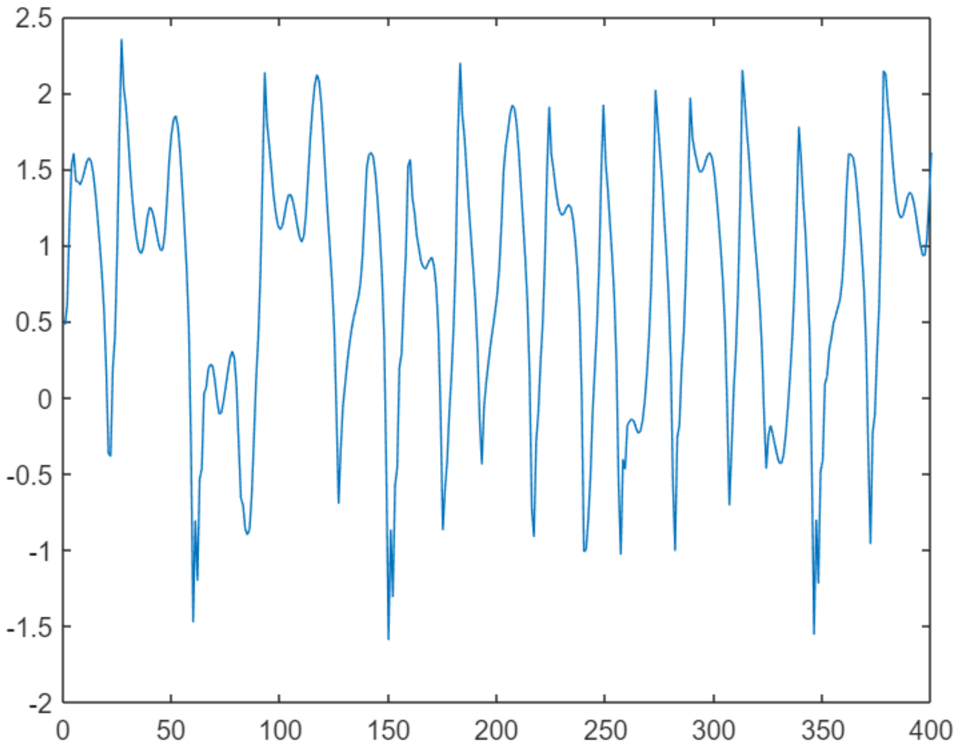
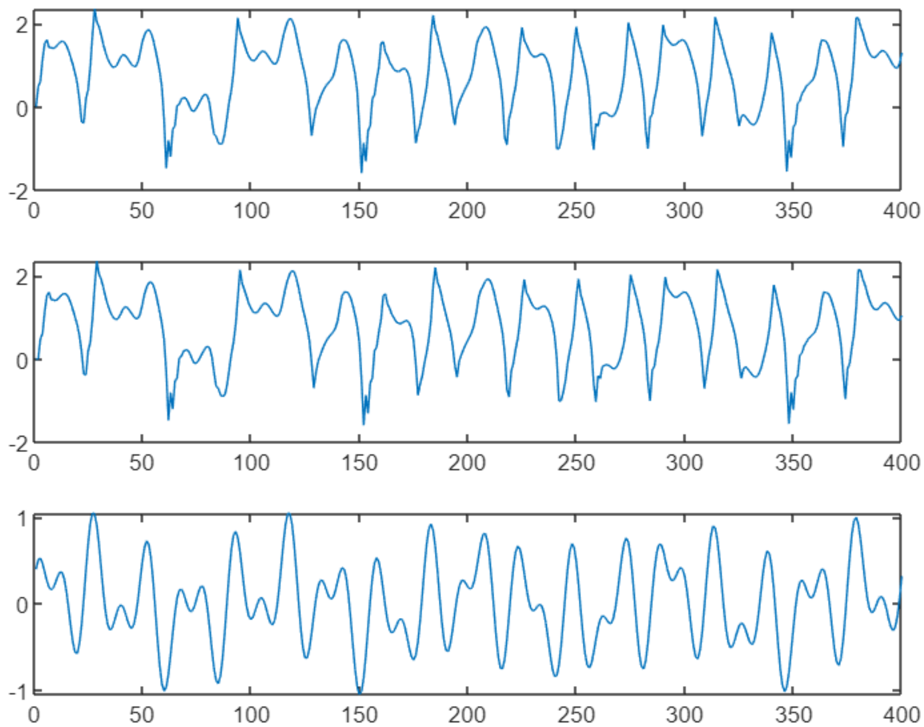
```
clear; close all; clc; format compact;
```

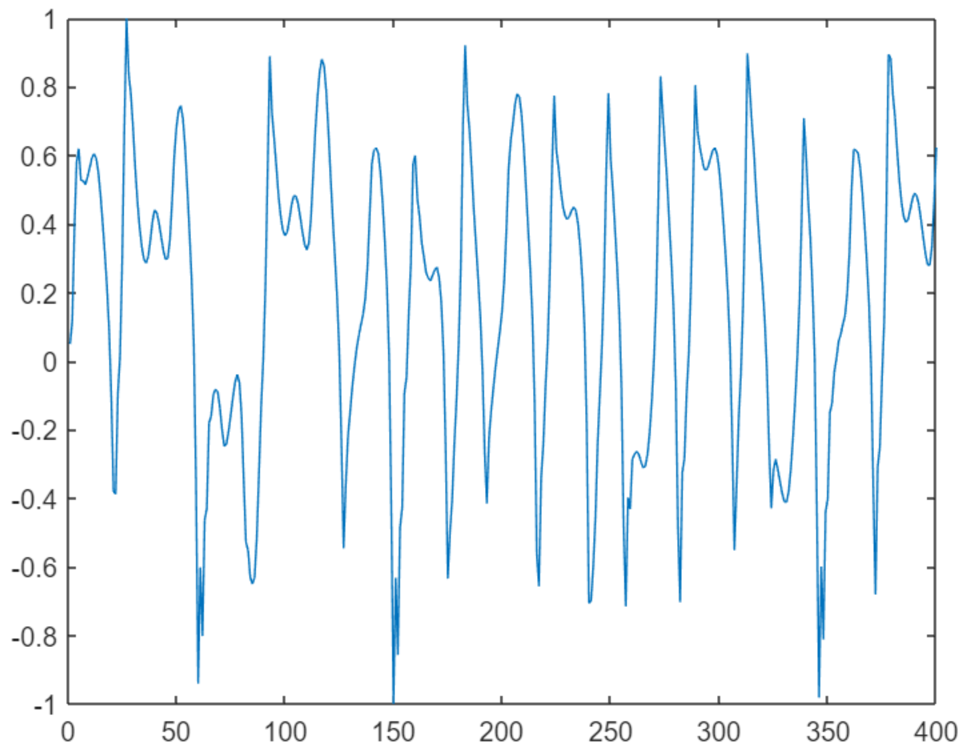
```
N = 400;

k = 1:N;
desired_origin = d(N);
inputs_origin = x(N);

figure
plot(k, desired_origin);
```



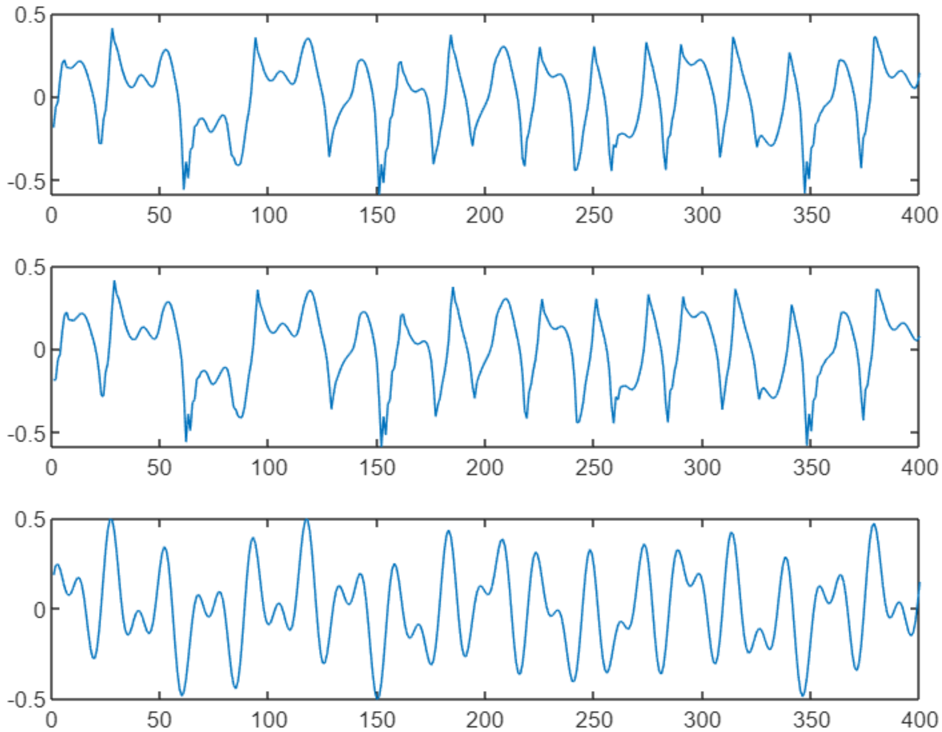

```

figure;
subplot(3,1,1);
plot(k, inputs_origin(1,:));
subplot(3,1,2);
plot(k, inputs_origin(2,:));
subplot(3,1,3);
plot(k, inputs_origin(3,:));
```




```
% offset the desired outputs between sigmoidal bound
max_d = max(desired_origin);
min_d = min(desired_origin);
width = max_d - min_d;
offset = (max_d + min_d) / 2;
desired_norm = 2 * (desired_origin - offset) / width;

figure
plot(k, desired_norm);
```




```
% mean removal preprocess on the input data
inputs_norm = inputs_origin;
mean_inputs = [mean(inputs_norm(1,:)); mean(inputs_norm(2,:)); mean(inputs_norm(3,:))];
inputs_norm = inputs_norm - mean_inputs;

max_inputs = [max(inputs_norm(1,:)); max(inputs_norm(2,:)); max(inputs_norm(3,:))];
min_inputs = [min(inputs_norm(1,:)); min(inputs_norm(2,:)); min(inputs_norm(3,:))];
width_inputs = max_inputs - min_inputs;

inputs_norm = inputs_norm ./ width_inputs;

