Peiyuan (Alexander) Liao

Csef 2018

research notebook

***Manipulator evaluation***: Motion of an anthropomorphic arm through a straight line in Cartesian space by interpolation & trajectory planning

Date: 9/3/17

Alexander Liao

Brainstorming

**I/O:**

Warning: floor tiles too small, making them 30.000000 x bigger - change the size or disable them

> In RTBPlot.create\_tiled\_floor (line 619)

In RTBPlot.create\_floor (line 575)

In SerialLink/plot (line 250)

In RobotTest (line 38)

linreg =

Linear regression model:

y ~ 1 + x1

Estimated Coefficients:

Estimate SE tStat pValue

\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_

(Intercept) 10.039 0.0066362 1512.7 0

x1 -0.0019077 0.00053394 -3.5729 0.00045138

Number of observations: 185, Error degrees of freedom: 183

Root Mean Squared Error: 0.0508

R-squared: 0.0652, Adjusted R-Squared 0.0601

F-statistic vs. constant model: 12.8, p-value = 0.000451

**Code:**

clear Arm

t=[0 0 0 0 0 0 0];

l=[17.25 15.85 5.75];

xdata=[];

ydata=[];

L(1)= Link([t(1) 0 0 pi/2 0],'modified');

L(2)= Link([t(2)+pi/2 0 0 pi/2 0],'modified');

L(3)= Link([t(3)+pi/2 l(1) 0 pi/2 0],'modified');

L(4)= Link([t(4)+pi 0 0 pi/2 0],'modified');

L(5)= Link([t(5)+pi l(2) 0 pi/2 0],'modified');

L(6)= Link([t(6)+pi/2 0 0 pi/2 0],'modified');

L(7)= Link([t(7)+pi 0 l(3) pi/2 0],'modified');

Arm=SerialLink([L(1) L(2) L(3) L(4) L(5) L(6) L(7)]);

t=20;

%ti=0:t^-1:1;

er=ctraj(transl(0,10,10),transl(20,10,10),t);

solv=[];

solve1=Arm.jtraj(er(:,:,1),er(:,:,2),5);

finale=solve1;

for i=2:t-1

solv=Arm.jtraj(er(:,:,i),er(:,:,i+1),10);

finale =[finale;solv];

end

clear i

for i=1:size(finale)

for k=1:7

t(k)=finale(i,k);

end

intm=Arm.fkine(t);

intm2=intm.t;

xdata=horzcat(xdata,intm2(1));

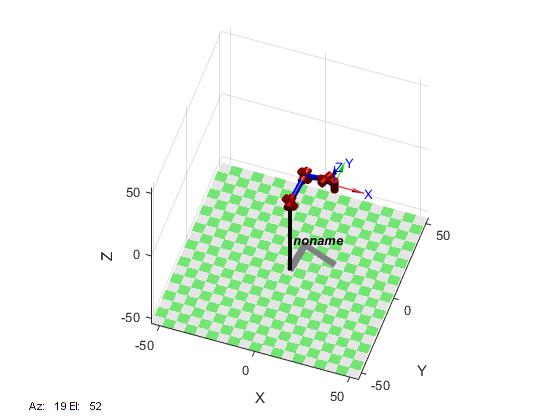
ydata=horzcat(ydata,intm2(2));

Arm.plot(t);

end

linreg=fitlm(xdata,ydata)

**Visualization:**



Improvement to allow

end

counter3 =counter3+1;

voxel1(:,:,counter3)=pixel1;

voxel2(:,:,counter3)=pixel2;

end

clear counter1 counter2

[sizeRow,sizeColumn,size3D]=size(voxel1);

%JointAngles=zeros(2,7);

for counter1=1:size3D

for counter2=1:sizeRow

LinPlan=trinterp(transl(voxel1(counter2,:,counter1)),transl(voxel2(counter2,:,counter1)),vxlPerRow);

TrajPlan=M.ikine(LinPlan);

JointAngles=[JointAngles;TrajPlan];

%SurfPlan=cat(4,SurfPlan,LinPlan);

end

for counter3=1:size(JointAngles)

hmTrans=M.fkine(JointAngles(counter3,:));

vector=hmTrans.t;

endX=horzcat(endX,vector(1));

endY=horzcat(endY,vector(2));

M.plot(JointAngles(counter3,:))

end

plot(endX,endY)

hold on

%clear counter2

%TrajPlan=Manipulator.ikinem(SurfPlan(:,:,1,counter1),SurfPlan(:,:,2,counter1),subVxlDensity)

%JointAngles=TrajPlan

%for counter2=2:vxlPerRow-1

% TrajPlan=Manipulator.jtraj(SurfPlan(:,:,counter2,counter1),SurfPlan(:,:,counter2+1,counter1),subVxlDensity);

% JointAngles=[JointAngles;TrajPlan];

%end

end

clear counter2

clear counter1 counter2 counter3

Date: 9/28/17

Alexander Liao

Brainstorming

planning in Cartesian

3D space:

**Code:**

%Initialization

clear all

theta=[0 0 0 0 0 0 0];

l=[17.25 15.85 5.75];

endX=[];

endY=[];

TrajPlan=[];

LinPlan=[];

SurfPlan=[];

JointSpaceTraj=[];

JointAngles=[];

hmTrans=[];

vector=[];

%subVxlDensity=19;

vxlPerRow=9;

counter3=0;

L(1)= Link([theta(1) 0 0 pi/2 0],'modified');

L(2)= Link([theta(2)+pi/2 0 0 pi/2 0],'modified');

L(3)= Link([theta(3)+pi/2 l(1) 0 pi/2 0],'modified');

L(4)= Link([theta(4)+pi 0 0 pi/2 0],'modified');

L(5)= Link([theta(5)+pi l(2) 0 pi/2 0],'modified');

L(6)= Link([theta(6)+pi/2 0 0 pi/2 0],'modified');

L(7)= Link([theta(7)+pi 0 l(3) pi/2 0],'modified');

M=SerialLink([L(1) L(2) L(3) L(4) L(5) L(6) L(7)]);

pixel=[];

%voxel=zeros(2\*(voxelPerRow),3,voxelPerRow);

for counter1=-20:20/(vxlPerRow-1):0

pixel1=[];

pixel2=[];

for counter2=10:20/(vxlPerRow-1):30

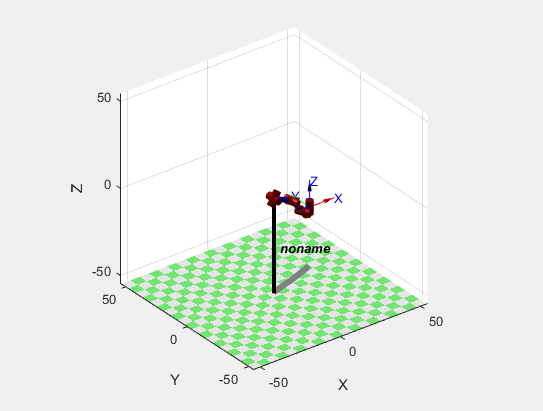
pixel1=vertcat(pixel1,[10,counter2,counter1]);

pixel2=vertcat(pixel2,[30,counter2,counter1]);

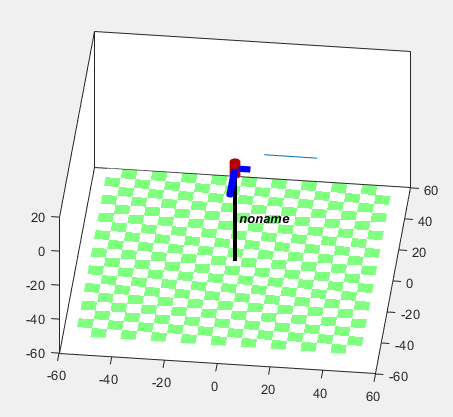
%pixel=vertcat(pixel,[counter2,10,counter1]);

%pixel=vertcat(pixel,[counter2,30,counter1]);

**Visualization 1:**



**Visualization 2 (failed when plotting the line of motion):**



**I/O:**

Warning: floor tiles too small, making them 30.000000 x bigger - change the size or disable them

> In RTBPlot.create\_tiled\_floor (line 619)

In RTBPlot.create\_floor (line 575)

In SerialLink/plot (line 250)

In Test (line 63)

Error using matlab.graphics.primitive.Group/set

Invalid or deleted object.

Error in SerialLink/animate (line 148)

set(handle, 'UserData', h);

Error in SerialLink/plot (line 297)

robot.animate(qq);

Error in Test (line 63)

M.plot(JointAngles(counter3,:))

**Workspace:**

**Pose planning**

LinPlan(:,:,1) =

1.0000 0 0 10.0000

0 1.0000 0 30.0000

0 0 1.0000 -17.5000

0 0 0 1.0000

LinPlan(:,:,2) =

1.0000 0 0 12.5000

0 1.0000 0 30.0000

0 0 1.0000 -17.5000

0 0 0 1.0000

LinPlan(:,:,3) =

1.0000 0 0 15.0000

0 1.0000 0 30.0000

0 0 1.0000 -17.5000

0 0 0 1.0000

LinPlan(:,:,4) =

1.0000 0 0 17.5000

0 1.0000 0 30.0000

0 0 1.0000 -17.5000

0 0 0 1.0000

LinPlan(:,:,5) =

1.0000 0 0 20.0000

0 1.0000 0 30.0000

0 0 1.0000 -17.5000

0 0 0 1.0000

**Workspace:**

JointAngles =

-0.4940 0.8524 1.2426 1.4271 0.0239 -0.5089 -0.7566

-0.3986 0.9342 1.3036 1.4916 -0.0537 -0.3972 -0.7325

-0.3292 1.0172 1.3613 1.5766 -0.1128 -0.2746 -0.6959

-0.2849 1.0957 1.4151 1.6820 -0.1534 -0.1431 -0.6494

-0.2650 1.1649 1.4633 1.8096 -0.1765 -0.0042 -0.5957

-0.2692 1.2217 1.5037 1.9638 -0.1852 0.1427 -0.5377

-0.3002 1.2653 1.5344 2.1539 -0.1833 0.3015 -0.4782

-0.3682 1.2968 1.5537 2.4043 -0.1755 0.4849 -0.4180

-0.5296 1.3179 1.5574 2.8316 -0.1687 0.7531 -0.3497

-0.3465 0.7728 1.1908 1.2621 -0.2330 -0.5622 -1.0570

-0.2384 0.8893 1.2739 1.3388 -0.3396 -0.4406 -1.0316

-0.1628 1.0120 1.3609 1.4319 -0.4200 -0.3027 -0.9847

-0.1182 1.1292 1.4499 1.5399 -0.4699 -0.1545 -0.9169

-0.1017 1.2289 1.5351 1.6637 -0.4895 -0.0033 -0.8332

-0.1097 1.3042 1.6107 1.8076 -0.4849 0.1475 -0.7413

-0.1403 1.3539 1.6743 1.9785 -0.4646 0.2996 -0.6472

-0.1962 1.3792 1.7250 2.1897 -0.4351 0.4606 -0.5526

-0.2920 1.3795 1.7624 2.4758 -0.4011 0.6492 -0.4537

-0.2864 0.6998 1.3830 1.3181 0.0787 -0.4369 -0.8139

-0.2048 0.7956 1.4300 1.3864 0.0110 -0.3302 -0.7748

-0.1509 0.8864 1.4667 1.4744 -0.0389 -0.2133 -0.7289

-0.1207 0.9689 1.4957 1.5820 -0.0733 -0.0884 -0.6791

-0.1121 1.0406 1.5180 1.7106 -0.0946 0.0433 -0.6271

-0.1247 1.1009 1.5334 1.8634 -0.1057 0.1824 -0.5749

-0.1605 1.1505 1.5410 2.0475 -0.1099 0.3321 -0.5238

-0.2266 1.1912 1.5400 2.2798 -0.1109 0.5011 -0.4746

-0.3504 1.2265 1.5276 2.6167 -0.1144 0.7191 -0.4252

-0.2511 0.5913 1.4258 1.4100 0.2142 -0.3067 -0.7806

-0.1851 0.6831 1.4607 1.4783 0.1618 -0.2117 -0.7339

-0.1457 0.7671 1.4785 1.5667 0.1225 -0.1058 -0.6859

-0.1286 0.8425 1.4841 1.6759 0.0934 0.0093 -0.6392

-0.1319 0.9095 1.4799 1.8077 0.0718 0.1333 -0.5953

-0.1563 0.9697 1.4673 1.9669 0.0549 0.2677 -0.5557

-0.2055 1.0260 1.4469 2.1632 0.0395 0.4173 -0.5210

-0.2915 1.0827 1.4186 2.4228 0.0214 0.5955 -0.4916

-0.4865 1.1564 1.3724 2.8915 -0.0133 0.8784 -0.4653

First attempt in formulating an evaluation method: absolute error between planned trajectory and straight line between nodes of cuboid partitions

Date: 9/29/17

Alexander Liao

Brainstorming

**Code:**

%Initialization

clear all

%SerialLink Parameters

theta=[0 0 0 0 0 0 0];

l=[17.25 15.85 5.75];

%Target Space

x1=10;

x2=20;

y1=10;

y2=20;

z1=-8;

z2=2;

%Specifications for Voxels

interpVal=3;

numVxl=5;

zLayerHeight=5;

%Final Result

dataGraySclImage=[];

%Creating the SerialLink object

L(1)= Link([theta(1) 0 0 pi/2 0],'modified');

L(2)= Link([theta(2)+pi/2 0 0 pi/2 0],'modified');

L(3)= Link([theta(3)+pi/2 l(1) 0 pi/2 0],'modified');

L(4)= Link([theta(4)+pi 0 0 pi/2 0],'modified');

L(5)= Link([theta(5)+pi l(2) 0 pi/2 0],'modified');

L(6)= Link([theta(6)+pi/2 0 0 pi/2 0],'modified');

L(7)= Link([theta(7)+pi 0 l(3) pi/2 0],'modified');

M=SerialLink([L(1) L(2) L(3) L(4) L(5) L(6) L(7)]);

%Generating grayscale image

for z=z1:zLayerHeight:z2;

if z==z2

disp('Test')

else

%Invoking the surface function for at the height "z"

[surfPlan,SizeZ] = surfaceRobotTest(L,M,interpVal,numVxl,x1,x2,y1,y2,z);

[SizeX,SizeY]=size(surfPlan);

endX=zeros(1,SizeX);

endY=zeros(1,SizeY);

%Calculating the trajectories from joint angle to Cartesian Coordinates

for i=1:size(surfPlan);

hmTrans=M.fkine(surfPlan(i,:));

vector=hmTrans.t;

endX(i)=vector(1);

endY(i)=vector(2);

%Optional Visualization: M.plot(surfPlan(i,:))

end

%Prelocating space for intermidiate matrices to save time

[~,y]=size(endY);

preFitx=zeros(1,(SizeZ-1)\*interpVal);

preFity=zeros(1,(SizeZ-1)\*interpVal);

standardD=zeros(1,y/((SizeZ-1)\*interpVal));

a=1;

b=(SizeZ-1)\*interpVal;

%Finding the standard deviation of actual trajectories to ideal

%ones

for i=1:(y/((SizeZ-1)\*interpVal))

for k=a:b

preFitx(k)=endX(1,k);

preFity(k)=endY(1,k);

end

[~,y3]=size(preFitx);

[~,y4]=size(endX);

normalx=preFitx(1):(preFitx(k)-preFitx(1))/(y3-1):preFitx(k);

normaly=preFity(1):(preFity(k)-preFity(1))/(y3-1):preFity(k);

for k1=1:1:((y4)/2)

preFity(k)=normaly(k)

end

for k2=(((y4)/2)+1):1:y4

preFitx(k)=normalx(k)

end

standardD=std([preFity;preFitx],0,1);

a=a+(SizeZ-1)\*interpVal;

b=b+(SizeZ-1)\*interpVal;

end

rowGrayScale=mat2gray(standardD);

dataGraySclImage=vertcat(dataGraySclImage,rowGrayScale);

end

end

%Trajectory Planning for a surface

function [surfPlan,SizeZ]= surfaceRobotTest(L,M,interpVal,numVxl,x1,x2,y1,y2,z)

surfPlan=[];

%Linear test along the y-direction

for i=x1:x2

terminal1=transl(i,y1,z);

terminal2=transl(i,y2,z);

[linPlan,SizeZ]=linearRobotTest(L,M,interpVal,numVxl,terminal1,terminal2);

surfPlan=vertcat(surfPlan,linPlan);

end

SizeZ=SizeZ;

%Linear test along the x-direction

for i=y1:y2

terminal1=transl(x1,i,z);

terminal2=transl(x2,i,z);

linPlan=linearRobotTest(L,M,interpVal,numVxl,terminal1,terminal2);

surfPlan=vertcat(surfPlan,linPlan);

end

end

%Trajectory Planning for a line

function [linPlan,SizeZ] = linearRobotTest(L,M,interpVal,numVxl,terminal1,terminal2)

linVoxel=trinterp(terminal1,terminal2,numVxl-1);

[~,~,SizeZ]=size(linVoxel);

linPlan=zeros((SizeZ-1)\*interpVal,numel(L));

for i=1:SizeZ-1

ptPlan=M.jtraj(linVoxel(:,:,i),linVoxel(:,:,i+1),interpVal);

index1=1+(i-1)\*interpVal;

index2=i\*interpVal;

linPlan(index1:index2,:)=ptPlan(:,:);

end

end

for i=1:size(surfPlan);

hmTrans=M.fkine(surfPlan(i,:));

vector=hmTrans.t;

endX(i)=vector(1);

endY(i)=vector(2);

%Optional Visualization: M.plot(surfPlan(i,:))

end

%Prelocating space for intermidiate matrices to save time

[~,y]=size(endY);

preFitx=zeros(1,(SizeZ-1)\*interpVal);

preFity=zeros(1,(SizeZ-1)\*interpVal);

standardD=zeros(1,y/((SizeZ-1)\*interpVal));

a=1;

b=(SizeZ-1)\*interpVal;

%Finding the standard deviation of actual trajectories to ideal

%ones

for i=1:(y/((SizeZ-1)\*interpVal))

for k=a:b

preFitx(k)=endX(1,k);

preFity(k)=endY(1,k);

end

[~,y3]=size(preFitx);

[~,y4]=size(endX);

normalx=preFitx(1):(preFitx(k)-preFitx(1))/(y3-1):preFitx(k);

normaly=preFity(1):(preFity(k)-preFity(1))/(y3-1):preFity(k);

for k1=1:1:((y4)/2)

preFity(k)=normaly(k)

end

for k2=(((y4)/2)+1):1:y4

preFitx(k)=normalx(k)

end

standardD=std([preFity;preFitx],0,1);

a=a+(SizeZ-1)\*interpVal;

b=b+(SizeZ-1)\*interpVal;

end

rowGrayScale=mat2gray(standardD);

dataGraySclImage=vertcat(dataGraySclImage,rowGrayScale);

end

end

%Trajectory Planning for a surface

function [surfPlan,SizeZ]= surfaceRobotTest(L,M,interpVal,numVxl,x1,x2,y1,y2,z)

surfPlan=[];

%Linear test along the y-direction

for i=x1:x2

terminal1=transl(i,y1,z);

terminal2=transl(i,y2,z);

[linPlan,SizeZ]=linearRobotTest(L,M,interpVal,numVxl,terminal1,terminal2);

surfPlan=vertcat(surfPlan,linPlan);

end

SizeZ=SizeZ;

%Linear test along the x-direction

for i=y1:y2

terminal1=transl(x1,i,z);

terminal2=transl(x2,i,z);

linPlan=linearRobotTest(L,M,interpVal,numVxl,terminal1,terminal2);

surfPlan=vertcat(surfPlan,linPlan);

end

end

%Trajectory Planning for a line

function [linPlan,SizeZ] = linearRobotTest(L,M,interpVal,numVxl,terminal1,terminal2)

linVoxel=trinterp(terminal1,terminal2,numVxl-1);

[~,~,SizeZ]=size(linVoxel);

linPlan=zeros((SizeZ-1)\*interpVal,numel(L));

for i=1:SizeZ-1

ptPlan=M.jtraj(linVoxel(:,:,i),linVoxel(:,:,i+1),interpVal);

index1=1+(i-1)\*interpVal;

