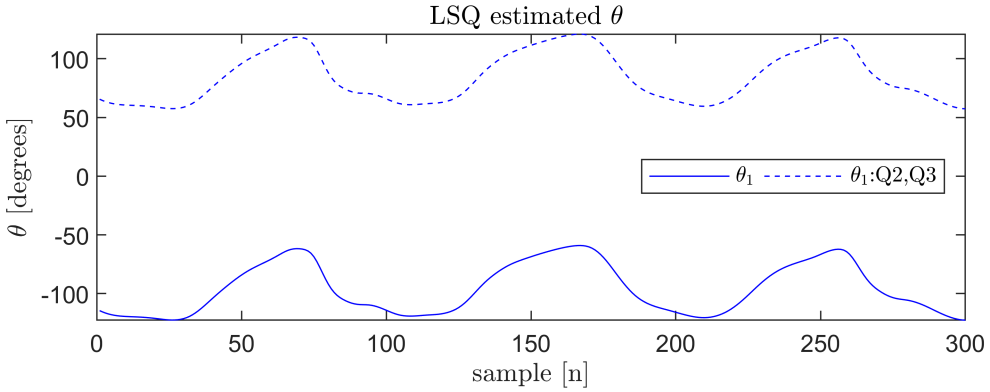

```
colordef white
% ----------------------------
p1=plot(th1(113:201),th1D(113:201),'b');
hold on
plot(th1(113),th1D(113),'o', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','g') % sta
plot(th1(201),th1D(201),'s', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','r') % end

p2=plot(th2(113:201),th2D(113:201),'g');
plot(th2(113),th2D(113),'o', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','g') % sta
plot(th2(201),th2D(201),'s', 'LineWidth',2, 'MarkerEdgeColor','k', 'MarkerFaceColor','r') % end
hold off
title('Phase space composite: $\theta_{1}$ and $\theta_{2}$ (gait $\#$2) ', 'Interpreter','late
legend([p1,p2],{'${\theta_{1}}$','${\theta_{2}}$'},'Location','north','NumColumns',2, 'Interpre
xlabel('$\theta$ [rad]', 'Interpreter','latex')
ylabel('$\dot\theta$ [rad/s]', 'Interpreter','latex')
grid on
```




```
% ------------------------------------------------------------------------------
% -----------------------------------
figure
subplot(2,1,1)
p1=plot(th1,'Color', cB);
hold on
p2=plot(th2,'Color', cJ);
hold off
title('LSQ estimated $\theta$ ', 'Interpreter','latex')
legend([p1,p2],{'${\theta_{1}}$','${\theta_{2}}$'},'Location','east','NumColumns',2, 'Interpret
xlabel('sample [n]', 'Interpreter','latex')
ylabel('$\theta$ [rad]', 'Interpreter','latex')

th1DEG = (180/pi)*th1 + 360; % angle th1 in DEGREES (+)
th2DEG = (180/pi)*th2;  % angle th2 in DEGREES (+)
subplot(2,1,2)
p1=plot(th1DEG,'Color', cB);  % <--- plot angle in DEGREES
hold on
p2=plot(th2DEG,'Color', cJ);  % <--- plot angle in DEGREES
hold off
title('LSQ estimated $\theta$ ', 'Interpreter','latex')
legend([p1,p2],{'${\theta_{1}}$','${\theta_{2}}$'},'Location','east','NumColumns',2, 'Interpret
xlabel('sample [n]', 'Interpreter','latex')
ylabel('$\theta$ [degrees]', 'Interpreter','latex')
```




```
figure
th1DEG = (180/pi)*th1 ; % angle th1 in DEGREES
th1DEG_L = th1DEG + 180;% angle th1 in DEGREES (+) + 180 DEG
th2DEG = (180/pi)*th2;  % angle th2 in DEGREES (+)
subplot(2,1,1)
p1=plot(th1DEG,'Color', cB, 'LineStyle','-');  % <--- plot angle in DEGREES
hold on
p2=plot(th1DEG_L,'Color', cB, 'LineStyle','--');  % <--- plot angle in DEGREES
%p3=plot(th2DEG,'Color', cJ);  % <--- plot angle in DEGREES
hold off
title('LSQ estimated $\theta$ ', 'Interpreter','latex')
legend([p1,p2],{'${\theta_{1}}$','${\theta_{1}}$:Q2,Q3'},'Location','east','NumColumns',2, 'Int
xlabel('sample [n]', 'Interpreter','latex')
ylabel('$\theta$ [degrees]', 'Interpreter','latex')
```


LSQ estimated θ
100
50
0
-50
-100
θ [degrees]
0
50
100
150
200
250
300
sample [n]
θ_1
θ_1:Q2,Q3