figure;
subplot(3,1,1);
plot(k, inputs_norm(1,:));
subplot(3,1,2);
plot(k, inputs_norm(2,:));
subplot(3,1,3);
plot(k, inputs_norm(3,:));
```




```
% shuffling the data presented to the network
% inputs_random = zeros(size(inputs_norm));
% desired_random = zeros(size(desired_norm));
%
% j = 0;
% index_shuffle = randperm(N);
% for i = index_shuffle
%     j = j + 1;
%     inputs_random(:, j) = inputs_norm(:, i);
%     desired_random(j) = desired_norm(i);
% end
%
% figure
% plot(k, desired_random);
%
% figure;
% subplot(3,1,1);
% plot(k, inputs_random(1,:));
% subplot(3,1,2);
% plot(k, inputs_random(2,:));
% subplot(3,1,3);
% plot(k, inputs_random(3,:));
```

```
dimIn = 3;          % number of inputs exc. bias
```

```
dimOut = 1;          % number of outputs
dimHidden = [15];     % dimensions of each hidden layer ex. bias

nHiddenLayers = size(dimHidden, 2);

N = 400;
trainRatio = 0.6;
validRatio = 0.2;
testRatio = 0.2;

nTrain = uint16(N * trainRatio);
nValid = uint16(N * validRatio);
nTest = uint16(N * testRatio);

maxEpoch = 500;     % maximum number of iterations
eta = 0.25;
alpha = 0.0;
```

```
% adding +1 row for including synaptic threshold
xi = ones([size(inputs_norm, 1)+1, nTrain]);