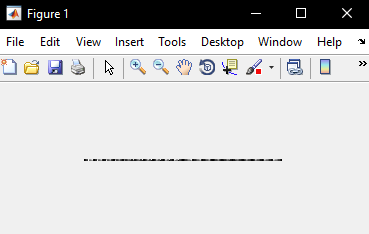
index2=i\*interpVal;

linPlan(index1:index2,:)=ptPlan(:,:);

end

end

**Visualization 1 (in grayscale image: darker means less error**



[linPlan,SizeZ]=linearRobotTest(L,M,interpVal,numVxl,terminal1,terminal2);

surfPlan=vertcat(surfPlan,linPlan);

end

SizeZ=SizeZ;

%Linear test along the x-direction

for i=y1:y2

terminal1=transl(x1,i,z);

terminal2=transl(x2,i,z);

linPlan=linearRobotTest(L,M,interpVal,numVxl,terminal1,terminal2);

surfPlan=vertcat(surfPlan,linPlan);

end

end

%Trajectory Planning for a line

function [linPlan,SizeZ] = linearRobotTest(L,M,interpVal,numVxl,terminal1,terminal2)

linVoxel=trinterp(terminal1,terminal2,numVxl-1);

[~,~,SizeZ]=size(linVoxel);

linPlan=zeros((SizeZ-1)\*interpVal,numel(L));

for i=1:SizeZ-1

ptPlan=M.jtraj(linVoxel(:,:,i),linVoxel(:,:,i+1),interpVal);

index1=1+(i-1)\*interpVal;

index2=i\*interpVal;

linPlan(index1:index2,:)=ptPlan(:,:);

end

end

**Workspace:**

**Trajectory planning of motion in 2D plane:**

Joint angles=

0.0162 0.1810 0.2488 0.9734 -1.4406 -1.3771 -2.3510

0.0151 0.1193 0.2329 1.1004 -1.4715 -1.3783 -2.5425

0.0140 0.0576 0.2170 1.2274 -1.5024 -1.3795 -2.7341

0.0140 0.0576 0.2170 1.2274 -1.5024 -1.3795 -2.7341

-0.8730 -0.3857 -0.1243 1.0747 -0.4216 -0.5829 -1.6583

-1.7600 -0.8289 -0.4655 0.9220 0.6592 0.2136 -0.5824

-1.7600 -0.8289 -0.4655 0.9220 0.6592 0.2136 -0.5824

-1.5690 -0.7554 -0.3825 1.0414 0.7982 0.3721 -0.5414

-1.3780 -0.6819 -0.2995 1.1608 0.9373 0.5306 -0.5004

0.4527 0.2919 0.7479 1.0388 -1.5221 -1.2385 -2.3574

0.2586 0.2036 0.5083 1.1650 -1.5215 -1.3053 -2.5500

0.0644 0.1153 0.2686 1.2911 -1.5208 -1.3722 -2.7427

0.0644 0.1153 0.2686 1.2911 -1.5208 -1.3722 -2.7427

-0.7971 -0.3293 -0.0995 1.1401 -0.3322 -0.5225 -1.5766

-1.6586 -0.7738 -0.4676 0.9891 0.8565 0.3272 -0.4106

-1.6586 -0.7738 -0.4676 0.9891 0.8565 0.3272 -0.4106

-1.4532 -0.6990 -0.3862 1.1008 0.9612 0.4916 -0.4053

-1.2477 -0.6242 -0.3049 1.2124 1.0660 0.6560 -0.3999

0.4542 0.3534 0.7597 1.1161 -1.5662 -1.2084 -2.3914

0.3225 0.2663 0.5868 1.2378 -1.5614 -1.2756 -2.5739

0.1908 0.1793 0.4138 1.3595 -1.5565 -1.3427 -2.7565

0.1908 0.1793 0.4138 1.3595 -1.5565 -1.3427 -2.7565

-0.6575 -0.2573 -0.0272 1.2092 -0.2566 -0.4280 -1.5091

-1.5059 -0.6939 -0.4683 1.0589 1.0432 0.4868 -0.2617

-1.5059 -0.6939 -0.4683 1.0589 1.0432 0.4868 -0.2617

-1.3186 -0.6289 -0.3911 1.1592 1.1025 0.6300 -0.2949

-1.1313 -0.5639 -0.3138 1.2595 1.1617 0.7732 -0.3281

0.4861 0.4276 0.8172 1.1990 -1.6275 -1.1592 -2.4351

0.4907 0.3612 0.8139 1.3181 -1.6490 -1.1918 -2.6115

0.4954 0.2948 0.8105 1.4372 -1.6706 -1.2243 -2.7878

0.4954 0.2948 0.8105 1.4372 -1.6706 -1.2243 -2.7878

-0.4012 -0.1489 0.1795 1.2805 -0.2318 -0.2698 -1.4689

-1.2979 -0.5926 -0.4515 1.1237 1.2070 0.6847 -0.1500

-1.2979 -0.5926 -0.4515 1.1237 1.2070 0.6847 -0.1500

-1.1444 -0.5443 -0.3783 1.2149 1.2304 0.7917 -0.2097

-0.9910 -0.4961 -0.3051 1.3062 1.2539 0.8987 -0.2693

0.5513 0.5310 0.9398 1.2927 -1.7302 -1.0725 -2.5025

0.5398 0.4582 0.9203 1.4084 -1.7442 -1.1184 -2.6691

0.5282 0.3854 0.9008 1.5240 -1.7582 -1.1643 -2.8358

0.5282 0.3854 0.9008 1.5240 -1.7582 -1.1643 -2.8358

-0.2288 -0.0442 0.2680 1.3530 -0.1972 -0.1204 -1.4537

-0.9857 -0.4737 -0.3648 1.1821 1.3638 0.9234 -0.0716

-0.9857 -0.4737 -0.3648 1.1821 1.3638 0.9234 -0.0716

-0.8620 -0.4447 -0.2939 1.2682 1.3685 0.9939 -0.1442

-0.7383 -0.4156 -0.2231 1.3544 1.3733 1.0644 -0.2168

0.6224 0.6798 1.1242 1.4124 -1.9206 -0.9421 -2.6373

0.5706 0.5720 1.0332 1.5152 -1.8818 -1.0337 -2.7659

0.5188 0.4641 0.9423 1.6180 -1.8429 -1.1254 -2.8945

0.5188 0.4641 0.9423 1.6180 -1.8429 -1.1254 -2.8945

-0.1203 0.0389 0.3288 1.4238 -0.1974 -0.0229 -1.4647

-0.7594 -0.3864 -0.2847 1.2295 1.4482 1.0797 -0.0349

-0.7594 -0.3864 -0.2847 1.2295 1.4482 1.0797 -0.0349

-0.6771 -0.3690 -0.2311 1.3135 1.4406 1.1198 -0.1118

-0.5949 -0.3516 -0.1775 1.3975 1.4329 1.1600 -0.1888

0.6406 0.8293 1.3004 1.5613 -2.1950 -0.8380 -2.8644

0.5574 0.6755 1.1140 1.6380 -2.0490 -0.9783 -2.9071

0.4742 0.5218 0.9276 1.7148 -1.9029 -1.1186 -2.9498

0.4742 0.5218 0.9276 1.7148 -1.9029 -1.1186 -2.9498

-0.0287 0.1055 0.3773 1.4951 -0.1945 0.0430 -1.4808

-0.5317 -0.3108 -0.1730 1.2754 1.5139 1.2046 -0.0118

-0.5317 -0.3108 -0.1730 1.2754 1.5139 1.2046 -0.0118

-0.4886 -0.3006 -0.1421 1.3583 1.4988 1.2230 -0.0900

-0.4455 -0.2903 -0.1112 1.4413 1.4838 1.2414 -0.1681

0.6000 0.8783 1.3207 1.6735 -2.3105 -0.8471 -2.9753

0.5155 0.7286 1.1196 1.7459 -2.1384 -0.9822 -2.9932

0.4311 0.5789 0.9184 1.8182 -1.9664 -1.1173 -3.0111

0.4311 0.5789 0.9184 1.8182 -1.9664 -1.1173 -3.0111

0.0546 0.1661 0.4360 1.5699 -0.2031 0.0883 -1.5041

-0.3218 -0.2467 -0.0464 1.3216 1.5603 1.2939 0.0029

-0.3218 -0.2467 -0.0464 1.3216 1.5603 1.2939 0.0029

-0.3103 -0.2395 -0.0379 1.4040 1.5418 1.2993 -0.0752

-0.2989 -0.2323 -0.0295 1.4865 1.5233 1.3046 -0.1533

0.4651 0.7652 0.9997 1.7126 -2.0465 -1.0153 -2.8197

0.4429 0.7148 0.9998 1.8263 -2.0745 -1.0522 -2.9657

0.4207 0.6643 0.9998 1.9401 -2.1025 -1.0891 -3.1116

0.4207 0.6643 0.9998 1.9401 -2.1025 -1.0891 -3.1116

0.1489 0.2373 0.5475 1.6547 -0.2555 0.1328 -1.5494

-0.1230 -0.1898 0.0951 1.3693 1.5915 1.3547 0.0129

-0.1230 -0.1898 0.0951 1.3693 1.5915 1.3547 0.0129

-0.1390 -0.1834 0.0812 1.4514 1.5714 1.3524 -0.0650

-0.1550 -0.1769 0.0672 1.5336 1.5513 1.3502 -0.1428

0.7200 1.6227 1.9723 1.0912 -0.8762 0.4372 -1.0640

0.5638 1.1937 1.5537 1.5851 -1.5915 -0.3119 0.9839

0.4077 0.7648 1.1350 2.0789 -2.3069 -1.0610 3.0317

0.4077 0.7648 1.1350 2.0789 -2.3069 -1.0610 3.0317

0.2363 0.3143 0.6918 1.7490 -0.3496 0.1646 1.5258

0.0650 -0.1362 0.2486 1.4192 1.6078 1.3901 0.0198

0.0650 -0.1362 0.2486 1.4192 1.6078 1.3901 0.0198

0.0239 -0.1295 0.2122 1.5011 1.5870 1.3841 -0.0579

-0.0172 -0.1227 0.1758 1.5830 1.5663 1.3780 -0.1356

0.7838 1.4140 1.9059 1.0881 -0.4173 0.3233 -0.7443

0.5748 1.1314 1.5749 1.6544 -1.4593 -0.3727 1.0788

0.3657 0.8488 1.2440 2.2207 -2.5013 -1.0686 2.9019

0.3657 0.8488 1.2440 2.2207 -2.5013 -1.0686 2.9019

0.3045 0.3835 0.8290 1.8461 -0.4468 0.1668 1.4633

0.2433 -0.0818 0.4140 1.4716 1.6078 1.4022 0.0246

0.2433 -0.0818 0.4140 1.4716 1.6078 1.4022 0.0246

0.1747 -0.0746 0.3512 1.5534 1.5870 1.3952 -0.0533

0.1061 -0.0673 0.2883 1.6352 1.5662 1.3883 -0.1311

0.0162 0.1810 0.2488 0.9734 -1.4406 -1.3771 -2.3510

0.2603 0.3193 0.5494 1.1010 -1.5479 -1.2563 -2.4023

0.5044 0.4577 0.8500 1.2286 -1.6552 -1.1355 -2.4536

0.5044 0.4577 0.8500 1.2286 -1.6552 -1.1355 -2.4536

0.5620 0.6688 1.0984 1.4370 -1.9854 -0.9818 -2.7135

0.6195 0.8799 1.3467 1.6454 -2.3155 -0.8281 -2.9735

0.6195 0.8799 1.3467 1.6454 -2.3155 -0.8281 -2.9735

0.7017 1.1470 1.6263 1.3668 -1.3664 -0.2524 -1.8589

0.7838 1.4140 1.9059 1.0881 -0.4173 0.3233 -0.7443

0.4210 0.1652 0.6845 1.0414 -1.4923 -1.3052 -2.4598

0.5390 0.3350 0.8839 1.1740 -1.6298 -1.1700 -2.5271

0.6570 0.5048 1.0833 1.3066 -1.7673 -1.0347 -2.5944

0.6570 0.5048 1.0833 1.3066 -1.7673 -1.0347 -2.5944

0.5433 0.5529 0.9658 1.4577 -1.8121 -1.0718 -2.6718

0.4296 0.6010 0.8483 1.6088 -1.8569 -1.1090 -2.7492

0.4296 0.6010 0.8483 1.6088 -1.8569 -1.1090 -2.7492

0.4339 0.7791 1.1019 1.8379 -2.2231 -1.0385 0.1228

0.4382 0.9573 1.3555 2.0669 -2.5894 -0.9681 2.9949

0.0813 0.0984 0.2986 1.1207 -1.4821 -1.3715 -2.5854

0.3703 0.2765 0.6896 1.2484 -1.6294 -1.2197 -2.6413

0.6593 0.4546 1.0806 1.3760 -1.7766 -1.0679 -2.6972

0.6593 0.4546 1.0806 1.3760 -1.7766 -1.0679 -2.6972

0.6128 0.5813 1.1338 1.5502 -1.9568 -1.0167 -2.8433

0.5663 0.7081 1.1869 1.7243 -2.1370 -0.9655 -2.9895

0.5663 0.7081 1.1869 1.7243 -2.1370 -0.9655 -2.9895

0.4169 0.7208 0.9743 1.8888 -2.0775 -1.0723 -3.0197

0.2674 0.7335 0.7617 2.0532 -2.0179 -1.1791 -3.0500

0.0548 0.0668 0.2621 1.2001 -1.4982 -1.3763 -2.6974

0.2985 0.2070 0.5762 1.3203 -1.6035 -1.2785 -2.7346

0.5422 0.3472 0.8904 1.4405 -1.7088 -1.1806 -2.7717

0.5422 0.3472 0.8904 1.4405 -1.7088 -1.1806 -2.7717

0.5184 0.4757 0.9559 1.6047 -1.8592 -1.1238 -2.8828

0.4947 0.6042 1.0215 1.7689 -2.0096 -1.0669 -2.9940

0.4947 0.6042 1.0215 1.7689 -2.0096 -1.0669 -2.9940

0.4389 0.7394 1.1599 1.9844 -2.2812 -1.0562 -0.0490

0.3831 0.8746 1.2984 2.1998 -2.5529 -1.0456 2.8959

0.1024 0.0437 0.3048 1.2828 -1.5169 -1.3754 -2.8053

0.3458 0.1922 0.6336 1.4032 -1.6353 -1.2721 -2.8442

0.5892 0.3406 0.9625 1.5235 -1.7536 -1.1688 -2.8831

0.5892 0.3406 0.9625 1.5235 -1.7536 -1.1688 -2.8831

0.5091 0.4411 0.9345 1.6798 -1.8527 -1.1516 -2.9670

0.4290 0.5417 0.9065 1.8360 -1.9519 -1.1344 -3.0508

0.4290 0.5417 0.9065 1.8360 -1.9519 -1.1344 -3.0508

0.3331 0.6285 0.8521 2.0335 -2.0264 -1.1700 -0.0088

0.2373 0.7154 0.7976 2.2310 -2.1010 -1.2057 3.0332

0.0015 0.0259 0.1959 1.3697 -1.5315 -1.3803 -2.9109

0.0615 0.1245 0.2678 1.4833 -1.5678 -1.3654 -2.9319

0.1215 0.2231 0.3396 1.5970 -1.6042 -1.3506 -2.9529

0.1215 0.2231 0.3396 1.5970 -1.6042 -1.3506 -2.9529

0.2514 0.3659 0.5913 1.7579 -1.7722 -1.2622 -3.0436

0.3813 0.5087 0.8431 1.9187 -1.9402 -1.1739 -3.1342

0.3813 0.5087 0.8431 1.9187 -1.9402 -1.1739 -3.1342

0.3012 0.6152 0.8468 2.1304 -2.0619 -1.1952 -0.1097

0.2211 0.7216 0.8506 2.3421 -2.1835 -1.2165 2.9148

-1.6988 -0.8134 -0.4272 0.9107 0.8152 0.2303 -0.4587

-1.2928 -0.6547 -0.3546 1.0193 1.1133 0.5846 -0.2517

-0.8868 -0.4960 -0.2821 1.1279 1.4114 0.9389 -0.0447

-0.8868 -0.4960 -0.2821 1.1279 1.4114 0.9389 -0.0447

-0.5746 -0.3805 -0.1389 1.2020 1.4957 1.1217 -0.0070

-0.2624 -0.2651 0.0043 1.2760 1.5800 1.3044 0.0308

-0.2624 -0.2651 0.0043 1.2760 1.5800 1.3044 0.0308

0.1889 -0.1851 0.3863 1.3588 1.6152 1.3770 0.0423

0.6401 -0.1052 0.7683 1.4415 1.6504 1.4495 0.0538

-1.5965 -0.7730 -0.3816 0.9769 0.8778 0.3209 -0.4475

-1.3656 -0.6541 -0.3901 1.0702 1.0804 0.5634 -0.2868

-1.1348 -0.5352 -0.3986 1.1634 1.2831 0.8060 -0.1262

-1.1348 -0.5352 -0.3986 1.1634 1.2831 0.8060 -0.1262

-0.7670 -0.4012 -0.2475 1.2424 1.4116 1.0355 -0.0717

-0.3992 -0.2671 -0.0965 1.3214 1.5401 1.2651 -0.0173

-0.3992 -0.2671 -0.0965 1.3214 1.5401 1.2651 -0.0173

-0.0813 -0.1745 0.1554 1.4040 1.5724 1.3334 -0.0042

0.2366 -0.0820 0.4073 1.4867 1.6047 1.4016 0.0090

-1.3704 -0.7086 -0.2911 1.0618 1.0398 0.4879 -0.3811

-1.1702 -0.6032 -0.3034 1.1401 1.1817 0.6963 -0.2689

-0.9700 -0.4977 -0.3156 1.2184 1.3235 0.9047 -0.1568

-0.9700 -0.4977 -0.3156 1.2184 1.3235 0.9047 -0.1568

-0.6769 -0.3811 -0.2000 1.2937 1.4266 1.0876 -0.1107

-0.3837 -0.2644 -0.0844 1.3690 1.5296 1.2706 -0.0646

-0.3837 -0.2644 -0.0844 1.3690 1.5296 1.2706 -0.0646

-0.1161 -0.1714 0.1223 1.4513 1.5595 1.3320 -0.0511

0.1515 -0.0784 0.3290 1.5336 1.5895 1.3935 -0.0376

-1.3528 -0.6921 -0.2865 1.1129 1.0042 0.5209 -0.4327

-1.1579 -0.5898 -0.2981 1.1907 1.1516 0.7192 -0.3196

-0.9630 -0.4875 -0.3098 1.2685 1.2989 0.9176 -0.2065

-0.9630 -0.4875 -0.3098 1.2685 1.2989 0.9176 -0.2065

-0.6728 -0.3735 -0.1966 1.3437 1.4077 1.0952 -0.1590

-0.3826 -0.2594 -0.0835 1.4189 1.5164 1.2729 -0.1116

-0.3826 -0.2594 -0.0835 1.4189 1.5164 1.2729 -0.1116

-0.1371 -0.1666 0.1031 1.5010 1.5465 1.3310 -0.0979

0.1084 -0.0738 0.2896 1.5830 1.5767 1.3892 -0.0843

-1.3780 -0.6819 -0.2995 1.1608 0.9373 0.5306 -0.5004

-1.1588 -0.5772 -0.2984 1.2411 1.1102 0.7357 -0.3766

-0.9397 -0.4726 -0.2973 1.3215 1.2832 0.9407 -0.2528

-0.9397 -0.4726 -0.2973 1.3215 1.2832 0.9407 -0.2528

-0.6424 -0.3619 -0.1770 1.3964 1.3975 1.1134 -0.2052

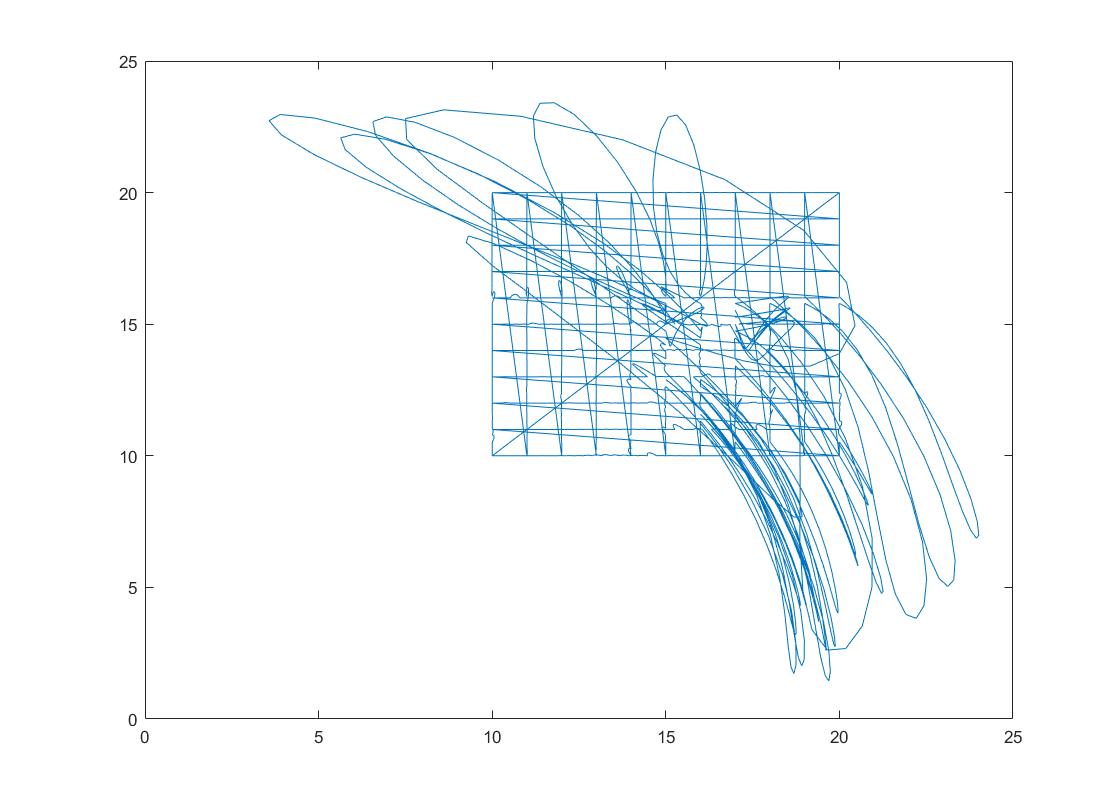
-0.3452 -0.2512 -0.0568 1.4712 1.5119 1.2861 -0.1577