xi(2:end, :) = inputs_norm(:, 1:nTrain)
```

```
xi = 4×240
    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000    1.0000 ···
   -0.1863   -0.0646   -0.0314    0.1033    0.2002    0.2203    0.1738    0.1736
   -0.1855   -0.1855   -0.0638   -0.0306    0.1041    0.2011    0.2211    0.1746
    0.1839    0.2358    0.2437    0.2161    0.1687    0.1190    0.0828    0.0697
```

```
dk = desired_norm(1:nTrain)
```

```
dk = 1×240
    0.0500    0.1163    0.3858    0.5796    0.6197    0.5267    0.5264    0.5145 ···
```

```
% weight initialization
m = [dimIn, (dimIn+dimOut)*dimHidden(1)];
stand_dev = m.^(-1/2);

wji = zeros([dimHidden(1), (dimIn+1)]);
wkj = zeros([dimOut, (dimHidden(1)+1)]);

wji(:, 2:end) = normrnd(0, stand_dev(1)^2, [dimHidden(1), dimIn])
```

```
wji = 15×4
         0    0.1792   -0.0683    0.2961
         0    0.6113   -0.0414   -0.3824
         0   -0.7529    0.4966   -0.3563
         0    0.2874    0.4697   -0.2698
         0    0.1063    0.4724   -0.9814
         0   -0.4359    0.2238    0.4795
         0   -0.1445   -0.4025    0.1084
         0    0.1142    0.2391   -0.2516
         0    1.1928    0.5434    0.4568
         0    0.9231    0.1630   -0.5705
```

⋮

```
wkj(:, 2:end) = normrnd(0, stand_dev(2)^2, [dimOut, dimHidden(1)])
```

```
wkj = 1×16
         0   -0.0005   -0.0027    0.0105    0.0182    0.0185   -0.0144    0.0013 ···
```

```
vj = zeros([dimHidden(1), 1]);
yj = zeros([(dimHidden(1)+1), 1]);
yj(1, :) = 1;

vk = zeros([dimOut, 1]);
yk = zeros([dimOut, nTrain]);
```

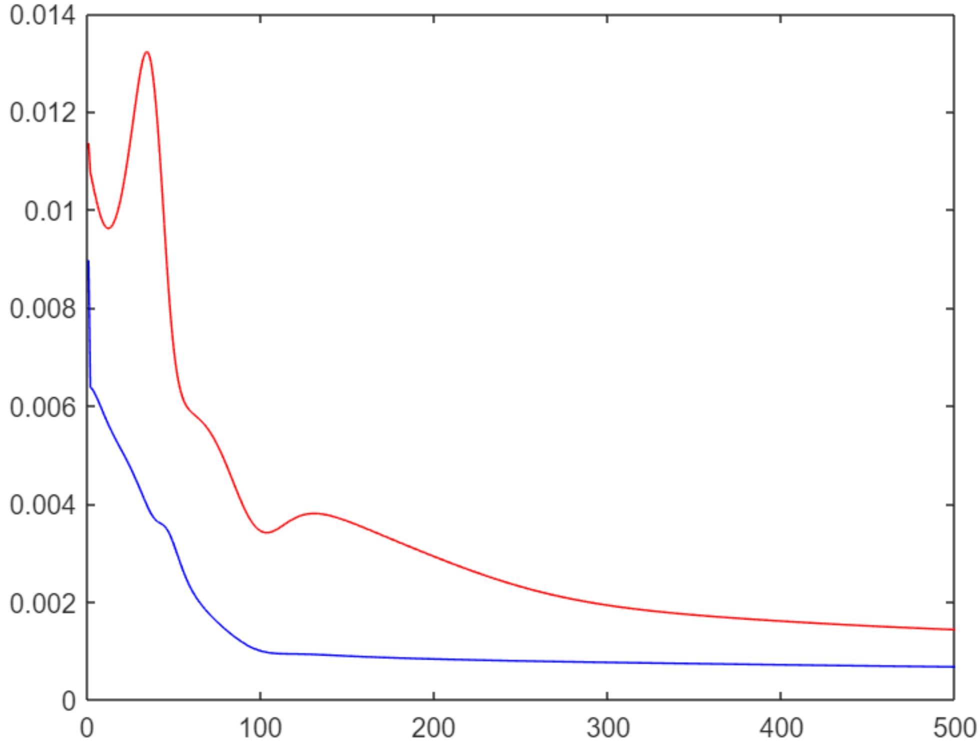
```
ek = -1 * ones(size(dk));   % instantaneous error signal
E = (1/2) * ek.^2;          % total instantaneous error energy
MSE = zeros([1, maxEpoch]);

delta_k = 0;    % local gradient for the output neuron
delta_j = 0;    % local gradient for the hidden layer

delta_wji = zeros(size(wji));
delta_wkj = zeros(size(wkj));
```

```
xvalid = ones([size(inputs_norm, 1)+1, nValid]);
xvalid(2:end, :) = inputs_norm(:, nTrain+1:nTrain+nValid);
dvalid = desired_norm(nTrain+1:nTrain+nValid);

yvalid = zeros([dimOut, nValid]);

ek_valid = -1 * ones(size(dvalid));   % instantaneous error signal
E_valid = (1/2) * ek_valid.^2;        % total instantaneous error energy
MSE_valid = zeros([1, maxEpoch]);
```

```
% MLP
for epoch = 1:maxEpoch
    for n = 1:nTrain
        % feed forward phase
        vj = wji * xi(:,n);