-0.3452 -0.2512 -0.0568 1.4712 1.5119 1.2861 -0.1577

-0.1195 -0.1593 0.1158 1.5532 1.5390 1.3372 -0.1444

0.1061 -0.0673 0.2883 1.6352 1.5662 1.3883 -0.1311

**Visualization 2: Trajectory of the manipulator**



Tentative data generation: Gray scale images corresponding to the accuracy map of a manipulator in motion between nodes of cuboid partitions in Cartesian 3D space

Date: 9/30/17

Alexander Liao

Brainstorming

**Function 1:**

%Trajectory Planning for a line

function [linPlan,SizeZ] = linearRobotTest(L,M,interpVal,numVxl,terminal1,terminal2)

linVoxel=trinterp(terminal1,terminal2,numVxl);

[~,~,SizeZ]=size(linVoxel);

linPlan=zeros((SizeZ-1)\*interpVal,numel(L));

for i=1:SizeZ-1

intm=ctraj(linVoxel(:,:,i),linVoxel(:,:,i+1),interpVal);

ptPlan=M.ikine6s(intm);

index1=1+(i-1)\*interpVal;

index2=i\*interpVal;

linPlan(index1:index2,:)=ptPlan(:,:);

end

end

**Function 2:**

%Trajectory Planning for a surface

function [surfPlan,SizeZ]= surfaceRobotTest(L,M,interpVal,numVxl,x1,x2,y1,y2,z)

surfPlan=[];

for i=x1:abs((x2-x1)/(numVxl)):x2

terminal1=transl(i,y1,z);

terminal2=transl(i,y2,z);

[linPlan,SizeZ]=linearRobotTest(L,M,interpVal,numVxl,terminal1,terminal2);

surfPlan=vertcat(surfPlan,linPlan);

end

end

**Main file:**

%Initialization

clear all

numData=1;

%Target Space

spc\_x1=0.2;

xmin=spc\_x1;

spc\_x2=0.6;

xmax=spc\_x2;

spc\_y1=-0.2;

ymin=spc\_y1;

spc\_y2=0.2;

ymax=spc\_y2;

spc\_z1=-0.4;

zmin=spc\_z1;

spc\_z2=0;

zmax=spc\_z2;

%Specifications for Voxels

vxl\_interpVal=10;

vxl\_num=5;

vxl\_zLayerHeight=0.025;

%Final Result

performanceVector=[];

performanceMatrix=[];

inputMatrix=[];

x1=[xmin xmin xmax xmax];

y1=[ymin ymax ymax ymin];

z1=[zmin zmin zmin zmin];

x2=[xmin xmin xmax xmax];

y2=[ymin ymax ymax ymin];

z2=[zmax zmax zmax zmax];

x3=[xmin xmin xmin xmin];

y3=[ymin ymax ymax ymin];

z3=[zmax zmax zmin zmin];

x4=[xmax xmax xmax xmax];

y4=[ymin ymax ymax ymin];

z4=[zmax zmax zmin zmin];

x5=[xmin xmax xmax xmin];

y5=[ymin ymin ymin ymin];

z5=[zmax zmax zmin zmin];

x6=[xmin xmax xmax xmin];

y6=[ymax ymax ymax ymax];

z6=[zmax zmax zmin zmin];

for num=1:numData

rawdata=[];

performanceVector=[];

%{

%SerialLink Parameters

link\_theta=[0 0 0 0 0 0];

link\_D=[ 0 0 rand() rand() 0 0];

link\_A=[0 rand() 0 0 0 0];

link\_Alpha=[pi/2 0 -pi/2 pi/2 -pi/2 0];

linkType=[0 0 0 0 0 0];

%Creating the SerialLink object

linkL(1)= Link([link\_theta(1) link\_D(1) link\_A(1) link\_Alpha(1) linkType(1)]);

linkL(2)= Link([link\_theta(2) link\_D(2) link\_A(2) link\_Alpha(2) linkType(2)]);

linkL(3)= Link([link\_theta(3) link\_D(3) link\_A(3) link\_Alpha(3) linkType(3)]);

linkL(4)= Link([link\_theta(4) link\_D(4) link\_A(4) link\_Alpha(4) linkType(4)]);

linkL(5)= Link([link\_theta(5) link\_D(5) link\_A(5) link\_Alpha(5) linkType(5)]);

linkL(6)= Link([link\_theta(6) link\_D(6) link\_A(6) link\_Alpha(6) linkType(6)]);

link\_M=SerialLink([linkL(1) linkL(2) linkL(3) linkL(4) linkL(5) linkL(6)]);

link\_M.plot(link\_theta);

%Generating grayscale image

%}

link\_D=[ 0 0 rand() rand() 0 0];

link\_A=[ 0 rand() 0 0 0 0];

link\_alpha=[ pi/2 0 -pi/2 pi/2 -pi/2 0];

l1=Link([0 link\_D(1) link\_A(1) link\_alpha(1)]);

l2=Link([0 link\_D(2) link\_A(2) link\_alpha(2)]);

l3=Link([0 link\_D(3) link\_A(3) link\_alpha(3)]);

l4=Link([0 link\_D(4) link\_A(4) link\_alpha(4)]);

l5=Link([0 link\_D(5) link\_A(5) link\_alpha(5)]);

l6=Link([0 link\_D(6) link\_A(6) link\_alpha(6)]);

linkL=[l1,l2,l3,l4,l5,l6];

mdl\_puma560;

link\_M=SerialLink(p560);

%{

link\_M.plot([0 0 0 0 0 0]);

hold on

patch(x1,y1,z1,'blue','facealpha',.25)

hold on

patch(x2,y2,z2,'blue','facealpha',.25)

hold on

patch(x3,y3,z3,'red','facealpha',.25)

hold on

patch(x4,y4,z4,'red','facealpha',.25)

hold on

patch(x5,y5,z5,'yellow','facealpha',.25)

hold on

patch(x6,y6,z6,'yellow','facealpha',.25)

hold on

%}

for z=spc\_z1:vxl\_zLayerHeight:spc\_z2

if z==spc\_z2

disp('\*');

else

%Invoking the surface function for at the height "z"

logic=0;

while logic==0

try

[surfPlan,SizeZ] = surfaceRobotTest(linkL,link\_M,vxl\_interpVal,vxl\_num,spc\_x1,spc\_x2,spc\_y1,spc\_y2,z);

logic=1;

catch

warning('jtraj function error. Generating a new random arm.')

link\_D=[ 0 0 rand() rand() 0 0];

link\_A=[ 0 rand() 0 0 0 0];

link\_alpha=[ pi/2 0 -pi/2 pi/2 -pi/2 0];

l1=Link([0 link\_D(1) link\_A(1) link\_alpha(1)]);

l2=Link([0 link\_D(2) link\_A(2) link\_alpha(2)]);

l3=Link([0 link\_D(3) link\_A(3) link\_alpha(3)]);

l4=Link([0 link\_D(4) link\_A(4) link\_alpha(4)]);

l5=Link([0 link\_D(5) link\_A(5) link\_alpha(5)]);

l6=Link([0 link\_D(6) link\_A(6) link\_alpha(6)]);

linkL=[l1,l2,l3,l4,l5,l6];

link\_M=SerialLink([l1,l2,l3,l4,l5,l6]);

logic=0;

end

end

[SizeX,SizeY]=size(surfPlan);

columnImage=surfPlan;

performanceVector=vertcat(performanceVector,columnImage);

end

end

inputVector=vertcat(link\_D',link\_A');

inputMatrix=horzcat(inputMatrix,inputVector);

performanceMatrix=horzcat(performanceMatrix,performanceVector);

end

for num=1:numData

rawdata=[];

performanceVector=[];

%{

%SerialLink Parameters

link\_theta=[0 0 0 0 0 0];

link\_D=[ 0 0 rand() rand() 0 0];

link\_A=[0 rand() 0 0 0 0];

link\_Alpha=[pi/2 0 -pi/2 pi/2 -pi/2 0];

linkType=[0 0 0 0 0 0];

%Creating the SerialLink object

linkL(1)= Link([link\_theta(1) link\_D(1) link\_A(1) link\_Alpha(1) linkType(1)]);

linkL(2)= Link([link\_theta(2) link\_D(2) link\_A(2) link\_Alpha(2) linkType(2)]);

linkL(3)= Link([link\_theta(3) link\_D(3) link\_A(3) link\_Alpha(3) linkType(3)]);

linkL(4)= Link([link\_theta(4) link\_D(4) link\_A(4) link\_Alpha(4) linkType(4)]);

linkL(5)= Link([link\_theta(5) link\_D(5) link\_A(5) link\_Alpha(5) linkType(5)]);

linkL(6)= Link([link\_theta(6) link\_D(6) link\_A(6) link\_Alpha(6) linkType(6)]);

link\_M=SerialLink([linkL(1) linkL(2) linkL(3) linkL(4) linkL(5) linkL(6)]);

link\_M.plot(link\_theta);

%Generating grayscale image

%}

link\_D=[ 0 0 rand() rand() 0 0];

link\_A=[ 0 rand() 0 0 0 0];

link\_alpha=[ pi/2 0 -pi/2 pi/2 -pi/2 0];

l1=Link([0 link\_D(1) link\_A(1) link\_alpha(1)]);

l2=Link([0 link\_D(2) link\_A(2) link\_alpha(2)]);

l3=Link([0 link\_D(3) link\_A(3) link\_alpha(3)]);

l4=Link([0 link\_D(4) link\_A(4) link\_alpha(4)]);

l5=Link([0 link\_D(5) link\_A(5) link\_alpha(5)]);

l6=Link([0 link\_D(6) link\_A(6) link\_alpha(6)]);

linkL=[l1,l2,l3,l4,l5,l6];

mdl\_puma560;

link\_M=SerialLink(p560);

%{

link\_M.plot([0 0 0 0 0 0]);

hold on

patch(x1,y1,z1,'blue','facealpha',.25)

hold on

patch(x2,y2,z2,'blue','facealpha',.25)

hold on

patch(x3,y3,z3,'red','facealpha',.25)

hold on

patch(x4,y4,z4,'red','facealpha',.25)

hold on

patch(x5,y5,z5,'yellow','facealpha',.25)

hold on

patch(x6,y6,z6,'yellow','facealpha',.25)

hold on

%}

for z=spc\_z1:vxl\_zLayerHeight:spc\_z2

if z==spc\_z2

disp('\*');

else

%Invoking the surface function for at the height "z"

logic=0;

while logic==0

try

[surfPlan,SizeZ] = surfaceRobotTest(linkL,link\_M,vxl\_interpVal,vxl\_num,spc\_x1,spc\_x2,spc\_y1,spc\_y2,z);

logic=1;

catch

warning('jtraj function error. Generating a new random arm.')

link\_D=[ 0 0 rand() rand() 0 0];

link\_A=[ 0 rand() 0 0 0 0];

link\_alpha=[ pi/2 0 -pi/2 pi/2 -pi/2 0];

l1=Link([0 link\_D(1) link\_A(1) link\_alpha(1)]);

l2=Link([0 link\_D(2) link\_A(2) link\_alpha(2)]);

l3=Link([0 link\_D(3) link\_A(3) link\_alpha(3)]);

l4=Link([0 link\_D(4) link\_A(4) link\_alpha(4)]);

l5=Link([0 link\_D(5) link\_A(5) link\_alpha(5)]);

l6=Link([0 link\_D(6) link\_A(6) link\_alpha(6)]);

linkL=[l1,l2,l3,l4,l5,l6];

link\_M=SerialLink([l1,l2,l3,l4,l5,l6]);

logic=0;

end

end

[SizeX,SizeY]=size(surfPlan);

columnImage=surfPlan;

performanceVector=vertcat(performanceVector,columnImage);

end

end

inputVector=vertcat(link\_D',link\_A');

inputMatrix=horzcat(inputMatrix,inputVector);

performanceMatrix=horzcat(performanceMatrix,performanceVector);

end

patch(x2,y2,z2,'blue','facealpha',.25)

hold on

patch(x3,y3,z3,'red','facealpha',.25)

hold on

patch(x4,y4,z4,'red','facealpha',.25)

hold on

patch(x5,y5,z5,'yellow','facealpha',.25)

hold on

patch(x6,y6,z6,'yellow','facealpha',.25)

hold on

%}

for z=spc\_z1:vxl\_zLayerHeight:spc\_z2

if z==spc\_z2

disp('\*');

else

%Invoking the surface function for at the height "z"

logic=0;

while logic==0

try

[surfPlan,SizeZ] = surfaceRobotTest(linkL,link\_M,vxl\_interpVal,vxl\_num,spc\_x1,spc\_x2,spc\_y1,spc\_y2,z);

logic=1;

catch

warning('jtraj function error. Generating a new random arm.')

link\_D=[ 0 0 rand() rand() 0 0];

link\_A=[ 0 rand() 0 0 0 0];

link\_alpha=[ pi/2 0 -pi/2 pi/2 -pi/2 0];

l1=Link([0 link\_D(1) link\_A(1) link\_alpha(1)]);

l2=Link([0 link\_D(2) link\_A(2) link\_alpha(2)]);

l3=Link([0 link\_D(3) link\_A(3) link\_alpha(3)]);

l4=Link([0 link\_D(4) link\_A(4) link\_alpha(4)]);

l5=Link([0 link\_D(5) link\_A(5) link\_alpha(5)]);

l6=Link([0 link\_D(6) link\_A(6) link\_alpha(6)]);

linkL=[l1,l2,l3,l4,l5,l6];

link\_M=SerialLink([l1,l2,l3,l4,l5,l6]);

logic=0;

end

end

[SizeX,SizeY]=size(surfPlan);

columnImage=surfPlan;

performanceVector=vertcat(performanceVector,columnImage);

end

end

inputVector=vertcat(link\_D',link\_A');

inputMatrix=horzcat(inputMatrix,inputVector);

performanceMatrix=horzcat(performanceMatrix,performanceVector);

end

columnImage=surfPlan;

performanceVector=vertcat(performanceVector,columnImage);

end

end

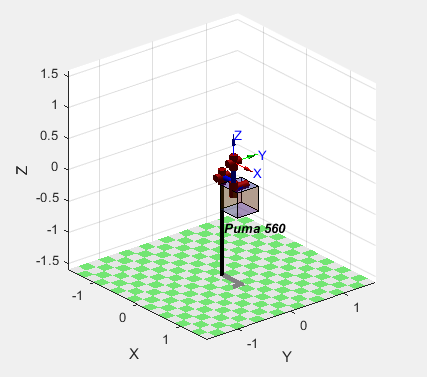
inputVector=vertcat(link\_D',link\_A');

inputMatrix=horzcat(inputMatrix,inputVector);

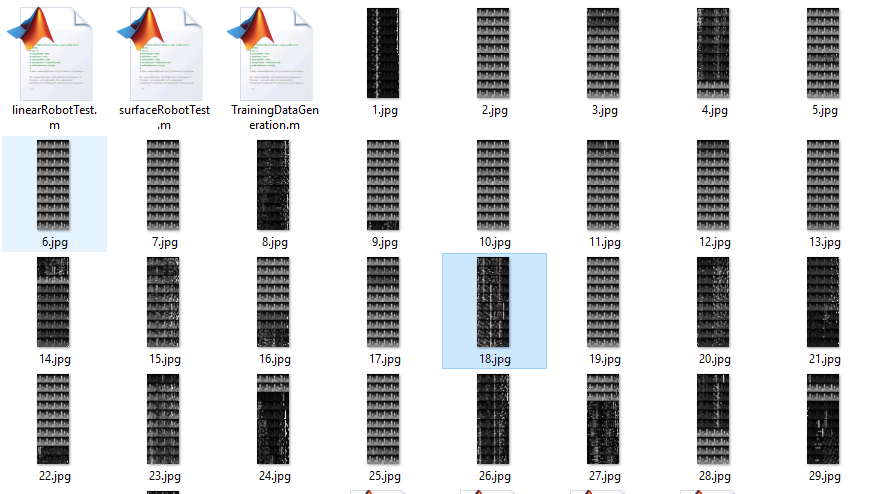
performanceMatrix=horzcat(performanceMatrix,performanceVector);

end

**Visualization 1: the transparent box denotes the boundary of the partitions**



**Sample data generation:**



***Goal: train a neural network that can predict the kinematic structure of a 7-DOF manipulator from the accuracy map***

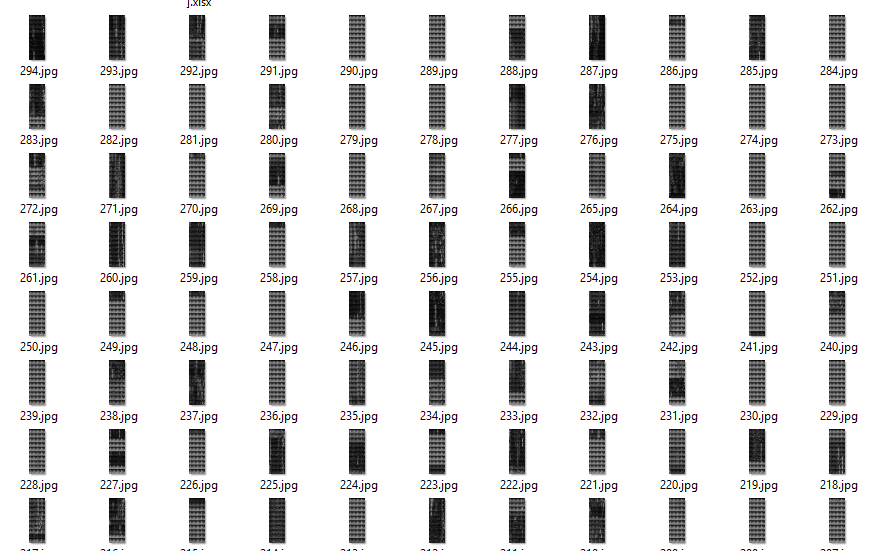
Date: 10/2/17

Alexander Liao

Idea 1

Intention: An input of artificially generated map of high accuracy will help the network to calculate the most suitable manipulator for the given task.