        yj(2:end) = phi(vj);

        vk = wkj * yj;
        yk(n) = phi(vk);

        % back-propagation algorithm
        ek(n) = dk(n) - yk(n);
        E(n) = (1/2) * ek(n)^2;
```

```
        delta_k = ek(n) * phi_derivative(yk(n));
        delta_j = delta_k * wkj(2:end)' .* phi_derivative(yj(2:end));

        delta_wji = (alpha * delta_wji) + (eta * delta_j * xi(:, n)');
        wji = wji + delta_wji;

        delta_wkj = (alpha * delta_wkj) + (eta * delta_k * yj');
        wkj = wkj + delta_wkj;
    end

    % cross validation
    for n = 1:nValid
        vj = wji * xvalid(:, n);
        yj(2:end) = phi(vj);

        vk = wkj * yj;
        yvalid(n) = phi(vk);

        ek_valid(n) = dvalid(n) - yvalid(n);
        E_valid(n) = (1/2) * ek_valid(n)^2;
    end

    MSE(epoch) = sum(E)/numel(E);
    MSE_valid(epoch) = sum(E_valid)/numel(E_valid);
end
```

```
% figure;
% plot(k, E);
figure;
plot(1:maxEpoch, MSE, 'b');
hold on;
plot(1:maxEpoch, MSE_valid, 'r');
```



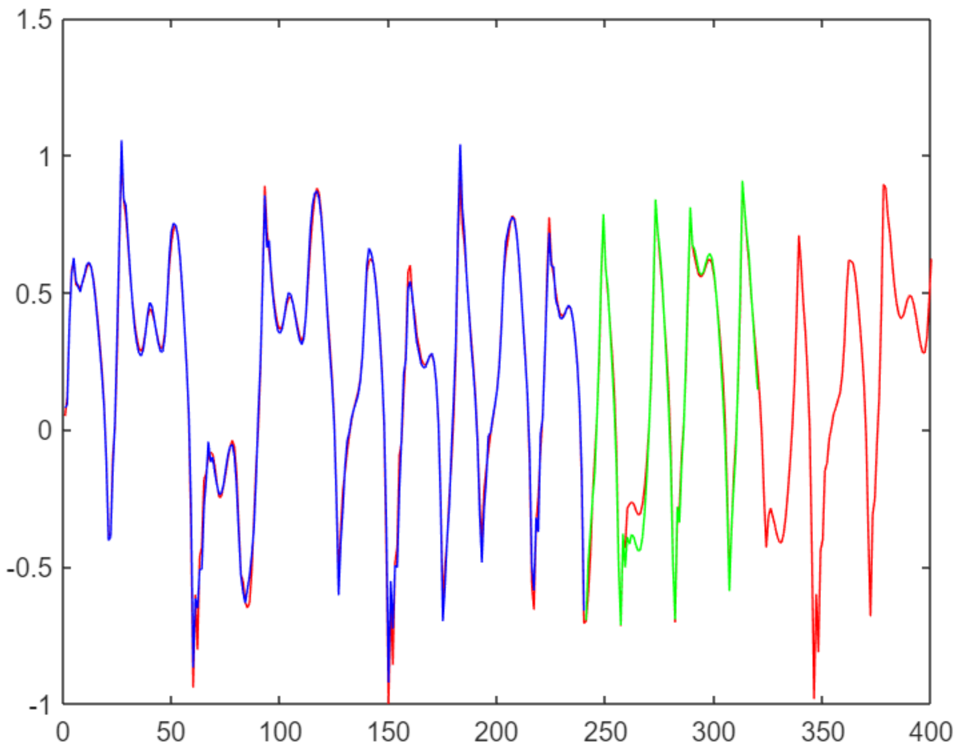

```
wkj
```

```
wkj = 1×16
    0.2355   -0.0276   -0.0664    0.1063   -0.0244   -0.0573    0.0487    0.0015 ···
```

```
wji
```

```
wji = 15×4
    0.0618    0.1343    0.0418   -0.0198