**Training batch of 1000 samples:**



**Rounded length of the first link (first 50 samples):**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| D3 | D27 | D13 | D16 | D23 |
| D15 | D1 | D5 | D17 | D2 |
| D19 | D10 | D28 | D0 | D14 |
| D10 | D3 | D28 | D13 | D9 |
| D7 | D13 | D30 | D28 | D6 |
| D15 | D29 | D16 | D28 | D11 |
| D9 | D11 | D24 | D6 | D23 |
| D7 | D27 | D8 | D10 | D18 |
| D3 | D12 | D27 | D1 | D2 |
| D7 | D16 | D2 | D22 | D13 |

**DH-parameters of a sample:**

2.533075365

11.99347947

7.796112086

24.00205441

12.94241482

27.31942783

5.455410849

7.914087496

4.366169412

4.082056761

26.07876623

17.39113762

16.49580606

4.348643947

1.570796327

1.570796327

1.570796327

1.570796327

1.570796327

1.570796327

1.570796327

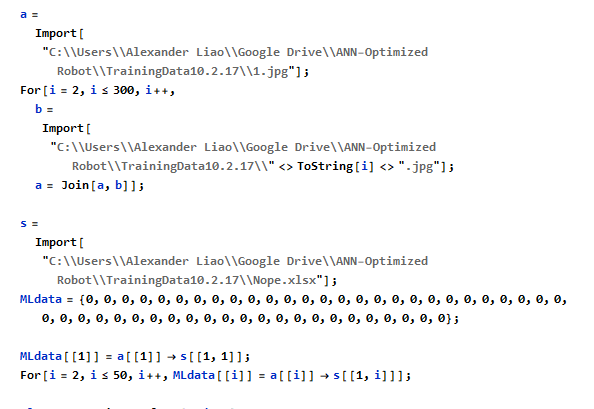
Implementation of a Convolutional Neural Network in Mathematica to predict the rounded length of the first link

Date: 10/4/17

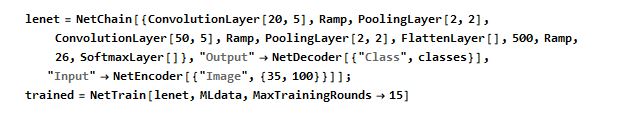
Alexander Liao

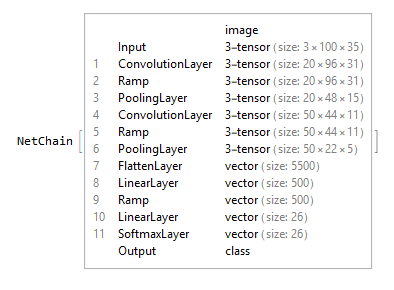
Idea 1

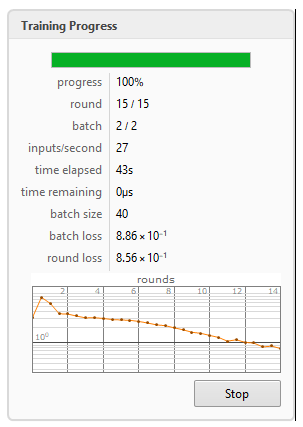
**Pre-processing of 50 samples:**



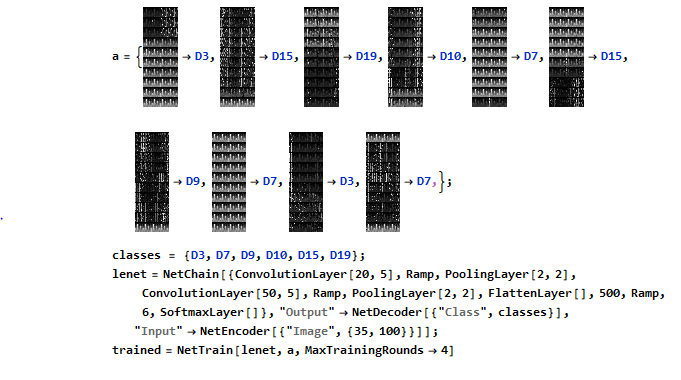
**ConvNet initialization:**



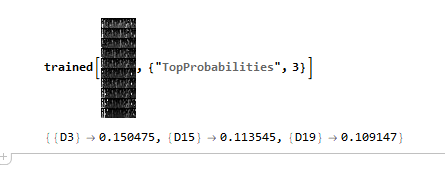


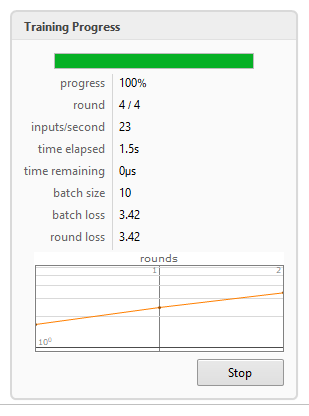


**2nd attempt:**

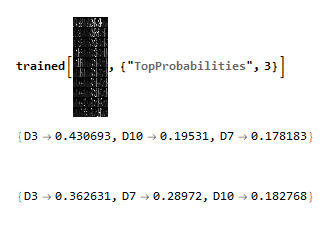


**Prediction failed:**





**Prediction failed even within the training batch (sample size too small):**



Minor modifications on the training data generation code

Date: 10/5/17

Alexander Liao

Idea 1

%Initialization

clear all

numData=1:50;

%Target Space

spc\_x1=10;

spc\_x2=20;

spc\_y1=10;

spc\_y2=20;

spc\_z1=-8;

spc\_z2=2;

%Specifications for Voxels

vxl\_interpVal=4;

vxl\_num=5;

vxl\_zLayerHeight=1;

%Final Result

Final\_dataImage=[];

Final=[];

parfor num= numData

rawdata=[];

Final\_dataImage=[];

%SerialLink Parameters

link\_theta=[0 0 0 0 0 0 0];

link\_D=30\*rand(1,7);

link\_A=30\*rand(1,7);

link\_Alpha=[pi/2,pi/2,pi/2,pi/2,pi/2,pi/2,pi/2];

linkType=[0 0 0 0 0 0 0];

linkNum=[1 2 3 4 5 6 7];

%Creating the SerialLink object

link1= Link([link\_theta(1) link\_D(1) link\_A(1) link\_Alpha(1) linkType(1)],'modified');

link2= Link([link\_theta(2) link\_D(2) link\_A(2) link\_Alpha(2) linkType(2)],'modified');

link3= Link([link\_theta(3) link\_D(3) link\_A(3) link\_Alpha(3) linkType(3)],'modified');

link4= Link([link\_theta(4) link\_D(4) link\_A(4) link\_Alpha(4) linkType(4)],'modified');

link5= Link([link\_theta(5) link\_D(5) link\_A(5) link\_Alpha(5) linkType(5)],'modified');

link6= Link([link\_theta(6) link\_D(6) link\_A(6) link\_Alpha(6) linkType(6)],'modified');

link7= Link([link\_theta(7) link\_D(7) link\_A(7) link\_Alpha(7) linkType(7)],'modified');

link\_M=SerialLink([link1 link2 link3 link4 link5 link6 link7]);

%Generating grayscale image

for z=spc\_z1:vxl\_zLayerHeight:spc\_z2

if z==spc\_z2

disp('\*');

else

%Invoking the surface function for at the height "z"

logic=0;

while logic==0

try

[surfPlan,SizeZ] = surfaceRobotTest(linkNum,link\_M,vxl\_interpVal,vxl\_num,spc\_x1,spc\_x2,spc\_y1,spc\_y2,z);

logic=1;

catch

warning('jtraj function error. Generating a new random arm.')

%SerialLink Parameters

link\_theta=[0 0 0 0 0 0 0];

link\_D=30\*rand(1,7);

link\_A=30\*rand(1,7);

link\_Alpha=[pi/2,pi/2,pi/2,pi/2,pi/2,pi/2,pi/2];

linkType=[0 0 0 0 0 0 0];

%Creating the SerialLink object

link1= Link([link\_theta(1) link\_D(1) link\_A(1) link\_Alpha(1) linkType(1)],'modified');

link2= Link([link\_theta(2) link\_D(2) link\_A(2) link\_Alpha(2) linkType(2)],'modified');

link3= Link([link\_theta(3) link\_D(3) link\_A(3) link\_Alpha(3) linkType(3)],'modified');

link4= Link([link\_theta(4) link\_D(4) link\_A(4) link\_Alpha(4) linkType(4)],'modified');

link5= Link([link\_theta(5) link\_D(5) link\_A(5) link\_Alpha(5) linkType(5)],'modified');

link6= Link([link\_theta(6) link\_D(6) link\_A(6) link\_Alpha(6) linkType(6)],'modified');

link7= Link([link\_theta(7) link\_D(7) link\_A(7) link\_Alpha(7) linkType(7)],'modified');

link\_M=SerialLink([link1 link2 link3 link4 link5 link6 link7]);

logic=0;

end

end

[SizeX,SizeY]=size(surfPlan);

intm\_endX=zeros(1,SizeX);

intm\_endY=zeros(1,SizeY);

%Calculating the trajectories from joint angle to Cartesian Coordinates

for i=1:size(surfPlan)

hmTrans=link\_M.fkine(surfPlan(i,:));

intm\_vector=hmTrans.t;

intm\_endX(i)=intm\_vector(1);

intm\_endY(i)=intm\_vector(2);

%Optional Visualization: M.plot(surfPlan(i,:))

end

[~,surfaceDataPtsSize]=size(intm\_endY);

intm\_preFitx=[];

intm\_preFity=[];

counter=1;

intm\_residVector=[];

rawImageData=[];

numDataPt=1;

intm\_normal=[];

%Normalizing the trajectories of robot to lines

while numDataPt<=surfaceDataPtsSize

if numDataPt<= (surfaceDataPtsSize/2)

intm\_comparedData=intm\_endY(numDataPt);

intm\_normal=[];

intm\_preFity=[];

for k=1:(vxl\_interpVal-2)\*vxl\_num

if numDataPt<=surfaceDataPtsSize

b=numDataPt+vxl\_interpVal;

intm\_normal=vertcat(intm\_normal,intm\_comparedData);

intm\_preFity=vertcat(intm\_preFity,intm\_endY(numDataPt));

numDataPt=numDataPt+1;

end

end

try

intm\_residVector=abs(intm\_normal-intm\_preFity);

rawImageData=horzcat(rawImageData,intm\_residVector);

end

end

if numDataPt> (surfaceDataPtsSize/2)

intm\_comparedData=intm\_endX(numDataPt);

intm\_normal=[];

intm\_preFitx=[];

for k=1:(vxl\_interpVal-2)\*vxl\_num

if numDataPt<=surfaceDataPtsSize

b=numDataPt+vxl\_interpVal;

intm\_normal=vertcat(intm\_normal,intm\_comparedData);

intm\_preFitx=vertcat(intm\_preFitx,intm\_endX(numDataPt));

numDataPt=numDataPt+1;

end

end

try

intm\_residVector=abs(intm\_normal-intm\_preFitx);

rawImageData=horzcat(rawImageData,intm\_residVector);

end

end

end

rowImage=rawImageData;

Final\_dataImage=vertcat(Final\_dataImage,rowImage);

end

end

Final=vertcat(Final,mean(Final\_dataImage));

%imageInfo=strcat(int2str(num),'.jpg');

%imwrite(Final\_dataImage,imageInfo);

rawdata=vertcat(link\_D',link\_A');

[sizeRaw,~]=size(rawdata);

filename='Data.xlsx';

startData=sizeRaw\*(num-1)+1;

endData=sizeRaw\*num;

dataOption=strcat('A',int2str(startData),':A',int2str(endData));

xlswrite(filename,rawdata,dataOption);

end

Formulation of a research topic, proposal to the pre-engineering department

A Method to Evaluate the Manipulability of a 6-DOF Manipulator and its Application in Artificial Neural Network

Date: 10/15/17

Alexander Liao

Idea 1

Alexander Liao

I. Introduction

* The determination of the length of a manipulator is often based on the torque of the motor
* Yet the manipulability of the arm is less taken care of when engineers determine the length of each link
* Over-designing is a common practice
* The purpose of this method is to shift the attention from the torque to the effect of lengths of links themselves on the dexterity of the robot.

\*refer to code in 10/5/17\*

II. Method

* Central idea:
  + divide the predetermined space in to voxels with equal volume
  + find a data point to represent the voxel
  + obtain the joint configuration of the robot in order to reach the point
  + calculate the manipulability
  + store all results in a vector
* Prevalent methods of a manipulator’s manipulability at a given joint configuration include Yoshikawa’s manipulability measure
* Levenberg–Marquardt algorithm is implemented to solve the inverse kinematics equation
* Peter Corke’s Robotics Toolbox in MATLAB provides great help on the calculation
  + Generate 6-DOF manipulator with random d/a parameters (from 1 to 10) with modified D-H convention
  + Generate matrix for voxels
  + Generate matrix for trajectory planning (joint configurations)
  + Calculate the manipulability index for each configuration
  + Store results

IV. Applications

* Since both the input and the output are vectors, they can be fed into an artificial neural network to look for an optimized result
* However, this unconventional approach might require a modified network structure

V. Possible Defects

* There are errors in the solutions of inverse kinematics function
* *I’m not sure if the manipulability of arm at a configuration obtained by approximation is still significant*

Warning: ikine: rejected-step limit 100 exceeded (pose 1), final err 0.300062

> In SerialLink/ikine (line 244)

In SerialLink>@(varargin)r.ikine(varargin{:}) (line 846)

In SerialLink/jtraj (line 851)

In linearRobotTest (line 10)

In surfaceRobotTest (line 9)

In TrainingDataGeneration (line 59)

Finished annotation of *Robotics, Vision and Control* by Peter Corke

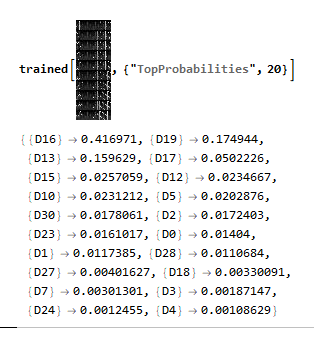
Date: 10/20/17

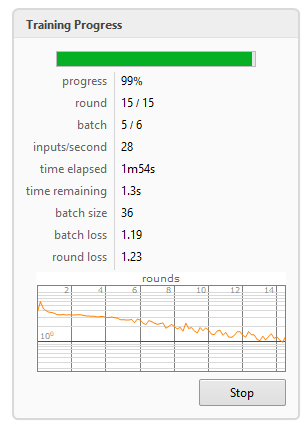
Alexander Liao

Idea 1

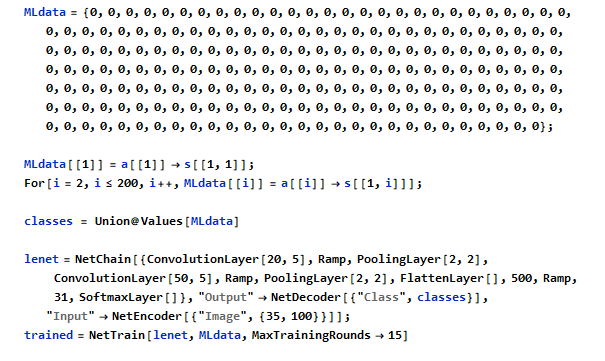
Improved version of ConvNet in Mathematica

**Successful prediction of member within the training batch**





**Initialization with 200 samples**

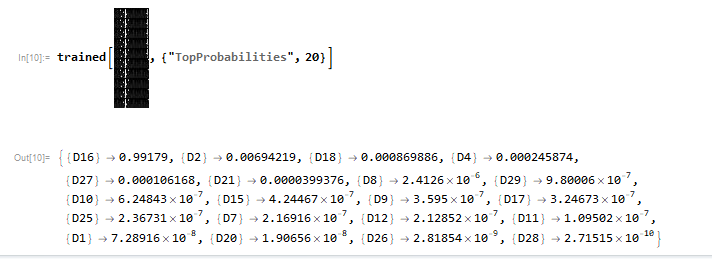


Date: 10/21/17

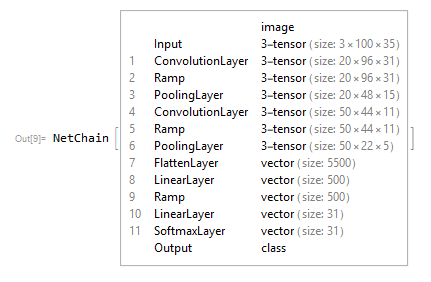
Alexander Liao

Idea 1

**Failed prediction of unseen sample:**



**ConvNet architecture**



Proposal 2nd draft:

Date: 10/22/17

Alexander Liao

Idea 1

A Method to Evaluate a Rigid-Link Manipulator and its Application in Artificial Neural Network

Alexander Liao

I. Introduction

* The determination of the length of a manipulator is often based on the torque of the motor
* Yet the manipulability of the arm is less taken care of when engineers determine the length of each link
* Over-designing is a common practice
* The purpose of this method is to shift the attention from the torque to the effect of lengths of links themselves on the performance of the robot.

II. Method

* Based on modified Denavit - Hartenberg convention, a specific vector can be created to define a specific rigid arm-type robot (assuming that all joints are revolute):

, where is the degree of freedom of the robot.

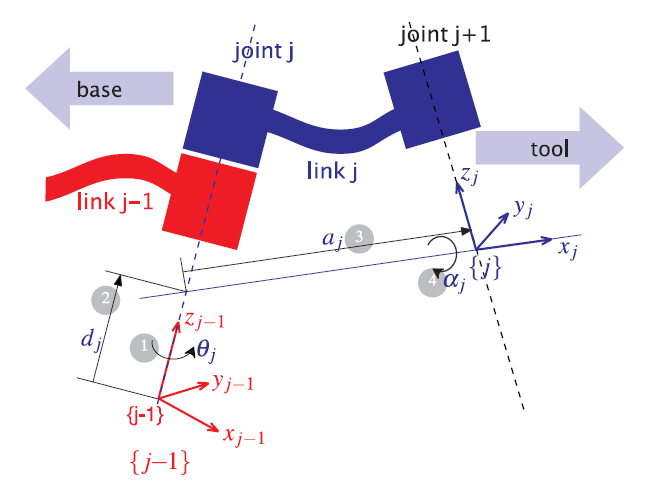
* The denotation of symbols in the vector can be found in Figure 1-1 (Corke, 2013, p. 138).

Figure -1

* The performance of robot in a given space is defined by its performance in every one of the voxels:
  + divide the predetermined space into voxels of equal volume
  + find a data point to represent the voxel
* Components of the test (For a 6 degrees-of-freedom robot):
  + Distance between the actual point of end-effector and the ideal point of the voxel based on the numerical approach of the inverse kinematics of the robot.
  + Manipulability of the robot in terms of Yoshikawa’s manipulability measure (a scalar) at different joint configurations
  + Joint speed at performing linear motions between voxels (x-direction and y-direction)
* Components of the test (For an under-actuated robot):
  + Whether the robot can reach the voxel
  + Manipulability of the robot for the voxels that are approachable.
* Evaluation primarily based on functions from Peter Corke’s Robotics Toolbox in MATLAB
  + Generate manipulator with a random (in an acceptable range) with modified D-H convention
  + Generate voxels that are stored in a matrix
  + Evaluate the performance of the robot that is then stored in a vector.
  + Output the two vectors in the form of a pair

III. Applications

* Although it has been proven mathematically that a 6-DOF manipulator is possible to reach every single position in the task-space, other factors like link collision and singularities could still create awkward situations (Corke, 2013, p. 150). So obviously some are better at performing tasks in a given space than others.
* For under-actuated rigid-link manipulators, it is useful to find out if a exists for a given space
* Since both the input and the output are vectors, they can be fed into an artificial neural network to look for a pattern, which means that an optimized result could be obtained.
* However, this unconventional approach might require a modified network structure.

References

Corke, P. I. (2013). *Robotics, vision and control: Fundamental algorithms in MATLAB*.

Exploring the possibility of using quaternions to represent poses

Date: 10/24/17

Alexander Liao

Idea 1

classdef VectorQuaternion

properties

t

q

end

methods

function r = VectorQuaternion(inT,inQ)

if size(inT)== [3 1]

r.t = inT;

else

error('t has to be a 3\*1 vector');

end

try

Quaternion(inQ);

catch

error('q has to be a unit Quaternion');

end

if inQ.norm==1

r.q= inQ;

else

error('q has to be a unit Quaternion');

end

end

function r = poseCompose(inVQ1,inVQ2)

if and(isQuaternion(inVQ1.q),isQuaternion(inVQ2.q))

r = VectorQuaternion([0;0;0],UnitQuaternion);

r.q=(inVQ1.q\*inVQ2.q);

q1 = inVQ1.q;

r.t=(inVQ1.t+(q1.R)\*inVQ2.t);

else

error('Only quaternion inputs are allowed');

end

end

function r = poseNegate(inVQ)

if isQuaternion(inVQ.q)

r = VectorQuaternion([0;0;0],UnitQuaternion);

q0= inVQ.q;

q\_inv= q0.inv;

t0= inVQ.t;

r.t=-(q\_inv.R)\*t0;

r.q=q\_inv;

else

error('Only quaternion input is allowed');

end

end

function r = VQtrans(inPt,inVQ)

if and(isQuaternion(inVQ.q),size(inPt)== [3 1])

q0= inVQ.q;

t0= inVQ.t;

r=-(q0.R)\*inPt+t0;

else

error('inputs must have the following form: desired point, quaternion');

end

end

end

end

function logic = isQuaternion(inQ)

try

determine = Quaternion(inQ)

logic = true();

catch

logic = false();

end

end

end

function r = poseNegate(inVQ)

if isQuaternion(inVQ.q)

r = VectorQuaternion([0;0;0],UnitQuaternion);

q0= inVQ.q;

q\_inv= q0.inv;

t0= inVQ.t;

r.t=-(q\_inv.R)\*t0;

r.q=q\_inv;

else

error('Only quaternion input is allowed');

end

end

function r = VQtrans(inPt,inVQ)

if and(isQuaternion(inVQ.q),size(inPt)== [3 1])

q0= inVQ.q;

t0= inVQ.t;

r=-(q0.R)\*inPt+t0;

else

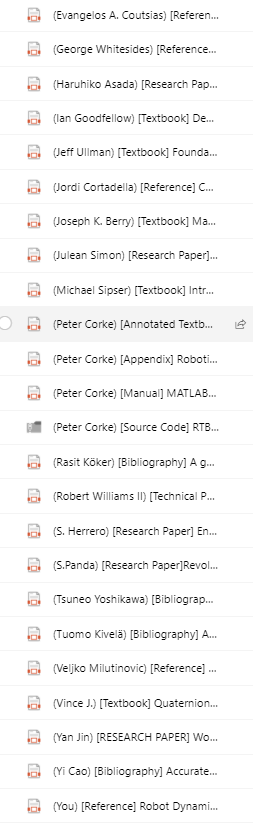
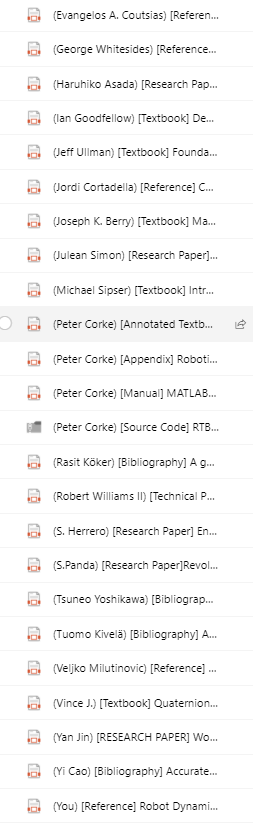
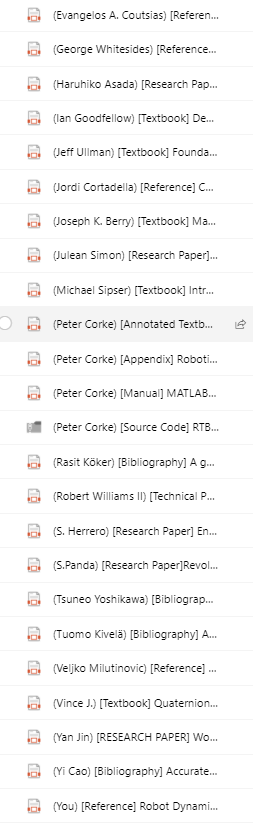
error('inputs must have the following form: desired point, quaternion');

end

end

end

end

Quaternion idea failed; starting literature research on web

Date: 10/25/17

Alexander Liao

Idea 1

***Goal: Train a neural network that can predict the manipulability map of manipulator given its kinematic structure***

Date: 10/29/17

Alexander Liao

Idea 2

First attempt of creating a script to generate random 6-DOF manipulators

**Code:**

D=10\*round(rand(1,6),3);

A=10\*round(rand(1,6),3);

alpha=zeros(1,6);

r1=rand(1,6)\*10;

%r2=rand(1,5)\*10;

r3=rand(1,6)\*10;

logic = 0;

for i = 1:5

if and(r1(i)>3, logic==0)

D(i)=0;

A(i)=0;

D(i+1)=0;

A(i+1)=0;

alpha(i)=0;

logic=1;

end

%if 6>r3(i)>3

% alpha(i)=pi/2;

%elseif r3(i)>6

% alpha(i)=-pi/2;

%end

end

lt=[0 0 0 0 0 0];

%lD=50\*round(rand(1,5),3);

%lA=50\*round(rand(1,5),3);

%lD(round(rand(1)\*5))=0;

%la=pi+pi/2\*-(rand(1,5));

%Creating the SerialLink object

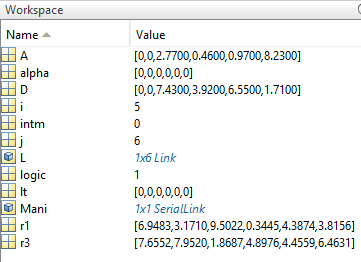
for j = 1:6

L(j)=Link([0 D(j) A(j) alpha(j)]);

end

intm = 0;

Mani=SerialLink(L);



Further improvements

Date: 10/30/17

Alexander Liao

Idea 2

**Scalar field of sum of manipulability measures in the trajectory** (transl(0.5,0,0),transl(0.5,0.5,0),10) **of a 6-DOF manipulator with random link lengths:**

times=5000;

answer=zeros(1,times);

error=answer;

matrix = zeros(18,times);

L=struct();

parfor me = 1:times

D=[ 0 0 0.2+0.5\*rand() 0.2+0.5\*rand() 0 0];

A=[ 0 0.2+0.5\*rand() 0 0 0 0];

alpha=[ pi/2 0 -pi/2 pi/2 -pi/2 0];

%{

D=[ 0 0 0 rand() rand() 0 ];

A=[ 0 0 rand() 0 0 0 ];

alpha=[ pi/2 pi/2 0 -pi/2 pi/2 -pi/2 ];

for j = 1:6

L(j)=Link([0 D(j) A(j) alpha(j)]);

end

%}

l1=Link([0 D(1) A(1) alpha(1)]);

l2=Link([0 D(2) A(2) alpha(2)]);

l3=Link([0 D(3) A(3) alpha(3)]);

l4=Link([0 D(4) A(4) alpha(4)]);

l5=Link([0 D(5) A(5) alpha(5)]);

l6=Link([0 D(6) A(6) alpha(6)]);

Mn=SerialLink([l1,l2,l3,l4,l5,l6]);

ger=[0 0 0 0 0 0];

intm=0;

%step=0:pi/4:pi/2

traj= ctraj(transl(0.5,0,0),transl(0.5,0.5,0),10);

traj1=traj(:,:,1);

qMn=zeros(10,6);

logic=1;

logic2=1;

ger=Mn.ikine(traj1,'rlimit',500,'ilimit',500);

if sum(ger)==0

answer(me)=0;

logic=0;

end

if logic==1

qMn(1,:)=ger;

for i = 2:10

ger=Mn.ikine(traj(:,:,i),'rlimit',200,'q0',qMn(i-1,:));

if sum(ger)==0

logic2=0;

else

qMn(i,:)=ger;

end

end

if logic2==1

in=Mn.maniplty(qMn);

intm=sum(in);

%intm = M.maniplty([0 pi/4 pi/4 0 pi/4 pi/4]);

answer(me)=intm;

%error(me)=sum(err1);

end

end

matrix(:,me)=[D,A,alpha];

end

gee=zeros(1,6);

for t = 1:times

if answer(t)==max(answer)

gee=matrix(:,t);

end

end

nD=gee(1:6,1);

nA=gee(7:12,1);

nAlpha=gee(13:18,1);

for nj = 1:6

nL(nj)=Link([0 nD(nj) nA(nj) nAlpha(nj)]);

end

nM=SerialLink(nL);

q0=[0 0 0 0 0 0];

%nM.plot(q0);

%nM.teach();

scatter3(matrix(3,:),matrix(4,:),matrix(8,:),7.5,answer,'filled')

D=[0 0 0 0.15 0.4318 0];

A=[0 0 0.4318 0.0203 0 0];

alpha=[pi/2 0 -pi/2 pi/2 -pi/2 0];

for j = 1:6

L(j)=Link([0 D(j) A(j) alpha(j)]);

end

intm = 0;

M=SerialLink(L);

intm=0;

%step=0:pi/4:pi/2

traj= ctraj(transl(0.5,0,0),transl(0.5,0.5,0),10);

traj1=traj(:,:,1);

qMn=zeros(10,6);

logic=1;

logic2=1;

ger=Mn.ikine(traj1,'rlimit',500,'ilimit',500);

if sum(ger)==0

answer(me)=0;

logic=0;

end

if logic==1

qMn(1,:)=ger;

for i = 2:10

ger=Mn.ikine(traj(:,:,i),'rlimit',200,'q0',qMn(i-1,:));

if sum(ger)==0

logic2=0;

else

qMn(i,:)=ger;

end

end

if logic2==1

in=Mn.maniplty(qMn);

intm=sum(in);

%intm = M.maniplty([0 pi/4 pi/4 0 pi/4 pi/4]);

answer(me)=intm;

%error(me)=sum(err1);

end

end

matrix(:,me)=[D,A,alpha];

end

gee=zeros(1,6);

for t = 1:times

if answer(t)==max(answer)

gee=matrix(:,t);

end

end

nD=gee(1:6,1);

nA=gee(7:12,1);

nAlpha=gee(13:18,1);

for nj = 1:6

nL(nj)=Link([0 nD(nj) nA(nj) nAlpha(nj)]);

end

nM=SerialLink(nL);

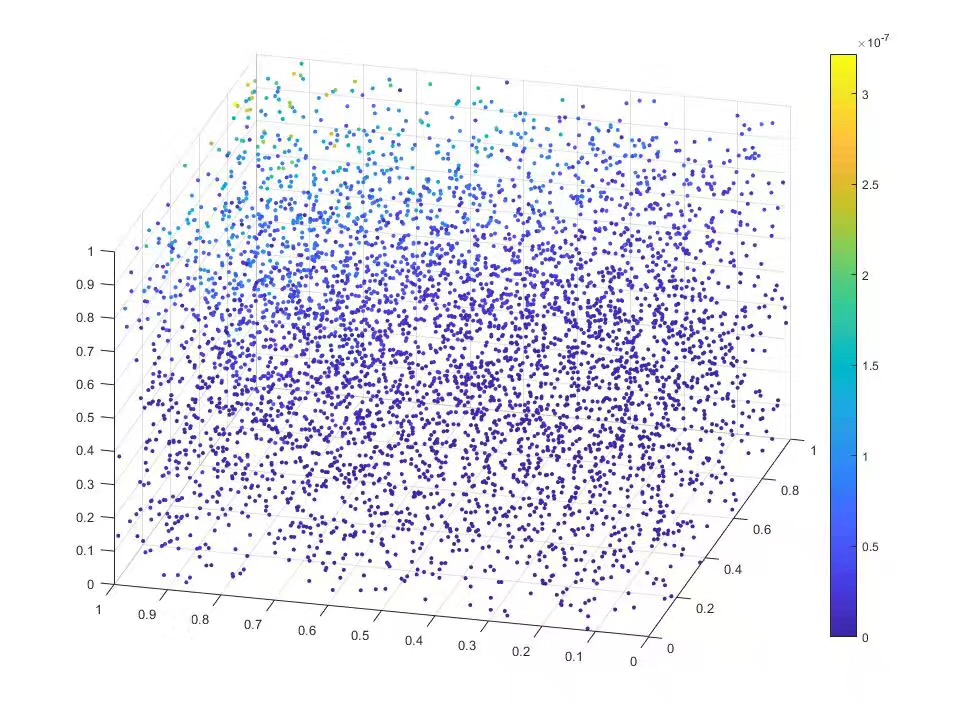
q0=[0 0 0 0 0 0];

%nM.plot(q0);

%nM.teach();

scatter3(matrix(3,:),matrix(4,:),matrix(8,:),7.5,answer,'filled')

**Visualization**



Manipulability measures of a given manipulator in vector form

Date: 10/31/17

Alexander Liao

Idea 2

**I/O:**

in =

1.0e-06 \*

0

0.1001

0

0.0954

0.0126

0

0.0245

0.0925

0.0873

0.1195

>>

**Code:**

D=[ 0 0 0.4793 1.3315 0 0];

A=[ 0 1.1765 0 0 0 0];

alpha=[ pi/2 0 -pi/2 pi/2 -pi/2 0];

l1=Link([0 D(1) A(1) alpha(1)]);

l2=Link([0 D(2) A(2) alpha(2)]);

l3=Link([0 D(3) A(3) alpha(3)]);

l4=Link([0 D(4) A(4) alpha(4)]);

l5=Link([0 D(5) A(5) alpha(5)]);

l6=Link([0 D(6) A(6) alpha(6)]);

Mn=SerialLink([l1,l2,l3,l4,l5,l6]);

intm=0;

traj= ctraj(transl(0.5,0,0),transl(0.5,1,0),10);

qMn=Mn.ikine6s(traj);

in=Mn.maniplty(qMn)

intm=sum(in);

%intm = M.maniplty([0 pi/4 pi/4 0 pi/4 pi/4]);

**Visualization algorithm of the scope of the manipulability map:**

D=[ 0 0 rand() rand() 0 0];

A=[ 0 rand() 0 0 0 0];

alpha=[ pi/2 0 -pi/2 pi/2 -pi/2 0];

l1=Link([0 D(1) A(1) alpha(1)]);

l2=Link([0 D(2) A(2) alpha(2)]);

l3=Link([0 D(3) A(3) alpha(3)]);

l4=Link([0 D(4) A(4) alpha(4)]);

l5=Link([0 D(5) A(5) alpha(5)]);

l6=Link([0 D(6) A(6) alpha(6)]);

Mn=SerialLink([l1,l2,l3,l4,l5,l6]);

xmin=0.2;

xmax=0.6;

ymin=-0.2;

ymax=0.2;

zmin=-0.4;

zmax=0;

q1=Mn.ikine6s(transl(xmin,ymin,zmin));

q2=Mn.ikine6s(transl(xmin,ymax,zmin));

q3=Mn.ikine6s(transl(xmax,xmin,zmin));

q4=Mn.ikine6s(transl(xmax,ymax,zmin));

q5=Mn.ikine6s(transl(xmin,ymin,zmax));

q6=Mn.ikine6s(transl(xmin,ymax,zmax));

q7=Mn.ikine6s(transl(xmax,ymin,zmax));

q8=Mn.ikine6s(transl(xmax,ymax,zmax));

mat=[q1;q2;q3;q4;q5;q6;q7;q8];

difmat=zeros(2,6);

for i=1:6

difmat(1,i)=min(mat(:,i));

difmat(2,i)=max(mat(:,i));

end

x1=[xmin xmin xmax xmax];

y1=[ymin ymax ymax ymin];

z1=[zmin zmin zmin zmin];

x2=[xmin xmin xmax xmax];

y2=[ymin ymax ymax ymin];

z2=[zmax zmax zmax zmax];

x3=[xmin xmin xmin xmin];

y3=[ymin ymax ymax ymin];

z3=[zmax zmax zmin zmin];

x4=[xmax xmax xmax xmax];

y4=[ymin ymax ymax ymin];

z4=[zmax zmax zmin zmin];

x5=[xmin xmax xmax xmin];

y5=[ymin ymin ymin ymin];

z5=[zmax zmax zmin zmin];

x6=[xmin xmax xmax xmin];

y6=[ymax ymax ymax ymax];

z6=[zmax zmax zmin zmin];

Mn.plot(qn);

hold on

patch(x1,y1,z1,'blue','facealpha',.25)

hold on

patch(x2,y2,z2,'blue','facealpha',.25)

hold on

patch(x3,y3,z3,'red','facealpha',.25)

hold on

patch(x4,y4,z4,'red','facealpha',.25)

hold on

patch(x5,y5,z5,'yellow','facealpha',.25)

hold on

patch(x6,y6,z6,'yellow','facealpha',.25)

hold on

diff=(difmat(2,:)-difmat(1,:))/20

x2=[xmin xmin xmax xmax];

y2=[ymin ymax ymax ymin];

z2=[zmax zmax zmax zmax];

x3=[xmin xmin xmin xmin];

y3=[ymin ymax ymax ymin];

z3=[zmax zmax zmin zmin];

x4=[xmax xmax xmax xmax];

y4=[ymin ymax ymax ymin];

z4=[zmax zmax zmin zmin];

x5=[xmin xmax xmax xmin];

y5=[ymin ymin ymin ymin];

z5=[zmax zmax zmin zmin];

x6=[xmin xmax xmax xmin];

y6=[ymax ymax ymax ymax];

z6=[zmax zmax zmin zmin];

Mn.plot(qn);

hold on

patch(x1,y1,z1,'blue','facealpha',.25)

hold on

patch(x2,y2,z2,'blue','facealpha',.25)

hold on

patch(x3,y3,z3,'red','facealpha',.25)

hold on

patch(x4,y4,z4,'red','facealpha',.25)

hold on

patch(x5,y5,z5,'yellow','facealpha',.25)

hold on

patch(x6,y6,z6,'yellow','facealpha',.25)

hold on

diff=(difmat(2,:)-difmat(1,:))/20

Improvements

Date: 11/1/17

Alexander Liao

Idea 2

**Scalar map algorithm version 2:**

times=100;

answer=zeros(1,times);

error=answer;

matrix = zeros(18,times);

parfor me =1:times

D=[ 0 0 rand() rand() 0 0];

A=[ 0 rand() 0 0 0 0];

alpha=[ pi/2 0 -pi/2 pi/2 -pi/2 0];

l1=Link([0 D(1) A(1) alpha(1)],'m',0,'l',[0.066,0,0;0,0.086,0;0,0,0.0125],[-0.0203,-0.0141,0.07]);

l2=Link([0 D(2) A(2) alpha(2)]);

l3=Link([0 D(3) A(3) alpha(3)],'m',A(2)\*40);

l4=Link([0 D(4) A(4) alpha(4)],'m',D(3)\*40);

l5=Link([0 D(5) A(5) alpha(5)],'m',D(4)\*20);

l6=Link([0 D(6) A(6) alpha(6)]);

Mn=SerialLink([l1,l2,l3,l4,l5,l6]);

qtraj=ctraj(transl(0.5,0,0),transl(0.5,0.5,0),25);

traj=Mn.ikine6s(qtraj);

vec=Mn.maniplty(traj,'asada');

intm=sum(vec);

answer(me)=intm;

matrix(:,me)=[D,A,alpha];

end

gee=zeros(1,6);

for t = 1:times

if answer(t)==max(answer)

gee=matrix(:,t);

end

end

nD=gee(1:6,1);

nA=gee(7:12,1);

nAlpha=gee(13:18,1);

for nj = 1:6

nL(nj)=Link([0 nD(nj) nA(nj) nAlpha(nj)]);

end

nM=SerialLink(nL);

q0=[0 0 0 0 0 0];

%nM.plot(q0);