   -0.0353    0.7245   -0.1067   -0.6079
   -0.1442   -0.8130    0.3051    0.1405
   -0.1128    0.2716    0.3746   -0.7661
   -0.2211    0.2549    0.1577   -0.7555
    0.0279   -0.5967    0.3100    0.3155
    0.0581   -0.0753   -0.3293    0.4556
   -0.0604    0.1211    0.1409   -0.3452
    0.3771    5.4526    4.5608   -0.8933
    0.4688    2.6443    0.9861   -2.6100
      ⋮
```

```
figure;
plot(k, desired_norm, 'r');
hold on
plot(1:nTrain, yk, 'b')
hold on;
plot(nTrain+1:nTrain+nValid, yvalid, 'g')
```




```
xtest = ones([size(inputs_norm, 1)+1, nTest]);
xtest(2:end, :) = inputs_norm(:, nTrain+nValid+1:nTrain+nValid+nTest);
dtest = desired_norm(nTrain+nValid+1:nTrain+nValid+nTest);

ytest = zeros([dimOut, nTest]);
```

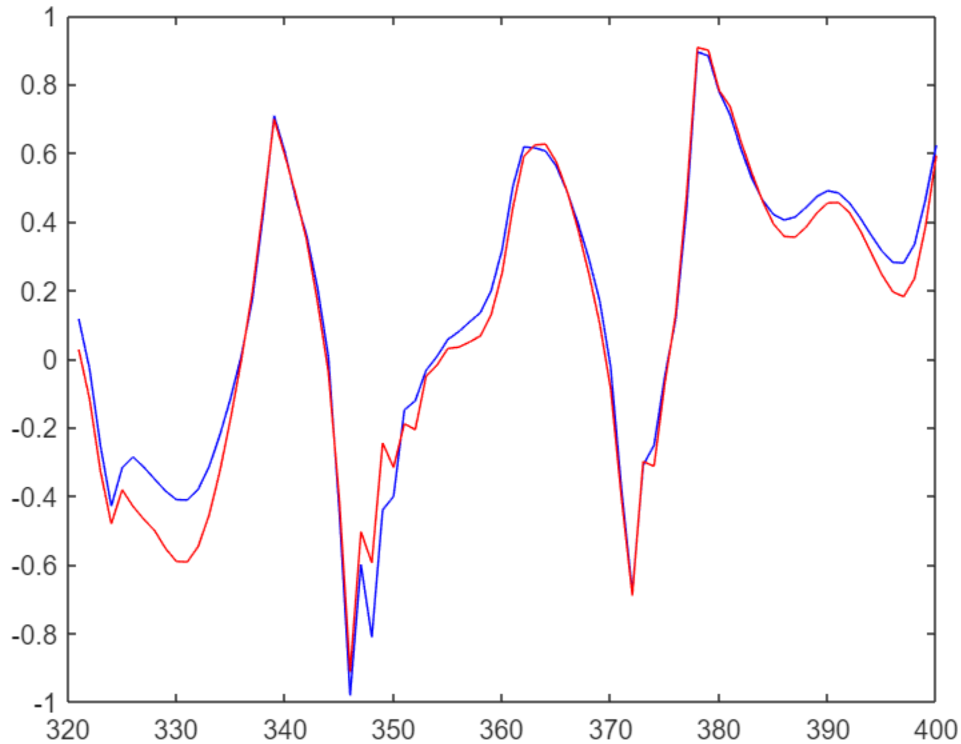
```
% MLP test
for n = 1:nTest
    vj = wji * xtest(:, n);
    yj(2:end) = phi(vj);

    vk = wkj * yj;
    ytest(n) = phi(vk);
end
```

```
ek_test = dtest - ytest;
E_test = (1/2) * ek_test(n).^2;
MSE_test = sum(E_test)/numel(E_test)
```

```
MSE_test = 4.5112e-04
```

```
figure;
```

```
plot(nTrain+nValid+1:nTrain+nValid+nTest, dtest, 'b');
hold on;
plot(nTrain+nValid+1:nTrain+nValid+nTest, ytest, 'r');