%nM.teach();

scatter3(matrix(3,:),matrix(4,:),matrix(8,:),7.5,answer,'filled')

for nj = 1:6

nL(nj)=Link([0 nD(nj) nA(nj) nAlpha(nj)]);

end

nM=SerialLink(nL);

q0=[0 0 0 0 0 0];

%nM.plot(q0);

%nM.teach();

scatter3(matrix(3,:),matrix(4,:),matrix(8,:),7.5,answer,'filled')

**Experimenting with kinematics structure of 6-DOF manipulators**

D=[ 0 0 14.7313 14.7713 0 0];

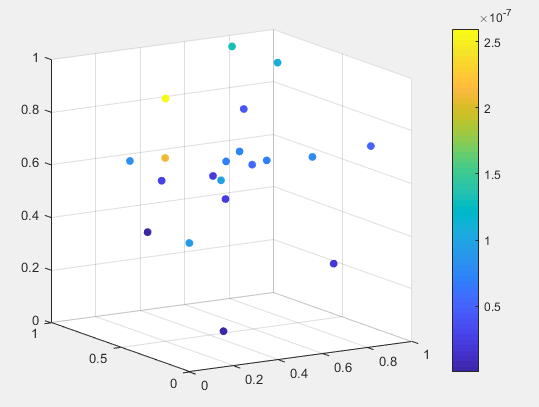
A=[ 14.7029 0 0 0 0 0];

alpha=[ pi/2 pi/2 -pi/2 pi/2 -pi/2 0];

D=[ 0 14.7313 0 14.7713 0 0];

A=[ 14.7029 0 0 0 0 0];

alpha=[ pi/2 -pi/2 pi/2 pi/2 -pi/2 0];



Proposal 3rd draft

Date: 11/2/17

Alexander Liao

Idea 2

A Portable Algorithm for Kinematic Evaluation of Robotic Manipulators Generated by Neural Network and Its Application in Optimization

Alexander Liao

Introduction

* Goal: design a test that could reflect properties of a manipulator’s kinematics model and mimic it by a neural network.
* Neural Networks are often used in research for robot control system (since 2001)
* Pure kinematics model of a serial-link manipulator is less taken care of compared to the dynamics model
* Yet the kinematic model of robot itself is significant as well-idealize other factors:
* *The performance of the manipulator is a function of the parameters that define the kinematics model*
* Yet traditional optimization includes arduous work in multivariable calculus (an optimization attempt of a specific redundant 8-DOF manipulator was done by NASA)
* Thus, it is reasonable to first find a way to describe the model, then use ANNs to mimic it
* Advantages of neural network: the process of LSTM/CNN/RNN/MLP is faster and more portable than analytical Jacobian/tensor arithmetic

Method

* Prerequisite:
  + Rigid-body
  + Serial-link
  + All-revolute
  + Standard D-H parameters
  + Functions based on MATLAB Robotics Toolbox (RTB) by professor Peter Corke
  + Neural network code based on Tensorflow
* 1.Designing the evaluation algorithm
  + 6-DOF with Spherical Wrist
    - Only three configurations are possible:

|  |  |  |  |
| --- | --- | --- | --- |
| j | d | a | alpha |
| 1 | 0 | 0 |  |
| 2 | 0 |  | 0 |
| 3 |  | 0 |  |
| 4 |  | 0 |  |
| 5 | 0 | 0 |  |
| 6 | 0 | 0 | 0 | |

|  |  |  |  |
| --- | --- | --- | --- |
| j | d | a | alpha |
| 1 | 0 |  |  |
| 2 | 0 | 0 |  |
| 3 |  | 0 |  |
| 4 |  | 0 |  |
| 5 | 0 | 0 |  |
| 6 | 0 | 0 | 0 |

|  |  |  |  |
| --- | --- | --- | --- |
| j | d | a | alpha |
| 1 | 0 |  |  |
| 2 |  | 0 |  |
| 3 | 0 | 0 |  |
| 4 |  | 0 |  |
| 5 | 0 | 0 |  |
| 6 | 0 | 0 | 0 |

* + - Input：
      * d-vector
      * a-vector
      * alpha-vector
    - Target space for evaluation:
    - Evaluation
      * Reachability
      * Manipulability
      * Joint-Space Usage
      * Linearity
* 2.Using Neural Networks to mimic the test
* 3.Optimization

**The orientation of the manipulator end-effector when performing Cartesian linear movement between nodes in the cuboid partitions:**

x1=[xmin xmin xmax xmax];

y1=[ymin ymax ymax ymin];

z1=[zmin zmin zmin zmin];

x2=[xmin xmin xmax xmax];

y2=[ymin ymax ymax ymin];

z2=[zmax zmax zmax zmax];

x3=[xmin xmin xmin xmin];

y3=[ymin ymax ymax ymin];

z3=[zmax zmax zmin zmin];

x4=[xmax xmax xmax xmax];

y4=[ymin ymax ymax ymin];

z4=[zmax zmax zmin zmin];

x5=[xmin xmax xmax xmin];

y5=[ymin ymin ymin ymin];

z5=[zmax zmax zmin zmin];

x6=[xmin xmax xmax xmin];

y6=[ymax ymax ymax ymax];

z6=[zmax zmax zmin zmin];

**Initialization:**

%Initialization

clear all

numData=100;

%Target Space

spc\_x1=0.2;

xmin=spc\_x1;

spc\_x2=0.6;

xmax=spc\_x2;

spc\_y1=-0.2;

ymin=spc\_y1;

spc\_y2=0.2;

ymax=spc\_y2;

spc\_z1=-0.4;

zmin=spc\_z1;

spc\_z2=0;

zmax=spc\_z2;

%Specifications for Voxels

vxl\_interpVal=10;

vxl\_num=10;

vxl\_zLayerHeight=0.025;

%Final Result

performanceVector=[];

performanceMatrix=[];

inputMatrix=[];

for num=1:numData

rawdata=[];

performanceVector=[];

link\_D=[ 0 0 0.2290 0.9133 0 0];

link\_A=[ 0 0.1524 0 0 0 0];

link\_alpha=[ pi/2 0 -pi/2 pi/2 -pi/2 0];

l1=Link([0 link\_D(1) link\_A(1) link\_alpha(1)]);

l2=Link([0 link\_D(2) link\_A(2) link\_alpha(2)]);

l3=Link([0 link\_D(3) link\_A(3) link\_alpha(3)]);

l4=Link([0 link\_D(4) link\_A(4) link\_alpha(4)]);

l5=Link([0 link\_D(5) link\_A(5) link\_alpha(5)]);

l6=Link([0 link\_D(6) link\_A(6) link\_alpha(6)]);

linkL=[l1,l2,l3,l4,l5,l6];

mdl\_puma560;

link\_M=SerialLink(p560);

for z=spc\_z1:vxl\_zLayerHeight:spc\_z2

if z==spc\_z2

disp('\*');

else

%Invoking the surface function for at the height "z"

logic=0;

while logic==0

[surfPlan,SizeZ] = surfaceRobotTest(linkL,link\_M,vxl\_interpVal,vxl\_num,spc\_x1,spc\_x2,spc\_y1,spc\_y2,z);

logic=1;

end

[SizeX,SizeY]=size(surfPlan);

columnImage=surfPlan;

performanceVector=vertcat(performanceVector,columnImage);

end

end

inputVector=vertcat(link\_D',link\_A');

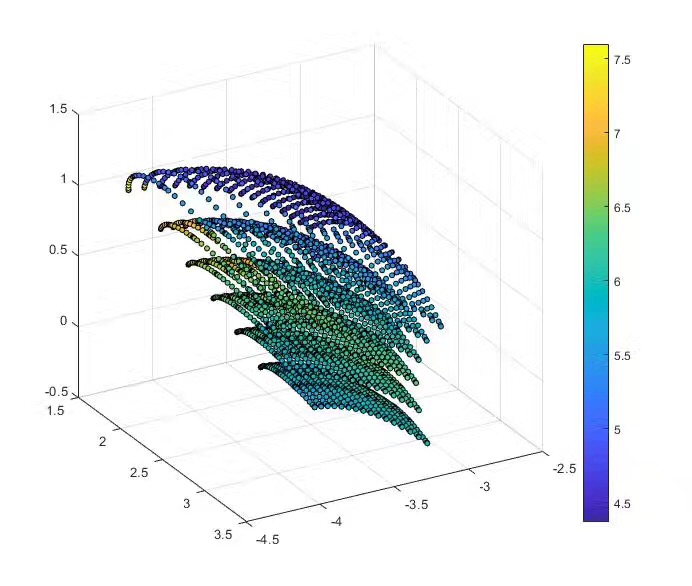
inputMatrix=horzcat(inputMatrix,inputVector);

performanceMatrix=horzcat(performanceMatrix,performanceVector);

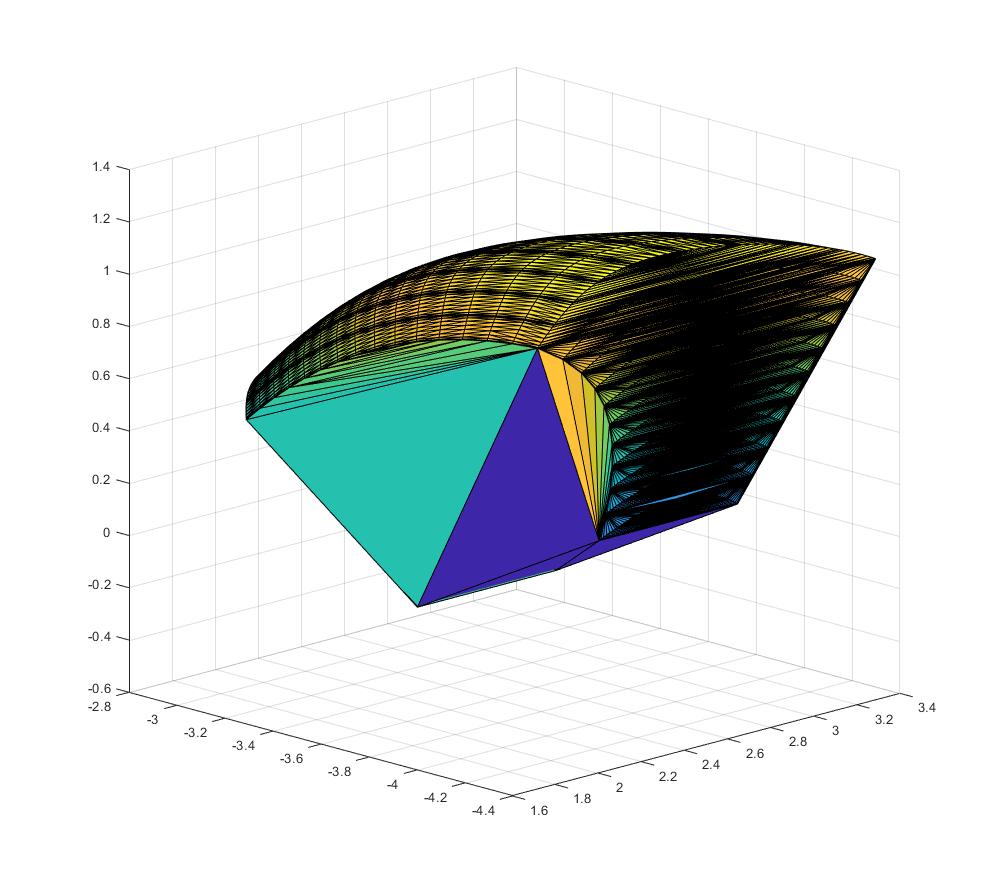
end

scatter3(performanceMatrix(:,1),performanceMatrix(:,2),performanceMatrix(:,3),15,(abs(performanceMatrix(:,4))+abs(performanceMatrix(:,5))+abs(performanceMatrix(:,6))),'filled','MarkerEdgeColor','k')

**Visualization for PUMA 560:**



**Convex hull:**



Further investigation of using convex hull volume to evaluate a manipulator

Date: 11/3/17

Alexander Liao

Idea 2

Attempt to use forward kinematics with uniform sampling of joint angles to map between joint space and workspace, failed due to the unachievable requirement on computational power

***Goal: Using neural network to predict the workspace of manipulator in the form of a binary map***

D=[ 0 0 0.4793 1.4315 0 0];

A=[ 0 1.0765 0.05 0 0 0];

alpha=[ pi/2 0 -pi/2 pi/2 -pi/2 0];

l1=Link([0 D(1) A(1) alpha(1)]);

l2=Link([0 D(2) A(2) alpha(2)]);

l3=Link([0 D(3) A(3) alpha(3)]);

l4=Link([0 D(4) A(4) alpha(4)]);

l5=Link([0 D(5) A(5) alpha(5)]);

l6=Link([0 D(6) A(6) alpha(6)]);

Mn=SerialLink([l1,l2,l3,l4,l5,l6]);

final=[];

parfor i=1:62

i2=-pi+i\*0.1

for j=-pi/2:0.1:pi/2

for k = -pi/2:0.1:pi/2

intm=Mn.fkine([i2 j k 0 0 0]);

final=horzcat(final,intm.t);

end

end

end

%try

%[~,vol]=convhull(performanceVector(:,1),performanceVector(:,2),performanceVector(:,3));

%hullV=horzcat(hullV,vol);

%catch

% hullV=horzcat(hullV,0);

%end

Date: 11/4/17

Alexander Liao

Idea 3 (final)

Attempt to reimplement Castelli’s method in MATLAB

%Initialization

clear all

numData=500;

%Target Space

xmin=0.2;

xmax=0.6;

ymin=-0.2;

ymax=0.2;

zmin=-0.4;

zmax=0;

%Specifications for Voxels

itpVal=4;

%Final Result

perfmat=[];

performanceMatrix=[];

inputMatrix=[];

coordinateData=[];

parfor num=1:numData

%for num=1:numData

rawdata=[];

perfmat=[];

surfPlan=[];

intm=[];

%D=[ 0 0 round(rand(),4) round(rand(),4) 0 0];

%A=[ 0 round(rand(),4) round(rand(),3)/10 0 0 0];

D=[0 0 rand() rand() 0 0];

A=[0 rand() rand()/10 0 0 0];

alpha=[ pi/2 0 -pi/2 pi/2 -pi/2 0];

l1=Link([0 D(1) A(1) alpha(1)]);

l2=Link([0 D(2) A(2) alpha(2)]);

l3=Link([0 D(3) A(3) alpha(3)]);

l4=Link([0 D(4) A(4) alpha(4)]);

l5=Link([0 D(5) A(5) alpha(5)]);

l6=Link([0 D(6) A(6) alpha(6)]);

linkL=[l1 l2 l3 l4 l5 l6];

M=SerialLink([l1,l2,l3,l4,l5,l6]);

for z=zmin:(zmax-zmin)/itpVal:zmax

%if z==spc\_z2

% disp('\*');

%else

%Invoking the surface function for at the height "z"

%logic=0;

%while logic==0

% [surfPlan,SizeZ] = surfaceRobotTest(linkL,M,vxl\_interpVal,vxl\_num,spc\_x1,spc\_x2,spc\_y1,spc\_y2,z);

%logic=1;

surfPlan=[];

for i=xmin:(xmax-xmin)/itpVal:xmax

for j=ymin:(ymax-ymin)/itpVal:ymax

try

intm=M.ikine6s(transl(i,j,z));

catch

bool=0;

end

if all(intm.\*1==intm)

bool=1;

if bool==[]

bool=0;

end

else

bool=0;

end

if bool==[]

bool=0;

end

%coordinateData= horzcat(coordinateData,[i;j;z]);

surfPlan=horzcat(surfPlan,bool);

%size(surfPlan)

end

end

%end

[SizeX,~]=size(surfPlan);

%{

for i = 1:SizeX

if ~all(surfPlan(i,:).\*1==surfPlan(i,:))

reachL=0;

else

reachL=1;

end

end

%}

%columnImage=surfPlan;

perfmat=horzcat(perfmat,surfPlan);

%end

end

try

performanceMatrix=vertcat(performanceMatrix,perfmat);

inputVector=vertcat(D(3:4)',A(2:3)',xmin,xmax,ymin,ymax,zmin,zmax);

inputMatrix=vertcat(inputMatrix,inputVector');

catch

end

end

d=[];

a=neural5(inputMatrix');

b=round(a');

for i=1:numData

c=sum(b(i,:)==performanceMatrix(i,:))/125;

d=[d,c];

end

%{

for i =1:numData

a=neru4(inputMatrix(i,:));

b=round(a);

c=sum(b==performanceMatrix(i,:))/125;

d=[d,c];

end

%}

l5=Link([0 D(5) A(5) alpha(5)]);

l6=Link([0 D(6) A(6) alpha(6)]);

linkL=[l1 l2 l3 l4 l5 l6];

M=SerialLink([l1,l2,l3,l4,l5,l6]);

for z=zmin:(zmax-zmin)/itpVal:zmax

%if z==spc\_z2

% disp('\*');

%else

%Invoking the surface function for at the height "z"

%logic=0;

%while logic==0

% [surfPlan,SizeZ] = surfaceRobotTest(linkL,M,vxl\_interpVal,vxl\_num,spc\_x1,spc\_x2,spc\_y1,spc\_y2,z);

%logic=1;

surfPlan=[];

for i=xmin:(xmax-xmin)/itpVal:xmax

for j=ymin:(ymax-ymin)/itpVal:ymax

try

intm=M.ikine6s(transl(i,j,z));

catch

bool=0;

end

if all(intm.\*1==intm)

bool=1;

if bool==[]

bool=0;

end

else

bool=0;

end

if bool==[]

bool=0;

end

%coordinateData= horzcat(coordinateData,[i;j;z]);

surfPlan=horzcat(surfPlan,bool);

%size(surfPlan)

end

end

%end

[SizeX,~]=size(surfPlan);

%{

for i = 1:SizeX

if ~all(surfPlan(i,:).\*1==surfPlan(i,:))

reachL=0;

else

reachL=1;

end

end

%}

%columnImage=surfPlan;

perfmat=horzcat(perfmat,surfPlan);

%end

end

try

performanceMatrix=vertcat(performanceMatrix,perfmat);

inputVector=vertcat(D(3:4)',A(2:3)',xmin,xmax,ymin,ymax,zmin,zmax);

inputMatrix=vertcat(inputMatrix,inputVector');

catch

end

end

d=[];

a=neural5(inputMatrix');

b=round(a');

for i=1:numData

c=sum(b(i,:)==performanceMatrix(i,:))/125;

d=[d,c];

end

%{

for i =1:numData

a=neru4(inputMatrix(i,:));

b=round(a);

c=sum(b==performanceMatrix(i,:))/125;

d=[d,c];

end

%}

%end

[SizeX,~]=size(surfPlan);

%{

for i = 1:SizeX

if ~all(surfPlan(i,:).\*1==surfPlan(i,:))

reachL=0;

else

reachL=1;

end

end

%}

%columnImage=surfPlan;

perfmat=horzcat(perfmat,surfPlan);

%end

end

try

performanceMatrix=vertcat(performanceMatrix,perfmat);

inputVector=vertcat(D(3:4)',A(2:3)',xmin,xmax,ymin,ymax,zmin,zmax);

inputMatrix=vertcat(inputMatrix,inputVector');

catch

end

end

d=[];

a=neural5(inputMatrix');

b=round(a');

for i=1:numData

c=sum(b(i,:)==performanceMatrix(i,:))/125;

d=[d,c];

end

%{

for i =1:numData

a=neru4(inputMatrix(i,:));

b=round(a);

c=sum(b==performanceMatrix(i,:))/125;

d=[d,c];

end

%}

1. Attempt to use forward kinematics joint space search method. Abandoned due to high computational cost

Date: 11/5/17

Alexander Liao

Idea 3 (final)

1. Cartesian linear trajectory planning for 6-DOF arm with spherical wrist

D=[ 0 0 0.4793 1.4315 0 0];

A=[ 0 1.0765 0.05 0 0 0];

alpha=[ pi/2 0 -pi/2 pi/2 -pi/2 0];

l1=Link([0 D(1) A(1) alpha(1)]);

l2=Link([0 D(2) A(2) alpha(2)]);

l3=Link([0 D(3) A(3) alpha(3)]);

l4=Link([0 D(4) A(4) alpha(4)]);

l5=Link([0 D(5) A(5) alpha(5)]);

l6=Link([0 D(6) A(6) alpha(6)]);

Mn=SerialLink([l1,l2,l3,l4,l5,l6]);

final=[];

parfor i=1:62

i2=-pi+i\*0.1

for j=-pi/2:0.1:pi/2

for k = -pi/2:0.1:pi/2

intm=Mn.fkine([i2 j k 0 0 0]);

final=horzcat(final,intm.t);

end

end

end

%Trajectory Planning for a line

function [linPlan,SizeZ] = linearRobotTest(L,M,interpVal,numVxl,terminal1,terminal2)

linVoxel=trinterp(terminal1,terminal2,numVxl);

[~,~,SizeZ]=size(linVoxel);

linPlan=zeros((SizeZ-1)\*interpVal,numel(L));

for i=1:SizeZ-1

intm=ctraj(linVoxel(:,:,i),linVoxel(:,:,i+1),interpVal);

ptPlan=M.ikine6s(intm);

index1=1+(i-1)\*interpVal;

index2=i\*interpVal;

linPlan(index1:index2,:)=ptPlan(:,:);

end

end

Using the MATLAB neural network toolbox to train data generated from the former scripts

Date: 11/6/17

Alexander Liao

Idea 3 (final)

function [y1] = RobotTest1(x1)

x1\_step1.keep = [1 2 3 4];

x1\_step2.xoffset = [5.90318136701325e-05;4.34334412752338e-05;9.77198810546733e-05;4.15630604533963e-05];

x1\_step2.gain = [2.00012319856925;2.00020952641606;2.00019854125312;20.008884450653];

x1\_step2.ymin = -1;

% Layer 1

b1 = [-4.2111134575487181309;-3.5567818840090552612;3.4266865864341884418;-0.8925772303867109958;4.400605991782107651;-1.1076507547425888944;-0.48563328903356794974;1.9505567287489016248;3.7891576910278370605;4.1024929712171180896];

IW1\_1 = [0.23698897572914937038 -0.84171426351152611733 0.14966972354667829048 0.48034682846524695554;-0.12339004258713216766 0.052960482513756304557 -0.29892756388066848983 -0.6740146917666646198;-0.040852616001215535935 0.15691991600313298649 0.31786688395363044135 -0.34729016858231503972;5.31886466321291973 -1.3144457826098903119 1.48979713115856649 -0.042178282396482143224;2.2046172998506055052 2.8223609691977618041 2.4817242307950522218 0.057230217764130404678;-1.6518595991411273438 0.86705437217034930786 -0.35338664811033770885 0.029347906802240367879;-2.1169950325689925741 0.8255606542426033867 -1.2659585382849058988 0.015930661777038276211;0.98482066385006994391 -1.5737483394783504664 1.4934001609300460167 -0.032741686816116659375;0.78097144387124706189 -0.18027686209956689245 0.30267749052907155782 0.15507152842617485944;0.13001320735781191074 -0.16794833314698498494 0.42870435000562334693 -0.46701341538071489135];

% Layer 2

b2 = [0.20301884013972409937;0.50730471376385477544;-0.221787313818108206;0.1863141292709220298;-0.2255677712622557729;0.11959270716025405257;-0.30541488070137517985;-0.82404264962696427421;-0.053100072918462921934;-1.3436692428892091922;-0.83747635085078542261;-0.091640419998204256102;0.62783768804853556933;0.44378342815856103298;-0.72039133166363245042;0.23907904500623194943;-0.40490180003762576977;0.023091064326665002027;-0.045732736459054137979;0.24495903742517041723;-0.53819887919784337171;-0.24083350435780775944;-0.65734172611872909719;0.41525782324546500757;0.35576657031833175404;0.55902187367202282875;-0.33986347550247109073;-0.28216232834707599686;-0.89226140566530531828;0.25683806814209675373;-0.57314687858597834769;-0.73307441498024705773;0.099407792538488373713;-0.096226487731696758177;0.64247314717993175837;-0.70715023973919954869;-0.19886429428096866201;-0.17883217689339142575;-0.92443071584361791171;-0.66779635469704745621;-0.64904682761155163551;0.44502811775020911789;-0.77242293644640025452;0.20003429975748049374;0.41535158496445628851;-0.58390726853029195631;-0.37239017294337450892;0.41834891628498643845;-0.10770027289094248613;-0.18519777915793703138;-0.44743945014597918952;-0.99413293222960275042;-0.42280435808952349097;-0.23659081502454654133;0.5840028190640341732;-0.13716682928466827907;-0.62212230472731622211;-0.072943459202218202675;-0.56964124652762360146;-0.50479518960159741603;-0.74060717619607840945;0.053922277207157941203;-0.59523748515909868928;-1.1150449795511883089;-0.85484324546357293162;-0.83127283334303303519;-0.20638502546502968116;0.23379704837866316369;-0.59385737563185658772;-0.56679831802865321411;-0.37805965196660668015;-0.33762518652425627108;-0.17231270074862778396;-0.1334185073005514921;-0.34042520164161660379;0.39736081339790058076;-0.60928636847835693224;-0.77594617893994843882;-1.3088376480915417943;-0.99795309814012644889;-0.72872639420111628983;-0.30699767602977706682;-0.76061475714218707012;-0.39792270345430991174;-0.86591666117182219953;-0.41632923732060389543;-0.22438543942720087787;0.16451587784558677208;0.083732763425259953971;-0.399194266798001407;0.5985797946933982816;0.15498726000904602951;-0.54746023205161054026;-0.45306160325771616115;-0.6390929106768649115;-1.0443161315147770907;-0.88024291859264058857;0.71216256023267709985;-0.7254839070249412547;-0.45898647092092981215;0.092453652078971479411;-0.6541153965736735687;-0.46813758895979062924;0.015313042110065781809;0.44788399298119557779;0.22535852143433526829;-0.67217554177860405762;-0.58275986554492886782;0.06797576241789698992;-0.41442678211589834003;-0.17287344329323084402;-0.21675312755428832734;0.047466587593139264456;-0.19085959376968170131;-1.0183671073764637427;-1.0398087416646535353;-0.52185061449494940522;0.40459635380083275313;-0.11478258231211492524;0.092384822564310589699;0.021836272558584564341;-0.63060933197534663197;-0.27017721034651193124;-0.46825346641071791121;-1.3172501791127224635];

LW2\_1 = [0.044497832052447311435 -0.40253405182179785582 -0.78177563505978064917 0.26592438952059715973 0.6092408988688458038 0.9640454027664908665 0.88098680112783589458 1.4995122230871027469 -0.66490045501415395712 -0.66443740318135280365;-0.10846498282148568648 0.89575695113845554829 -0.48906172385064156094 0.36723448019156079702 0.39282588089124270692 0.94091368738513891934 0.78244309545969847886 1.2790882750527319267 -0.60074438720086087429 0.053189996094627642331;0.46329677620897413703 0.91298370635432057885 0.68019740924403671034 0.33332571984168585244 0.29600969108220842596 0.96626709815643885282 0.62417853168077108705 1.1557130759367308936 -0.16832769560855243007 -0.11113799583722211439;0.46843244900589803281 0.22950406081898336308 -0.71063725622504758661 0.35548196010666061051 0.36958297921078581139 0.97532816695448065758 0.74022285671111121008 1.2652886160858349829 -0.5944754138612842187 0.53795070367705111192;-0.0039299355647654148418 -0.1306862721336686517 -0.49545004918252216752 0.34079932080029351482 0.59355952399587819102 0.9883376122643035 0.91050249684009276763 1.4697093231790903101 -0.089152565402892389179 -0.83959787573554667262;0.39389528525206707332 -0.012374956317702547753 -1.028822181687399695 0.16912194304628047625 0.860890476793758741 0.99272301457508849154 0.8759595601015291999 1.579963403746351025 0.16444973366446258289 -0.64468868742892271317;0.44609403322384205692 0.055635704981933452318 0.56128862013977431911 0.22249258443988559342 0.75295115908545096062 0.96417277930100875327 0.90736508924798642273 1.5627993079662556575 -1.2077441231322403326 -0.24123404497833283999;0.55371486730022390077 0.6214549443679444618 0.33096227505161818216 0.29121293533859365921 0.632977854536109108 1.0167771637042677391 0.87366466077342652685 1.4900080826391548516 -0.36662122825736609411 0.48902731073047944754;0.58899392665080507747 -0.62071028207271039534 -0.19015528353994312627 0.26437268038630457045 0.69710512478440245232 1.0099368402618167373 0.88509535159110319658 1.5300791543886365087 -0.87854477136797159975 -0.52865279880212412422;0.72864635689467505131 -0.36352199446135968763 -0.2697718092388445843 0.13150652916540001014 0.81013101063149250969 1.0536996241951712694 0.7758735056894960902 1.5378681349738494433 -0.024607815830051879558 0.31700340573511498476;-0.058729157859711673961 -0.057432418046311370374 -1.2071216324009221843 -0.24869151724239191292 0.96727132471664423186 1.1188581333089400172 0.35664568947787994579 1.4304229362671019299 0.20770589245584036853 -0.01252514463530009399;0.69569857198292317513 0.48348354182712760529 0.14065477347733010283 -0.05130273790958156388 0.96030678331295937777 1.024531005781052162 0.64667790174356820643 1.5120244055616696155 -1.0780359133283965445 0.41299377699755707161;0.31225717149922693761 0.46223011735055763438 -0.89944972066061013027 -0.0035949451630336564517 0.92317372309578116241 1.0504163129621657546 0.67417419474563222703 1.5341678647708436589 0.4062067526539006046 -1.133481114322977712;-0.47892170382173676613 0.37055833626635525935 -0.92343668207121465397 -0.045489967904485048567 0.96178265570074938928 1.0288440585773388491 0.65260725218855375473 1.5231463221400800556 -0.99101744395326518688 -0.44096406443316404911;-0.24157591362468194829 0.32660916835039210948 -0.39976097824438128203 -0.23199888402964022327 1.0020672251703424127 1.0670668441249748781 0.41696843928541932334 1.4425702055880504915 -0.25860225166290773391 -0.32002339952257274902;-0.0080787272187477741914 0.51417302437784839775 -0.77819604823081167666 -0.70949976314469698213 0.97866954495722824348 1.2208432266929283294 -0.3549419344964534484 1.0738262883447629026 0.016086677299527511048 -0.47926715667471636584;0.88266296225127027775 -0.24493818993484539615 0.52436022420547079292 -0.58047579644964220069 0.97425869639902284991 1.187826780534197546 -0.13730368220064431695 1.1751568247967283387 -0.28995817694431719191 -0.76337258037070865324;0.28335146456161641737 1.1796779390131328924 -0.0043039852181831657341 -0.50503111925187871289 1.0092974875236429 1.1279706834303062646 0.014923602535668880134 1.2530583043334959648 -0.025364174414193148277 -0.20139362760586682066;0.67361556383444542995 0.31813742650877385731 -0.18480652810220049576 -0.55593376361965829435 1.0030951175659306163 1.1518964326421212707 -0.076991790879053778607 1.2025449722370675776 -0.038101309175098754811 -0.36259070470233634165;-0.23610083617890589847 0.82307951016547686862 -0.85953247628933115987 -0.69023713742060477383 0.9993628964761293032 1.1917987715594389186 -0.3084102217428861259 1.0974315667551928222 -0.23552672422316317524 -0.10978380828824550741;0.61594683613692202684 -0.37321835655916857366 0.071738363828961010382 -0.94013889686756701991 0.99273764093985239487 1.2631190061682067149 -0.84336814221344380549 0.80433561419033416939 -0.67643599153536304591 0.090210575244220145286;-0.3164592914076840291 -0.1372789200104261309 -0.029738195421712930455 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0.83369761022555144425 0.27316601897008835342 0.23530551919951750439 -0.032807429305132543296 0.42081354145371935305 0.414955219750257287 0.66160427564051316196 0.29940717098126223839 0.0031492514330214325599;0.42343677194490941806 -0.27991980832091795106 -0.68255494830198881751 0.24736641558859434609 -0.055573610430434287888 0.56077451951347900838 0.43424947198816182814 0.78067195294449653886 0.033846745398182435938 -0.20162026140006622521;0.052627062688791352574 0.61309739056293111048 0.019306221258091543075 0.3529526452315082663 0.095475205202836088691 0.66728931505709776495 0.76584247913353420412 1.1846053682544419594 -0.15933927554200016941 -0.83309997130526047826;-0.52491754444596905316 -0.0084382279434236286825 -1.1843261568071226097 0.36047598950905224147 0.30784594242670809683 0.68664506270578817837 1.0417908573636736058 1.5025353230164788521 0.095721721369064025065 -1.1209739341495315035;-0.40550669556289470341 0.17922203030749603303 -0.17860594949115946029 0.35662867587527874447 0.20259543857049261417 0.70494278948376631888 0.87539184067674924439 1.3245773250041681379 -0.65268256955240755435 -0.029304514863034196448;-0.62967730061970750288 0.02907065375780544525 -0.34078374863344557122 0.34598881074213566622 0.13724628445450029468 0.71309826642256790574 0.79952584925415803863 1.2483444691318741349 -0.39590824545689312641 -0.50493160878606457853;-0.13648875608896843259 0.91641477961471118352 -0.95031754692774406124 0.38682173903315258956 0.25004635934044622259 0.64394385907832463189 0.9640062985236442783 1.3538360694479394386 0.1128947840634397376 0.16803161498593044421;-0.16844759569688616541 0.88162887349667284909 -0.90266524230357458869 0.35594746374152319568 0.30210133275548595178 0.69555830892067638249 1.0291689976585540744 1.4956996984874963985 0.10886600172753702065 0.48038630054298359084;-0.18272150433548439707 1.041714899103027836 -0.26298933854231598684 0.11211800193666927872 0.58291587934156952056 0.8368578935579173983 0.89371181952047618058 1.663376924812262958 0.008130043994939510979 -0.37641314369174250221;-0.55596570641515574707 0.89657887438595573748 -0.97655196643350183905 0.27846016028363185235 0.52350340109458559645 0.68885252442861444333 1.1125463699082334124 1.6712327835855302904 -0.23285379874286835089 0.081438772334270256859;1.0392599752688767012 0.14757011839237835216 -0.056666992573614058393 0.30400997747206465194 0.4826347387670635869 0.66303551569616014927 1.1322515534496200296 1.6450580199928164227 -0.76003510950118102762 0.30541742854187509115;0.97160247859661663661 0.56847886603274344619 -0.16388314738346390631 0.26944608760076582676 0.49701771422858764815 0.72700772315596029483 1.0740156282486958972 1.6664987721305224433 0.27656455727066803219 -0.027735290388858201832;0.37338658504881083733 -0.28977057583856841161 0.17124664225042898758 0.1170100204231538793 0.59043013424875123718 0.82417451216220627419 0.91032090374599383686 1.6685141270565784222 -1.0359738693012068289 0.29467335783669518223;0.56052544815552018953 -0.15771366714853335411 -0.24756510830833486358 -0.32577785285619076383 0.85087643019842185144 0.95193007530691620133 0.38248976976191073618 1.5411929822717769234 -0.24970973181617692194 0.16416121001063396778;0.0094909698596854861347 0.77216662318109430263 -0.044905473087330484427 -0.19689311499473996503 0.77768690242774030086 0.93179555158734272968 0.54758316831823705684 1.6095632386087430632 -0.23427422449232912505 -0.18133010971839838565;0.91829377544633972175 0.35961922548832847557 -1.0693527732870604652 -0.12124111894027565783 0.76028067565193691024 0.86108433704242648421 0.68163858333775562137 1.6484662411800259374 0.10177948549205460826 0.056199994209798147249;-0.031501501995131436784 0.010052250354338652591 -0.94310428105422106082 -0.1794645582711489884 0.80677140292620119766 0.88447896714443652311 0.60260437393871535416 1.6276273756937347237 -0.47144678371756820745 -0.30334763429651884215;-0.59589737462372449617 0.92851796562070443297 -0.58389285269436885795 -0.31286983457521633234 0.86936017770668061466 0.92657252413253055057 0.41742376281010512562 1.5577027510357084328 0.10733915589268047674 -1.0932604160677448224;0.74245989652152788452 0.40657067919107436893 -0.030911946065721923604 -0.71380514483412949023 1.0139945991680949788 1.0763417963983217263 -0.24511060209046467429 1.242093452557286426 0.044742644401023115575 -0.55307970122974370319;0.046444285533173826352 0.45058450257500692882 0.051708223951609739999 -0.6537936207516741316 0.98763552055294945298 1.047404751395025313 -0.11301041569191103142 1.3149338208867922262 -0.63392526304119911629 -0.0060294115798133710721;-0.24833941939010381605 0.71056752155228508627 -0.43949697482509841873 -0.6078442779513356653 0.98609962482994195643 1.0267011175007096924 -0.029579280312307342643 1.3544323757950069709 -0.22540019174081821207 -0.34634944443486326282;0.1745038632512841692 0.78063944485863678846 0.14157697393514687145 -0.6649860792650695851 0.96725541399355230432 1.0754435029302740201 -0.14865011520553078617 1.3054657530746698324 0.37058023773979753557 -0.7736925138335324359;-0.31470426896772668579 0.54008218518632267191 -0.0090800779837170216696 -0.73874662941552515782 0.97674525602930073465 1.1272825223914557657 -0.3184745780091697287 1.2154948782597811974 -0.3553344437934319866 0.29930469946004689685];

% Output 1

y1\_step1.ymin = -1;

y1\_step1.gain = [2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2];

y1\_step1.xoffset = [0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0];

% ===== SIMULATION ========

% Dimensions

Q = size(x1,1); % samples

% Input 1

x1 = x1';

xp1 = removeconstantrows\_apply(x1,x1\_step1);

xp1 = mapminmax\_apply(xp1,x1\_step2);

% Layer 1

a1 = tansig\_apply(repmat(b1,1,Q) + IW1\_1\*xp1);

% Layer 2

a2 = repmat(b2,1,Q) + LW2\_1\*a1;

% Output 1

y1 = mapminmax\_reverse(a2,y1\_step1);

y1 = y1';

end

% ===== MODULE FUNCTIONS ========

% Map Minimum and Maximum Input Processing Function

function y = mapminmax\_apply(x,settings)

y = bsxfun(@minus,x,settings.xoffset);

y = bsxfun(@times,y,settings.gain);

y = bsxfun(@plus,y,settings.ymin);

end

% Remove Constants Input Processing Function

function y = removeconstantrows\_apply(x,settings)

y = x(settings.keep,:);

end

% Sigmoid Symmetric Transfer Function

function a = tansig\_apply(n,~)

a = 2 ./ (1 + exp(-2\*n)) - 1;

end

% Map Minimum and Maximum Output Reverse-Processing Function

function x = mapminmax\_reverse(y,settings)

x = bsxfun(@minus,y,settings.ymin);

x = bsxfun(@rdivide,x,settings.gain);

x = bsxfun(@plus,x,settings.xoffset);

end

0.10770027289094248613;-0.18519777915793703138;-0.44743945014597918952;-0.99413293222960275042;-0.42280435808952349097;-0.23659081502454654133;0.5840028190640341732;-0.13716682928466827907;-0.62212230472731622211;-0.072943459202218202675;-0.56964124652762360146;-0.50479518960159741603;-0.74060717619607840945;0.053922277207157941203;-0.59523748515909868928;-1.1150449795511883089;-0.85484324546357293162;-0.83127283334303303519;-0.20638502546502968116;0.23379704837866316369;-0.59385737563185658772;-0.56679831802865321411;-0.37805965196660668015;-0.33762518652425627108;-0.17231270074862778396;-0.1334185073005514921;-0.34042520164161660379;0.39736081339790058076;-0.60928636847835693224;-0.77594617893994843882;-1.3088376480915417943;-0.99795309814012644889;-0.72872639420111628983;-0.30699767602977706682;-0.76061475714218707012;-0.39792270345430991174;-0.86591666117182219953;-0.41632923732060389543;-0.22438543942720087787;0.16451587784558677208;0.083732763425259953971;-0.399194266798001407;0.5985797946933982816;0.15498726000904602951;-0.54746023205161054026;-0.45306160325771616115;-0.6390929106768649115;-1.0443161315147770907;-0.88024291859264058857;0.71216256023267709985;-0.7254839070249412547;-0.45898647092092981215;0.092453652078971479411;-0.6541153965736735687;-0.46813758895979062924;0.015313042110065781809;0.44788399298119557779;0.22535852143433526829;-0.67217554177860405762;-0.58275986554492886782;0.06797576241789698992;-0.41442678211589834003;-0.17287344329323084402;-0.21675312755428832734;0.047466587593139264456;-0.19085959376968170131;-1.0183671073764637427;-1.0398087416646535353;-0.52185061449494940522;0.40459635380083275313;-0.11478258231211492524;0.092384822564310589699;0.021836272558584564341;-0.63060933197534663197;-0.27017721034651193124;-0.46825346641071791121;-1.3172501791127224635];