```



Functions

```
function [control_sig] = u(k)
    control_sig = 0.5*sin(k*(pi/11)) + 0.4*cos(k*(pi/6.5)) + 0.2*sin(k*(pi/45));
end

function [desired_vec] = d(N)
    alpha = 1.2;
    beta = 1.1;

    if N <= 1
        N = 1;
    elseif N >= 400
        N = 400;
    end

    desired_vec = zeros([1, N]);
    for k = 1:N
        if k < 3
            desired_vec(k) = alpha * u(k-1);
```

```
        else
            desired_vec(k) = alpha * ((desired_vec(k-1)*desired_vec(k-2)*(desired_vec(k-2) + be
        end
    end
end

function [input_vec] = x(N)
    if N <= 1
        N = 1;
    elseif N >= 400
        N = 400;
    end

    input_vec = zeros([3, N]);
    desired_vec = d(N);

    for k = 1:N
        if k == 1
            input_vec(:, k) = [    0,    0,  u(k-1)]';
        elseif k == 2
            input_vec(:, k) = [ desired_vec(1),    0,  u(k-1)]';
        else
            input_vec(:, k) = [ desired_vec(k-1),  desired_vec(k-2), u(k-1)]';
        end
    end
end

function [activation] = phi(v)
    a = 1.7159;
    b = 2/3;
    activation = a*tanh(b*v);
end

function [derivative] = phi_derivative(y)
    a = 1.7159;
    b = 2/3;
    derivative = (b/a)*(a - y).*(a + y);
end
```