LW2\_1 = [0.044497832052447311435 -0.40253405182179785582 -0.78177563505978064917 0.26592438952059715973 0.6092408988688458038 0.9640454027664908665 0.88098680112783589458 1.4995122230871027469 -0.66490045501415395712 -0.66443740318135280365;-0.10846498282148568648 0.89575695113845554829 -0.48906172385064156094 0.36723448019156079702 0.39282588089124270692 0.94091368738513891934 0.78244309545969847886 1.2790882750527319267 -0.60074438720086087429 0.053189996094627642331;0.46329677620897413703 0.91298370635432057885 0.68019740924403671034 0.33332571984168585244 0.29600969108220842596 0.96626709815643885282 0.62417853168077108705 1.1557130759367308936 -0.16832769560855243007 -0.11113799583722211439;0.46843244900589803281 0.22950406081898336308 -0.71063725622504758661 0.35548196010666061051 0.36958297921078581139 0.97532816695448065758 0.74022285671111121008 1.2652886160858349829 -0.5944754138612842187 0.53795070367705111192;-0.0039299355647654148418 -0.1306862721336686517 -0.49545004918252216752 0.34079932080029351482 0.59355952399587819102 0.9883376122643035 0.91050249684009276763 1.4697093231790903101 -0.089152565402892389179 -0.83959787573554667262;0.39389528525206707332 -0.012374956317702547753 -1.028822181687399695 0.16912194304628047625 0.860890476793758741 0.99272301457508849154 0.8759595601015291999 1.579963403746351025 0.16444973366446258289 -0.64468868742892271317;0.44609403322384205692 0.055635704981933452318 0.56128862013977431911 0.22249258443988559342 0.75295115908545096062 0.96417277930100875327 0.90736508924798642273 1.5627993079662556575 -1.2077441231322403326 -0.24123404497833283999;0.55371486730022390077 0.6214549443679444618 0.33096227505161818216 0.29121293533859365921 0.632977854536109108 1.0167771637042677391 0.87366466077342652685 1.4900080826391548516 -0.36662122825736609411 0.48902731073047944754;0.58899392665080507747 –

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0.82417451216220627419 0.91032090374599383686 1.6685141270565784222 -1.0359738693012068289 0.29467335783669518223;0.56052544815552018953 -0.15771366714853335411 -0.24756510830833486358 -0.32577785285619076383 0.85087643019842185144 0.95193007530691620133 0.38248976976191073618 1.5411929822717769234 -0.24970973181617692194 0.16416121001063396778;0.0094909698596854861347 0.77216662318109430263 -0.044905473087330484427 -0.19689311499473996503 0.77768690242774030086 0.93179555158734272968 0.54758316831823705684 1.6095632386087430632 -0.23427422449232912505 -0.18133010971839838565;0.91829377544633972175 0.35961922548832847557 -1.0693527732870604652 -0.12124111894027565783 0.76028067565193691024 0.86108433704242648421 0.68163858333775562137 1.6484662411800259374 0.10177948549205460826 0.056199994209798147249;-0.031501501995131436784 0.010052250354338652591 -0.94310428105422106082 -0.1794645582711489884 0.80677140292620119766 0.88447896714443652311 0.60260437393871535416 1.6276273756937347237 -0.47144678371756820745 -0.30334763429651884215;-0.59589737462372449617 0.92851796562070443297 -0.58389285269436885795 -0.31286983457521633234 0.86936017770668061466 0.92657252413253055057 0.41742376281010512562 1.5577027510357084328 0.10733915589268047674 -1.0932604160677448224;0.74245989652152788452 0.40657067919107436893 -0.030911946065721923604 -0.71380514483412949023 1.0139945991680949788 1.0763417963983217263 -0.24511060209046467429 1.242093452557286426 0.044742644401023115575 -0.55307970122974370319;0.046444285533173826352 0.45058450257500692882 0.051708223951609739999 -0.6537936207516741316 0.98763552055294945298 1.047404751395025313 -0.11301041569191103142 1.3149338208867922262 -0.63392526304119911629 -0.0060294115798133710721;-0.24833941939010381605 0.71056752155228508627 -0.43949697482509841873 -0.6078442779513356653 0.98609962482994195643 1.0267011175007096924 -0.029579280312307342643 1.3544323757950069709 -0.22540019174081821207 -0.34634944443486326282;0.1745038632512841692 0.78063944485863678846 0.14157697393514687145 -0.6649860792650695851 0.96725541399355230432 1.0754435029302740201 -0.14865011520553078617 1.3054657530746698324 0.37058023773979753557 -0.7736925138335324359;-0.31470426896772668579 0.54008218518632267191 -0.0090800779837170216696 -0.73874662941552515782 0.97674525602930073465 1.1272825223914557657 -0.3184745780091697287 1.2154948782597811974 -0.3553344437934319866 0.29930469946004689685];

% Output 1

y1\_step1.ymin = -1;

y1\_step1.gain = [2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2];

y1\_step1.xoffset = [0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0];

% ===== SIMULATION ========

% Dimensions

Q = size(x1,1); % samples

% Input 1

x1 = x1';

xp1 = removeconstantrows\_apply(x1,x1\_step1);

xp1 = mapminmax\_apply(xp1,x1\_step2);

% Layer 1

a1 = tansig\_apply(repmat(b1,1,Q) + IW1\_1\*xp1);

% Layer 2

a2 = repmat(b2,1,Q) + LW2\_1\*a1;

% Output 1

y1 = mapminmax\_reverse(a2,y1\_step1);

y1 = y1';

end

% ===== MODULE FUNCTIONS ========

% Map Minimum and Maximum Input Processing Function

function y = mapminmax\_apply(x,settings)

y = bsxfun(@minus,x,settings.xoffset);

y = bsxfun(@times,y,settings.gain);

y = bsxfun(@plus,y,settings.ymin);

end

% Remove Constants Input Processing Function

function y = removeconstantrows\_apply(x,settings)

y = x(settings.keep,:);

end

% Sigmoid Symmetric Transfer Function

function a = tansig\_apply(n,~)

a = 2 ./ (1 + exp(-2\*n)) - 1;

end

% Map Minimum and Maximum Output Reverse-Processing Function

function x = mapminmax\_reverse(y,settings)

x = bsxfun(@minus,y,settings.ymin);

x = bsxfun(@rdivide,x,settings.gain);

x = bsxfun(@plus,x,settings.xoffset);

end

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1.0601624656076154007 1.5516985217747407688 -0.85213040038343712546 0.1358665330128047688;0.77857117768247618983 -0.23086246148021311031 -0.13715622848400940703 0.41036905390425448825 0.33654007402447849717 0.59601430379459618969 1.0805165377607066635 1.4447367279969900444 -0.57373796775609653409 0.062943296642337845381;-1.0861817796064345831 -0.1115696932332351371 -0.45121295685892642835 0.37234346747979174541 0.2264995001617856607 0.6841804545336155341 0.90170072472721818357 1.3232975917782019426 -0.58665788137251007051 -0.7326707370481149173;0.77597173784599859925 -0.15497097287874025962 -0.36110153016255902569 0.34368746556079776688 0.24107884248084018863 0.73721729290092663511 0.88459912572358390115 1.3712216695555627943 -0.40335921649521216947 0.43752360600229001086;0.58558348487527789317 -0.064614179760463935631 0.02022979772091780884 0.36603131084095413827 0.37420469299396585949 0.65209084835458119844 1.1168824120175804282 1.5661818053291827191 -0.63878309873814020925 0.46818302902052311154;0.37993141441217720411 0.58600354570908652629 -0.49157099048349045534 0.10175871847225813338 0.62582969208650329751 0.83516703978616424475 0.90430577006673995566 1.6760166360894288573 0.47628020356291944637 -0.29492339193072913961;-0.34357665914099844162 0.19509525136902811093 -0.16259292479402323583 0.21959748608353024668 0.52651236741464657598 0.77653118280434751952 1.0121120622090196139 1.6615538413520880567 -0.95255189620089386615 -0.4536494548126083215;0.16070291439117725951 0.32668070806523497041 -0.89680903529006217312 0.29900679565218046818 0.5308914386893022197 0.68205927427684565068 1.1399596157424374265 1.6846693464012911789 -0.9622729473728099947 0.48174382894467637772;0.17118653385758769714 -0.0084059357920857839114 -0.72978941359113302934 0.21581882025393611668 0.51507016712367847955 0.79893354637775049198 0.9934513040814325624 1.6602413973094698463 -0.49275725115770968587 -0.3266444414648901895;0.9611053390116707229 0.13985688743503549292 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-0.40763633372527480203 0.11651489881256628378;0.28924472569677878164 0.83369761022555144425 0.27316601897008835342 0.23530551919951750439 -0.032807429305132543296 0.42081354145371935305 0.414955219750257287 0.66160427564051316196 0.29940717098126223839 0.0031492514330214325599;0.42343677194490941806 -0.27991980832091795106 -0.68255494830198881751 0.24736641558859434609 -0.055573610430434287888 0.56077451951347900838 0.43424947198816182814 0.78067195294449653886 0.033846745398182435938 -0.20162026140006622521;0.052627062688791352574 0.61309739056293111048 0.019306221258091543075 0.3529526452315082663 0.095475205202836088691 0.66728931505709776495 0.76584247913353420412 1.1846053682544419594 -0.15933927554200016941 -0.83309997130526047826;-0.52491754444596905316 -0.0084382279434236286825 -1.1843261568071226097 0.36047598950905224147 0.30784594242670809683 0.68664506270578817837 1.0417908573636736058 1.5025353230164788521 0.095721721369064025065 -1.1209739341495315035;-0.40550669556289470341 0.17922203030749603303 -0.17860594949115946029 0.35662867587527874447 0.20259543857049261417 0.70494278948376631888 0.87539184067674924439 1.3245773250041681379 -0.65268256955240755435 -0.029304514863034196448;-0.62967730061970750288 0.02907065375780544525 -0.34078374863344557122 0.34598881074213566622 0.13724628445450029468 0.71309826642256790574 0.79952584925415803863 1.2483444691318741349 -0.39590824545689312641 -0.50493160878606457853;-0.13648875608896843259 0.91641477961471118352 -0.95031754692774406124 0.38682173903315258956 0.25004635934044622259 0.64394385907832463189 0.9640062985236442783 1.3538360694479394386 0.1128947840634397376 0.16803161498593044421;-0.16844759569688616541 0.88162887349667284909 -0.90266524230357458869 0.35594746374152319568 0.30210133275548595178 0.69555830892067638249 1.0291689976585540744 1.4956996984874963985 0.10886600172753702065 0.48038630054298359084;-0.18272150433548439707 1.041714899103027836 -0.26298933854231598684 0.11211800193666927872 0.58291587934156952056 0.8368578935579173983 0.89371181952047618058 1.663376924812262958 0.008130043994939510979 -0.37641314369174250221;-0.55596570641515574707 0.89657887438595573748 -0.97655196643350183905 0.27846016028363185235 0.52350340109458559645 0.68885252442861444333 1.1125463699082334124 1.6712327835855302904 -0.23285379874286835089 0.081438772334270256859;1.0392599752688767012 0.14757011839237835216 -0.056666992573614058393 0.30400997747206465194 0.4826347387670635869 0.66303551569616014927 1.1322515534496200296 1.6450580199928164227 -0.76003510950118102762 0.30541742854187509115;0.97160247859661663661 0.56847886603274344619 -0.16388314738346390631 0.26944608760076582676 0.49701771422858764815 0.72700772315596029483 1.0740156282486958972 1.6664987721305224433 0.27656455727066803219 -0.027735290388858201832;0.37338658504881083733 -0.28977057583856841161 0.17124664225042898758 0.1170100204231538793 0.59043013424875123718 0.82417451216220627419 0.91032090374599383686 1.6685141270565784222 -1.0359738693012068289 0.29467335783669518223;0.56052544815552018953 -0.15771366714853335411 -0.24756510830833486358 -0.32577785285619076383 0.85087643019842185144 0.95193007530691620133 0.38248976976191073618 1.5411929822717769234 -0.24970973181617692194 0.16416121001063396778;0.0094909698596854861347 0.77216662318109430263 -0.044905473087330484427 -0.19689311499473996503 0.77768690242774030086 0.93179555158734272968 0.54758316831823705684 1.6095632386087430632 -0.23427422449232912505 -0.18133010971839838565;0.91829377544633972175 0.35961922548832847557 -1.0693527732870604652 -0.12124111894027565783 0.76028067565193691024 0.86108433704242648421 0.68163858333775562137 1.6484662411800259374 0.10177948549205460826 0.056199994209798147249;-0.031501501995131436784 0.010052250354338652591 -0.94310428105422106082 -0.1794645582711489884 0.80677140292620119766 0.88447896714443652311 0.60260437393871535416 1.6276273756937347237 -0.47144678371756820745 -0.30334763429651884215;-0.59589737462372449617 0.92851796562070443297 -0.58389285269436885795 -0.31286983457521633234 0.86936017770668061466 0.92657252413253055057 0.41742376281010512562 1.5577027510357084328 0.10733915589268047674 -1.0932604160677448224;0.74245989652152788452 0.40657067919107436893 -0.030911946065721923604 -0.71380514483412949023 1.0139945991680949788 1.0763417963983217263 -0.24511060209046467429 1.242093452557286426 0.044742644401023115575 -0.55307970122974370319;0.046444285533173826352 0.45058450257500692882 0.051708223951609739999 -0.6537936207516741316 0.98763552055294945298 1.047404751395025313 -0.11301041569191103142 1.3149338208867922262 -0.63392526304119911629 -0.0060294115798133710721;-0.24833941939010381605 0.71056752155228508627 -0.43949697482509841873 -0.6078442779513356653 0.98609962482994195643 1.0267011175007096924 -0.029579280312307342643 1.3544323757950069709 -0.22540019174081821207 -0.34634944443486326282;0.1745038632512841692 0.78063944485863678846 0.14157697393514687145 -0.6649860792650695851 0.96725541399355230432 1.0754435029302740201 -0.14865011520553078617 1.3054657530746698324 0.37058023773979753557 -0.7736925138335324359;-0.31470426896772668579 0.54008218518632267191 -0.0090800779837170216696 -0.73874662941552515782 0.97674525602930073465 1.1272825223914557657 -0.3184745780091697287 1.2154948782597811974 -0.3553344437934319866 0.29930469946004689685];

% Output 1

y1\_step1.ymin = -1;

y1\_step1.gain = [2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2];

y1\_step1.xoffset = [0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0];

% ===== SIMULATION ========

% Dimensions

Q = size(x1,1); % samples

% Input 1

x1 = x1';

xp1 = removeconstantrows\_apply(x1,x1\_step1);

xp1 = mapminmax\_apply(xp1,x1\_step2);

% Layer 1

a1 = tansig\_apply(repmat(b1,1,Q) + IW1\_1\*xp1);

% Layer 2

a2 = repmat(b2,1,Q) + LW2\_1\*a1;

% Output 1

y1 = mapminmax\_reverse(a2,y1\_step1);

y1 = y1';

end

% ===== MODULE FUNCTIONS ========

% Map Minimum and Maximum Input Processing Function

function y = mapminmax\_apply(x,settings)

y = bsxfun(@minus,x,settings.xoffset);

y = bsxfun(@times,y,settings.gain);

y = bsxfun(@plus,y,settings.ymin);

end

% Remove Constants Input Processing Function

function y = removeconstantrows\_apply(x,settings)

y = x(settings.keep,:);

end

% Sigmoid Symmetric Transfer Function

function a = tansig\_apply(n,~)

a = 2 ./ (1 + exp(-2\*n)) - 1;

end

% Map Minimum and Maximum Output Reverse-Processing Function

function x = mapminmax\_reverse(y,settings)

x = bsxfun(@minus,y,settings.ymin);

x = bsxfun(@rdivide,x,settings.gain);

x = bsxfun(@plus,x,settings.xoffset);

end

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-0.16388314738346390631 0.26944608760076582676 0.49701771422858764815 0.72700772315596029483 1.0740156282486958972 1.6664987721305224433 0.27656455727066803219 -0.027735290388858201832;0.37338658504881083733 -0.28977057583856841161 0.17124664225042898758 0.1170100204231538793 0.59043013424875123718 0.82417451216220627419 0.91032090374599383686 1.6685141270565784222 -1.0359738693012068289 0.29467335783669518223;0.56052544815552018953 -0.15771366714853335411 -0.24756510830833486358 -0.32577785285619076383 0.85087643019842185144 0.95193007530691620133 0.38248976976191073618 1.5411929822717769234 -0.24970973181617692194 0.16416121001063396778;0.0094909698596854861347 0.77216662318109430263 -0.044905473087330484427 -0.19689311499473996503 0.77768690242774030086 0.93179555158734272968 0.54758316831823705684 1.6095632386087430632 -0.23427422449232912505 -0.18133010971839838565;0.91829377544633972175 0.35961922548832847557 -1.0693527732870604652 -0.12124111894027565783 0.76028067565193691024 0.86108433704242648421 0.68163858333775562137 1.6484662411800259374 0.10177948549205460826 0.056199994209798147249;-0.031501501995131436784 0.010052250354338652591 -0.94310428105422106082 -0.1794645582711489884 0.80677140292620119766 0.88447896714443652311 0.60260437393871535416 1.6276273756937347237 -0.47144678371756820745 -0.30334763429651884215;-0.59589737462372449617 0.92851796562070443297 -0.58389285269436885795 -0.31286983457521633234 0.86936017770668061466 0.92657252413253055057 0.41742376281010512562 1.5577027510357084328 0.10733915589268047674 -1.0932604160677448224;0.74245989652152788452 0.40657067919107436893 -0.030911946065721923604 -0.71380514483412949023 1.0139945991680949788 1.0763417963983217263 -0.24511060209046467429 1.242093452557286426 0.044742644401023115575 -0.55307970122974370319;0.046444285533173826352 0.45058450257500692882 0.051708223951609739999 -0.6537936207516741316 0.98763552055294945298 1.047404751395025313 -0.11301041569191103142 1.3149338208867922262 -0.63392526304119911629 -0.0060294115798133710721;-0.24833941939010381605 0.71056752155228508627 -0.43949697482509841873 -0.6078442779513356653 0.98609962482994195643 1.0267011175007096924 -0.029579280312307342643 1.3544323757950069709 -0.22540019174081821207 -0.34634944443486326282;0.1745038632512841692 0.78063944485863678846 0.14157697393514687145 -0.6649860792650695851 0.96725541399355230432 1.0754435029302740201 -0.14865011520553078617 1.3054657530746698324 0.37058023773979753557 -0.7736925138335324359;-0.31470426896772668579 0.54008218518632267191 -0.0090800779837170216696 -0.73874662941552515782 0.97674525602930073465 1.1272825223914557657 -0.3184745780091697287 1.2154948782597811974 -0.3553344437934319866 0.29930469946004689685];

% Output 1

y1\_step1.ymin = -1;

y1\_step1.gain = [2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2];

y1\_step1.xoffset = [0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0];

% ===== SIMULATION ========

% Dimensions

Q = size(x1,1); % samples

% Input 1

x1 = x1';

xp1 = removeconstantrows\_apply(x1,x1\_step1);

xp1 = mapminmax\_apply(xp1,x1\_step2);

% Layer 1

a1 = tansig\_apply(repmat(b1,1,Q) + IW1\_1\*xp1);

% Layer 2

a2 = repmat(b2,1,Q) + LW2\_1\*a1;

% Output 1

y1 = mapminmax\_reverse(a2,y1\_step1);

y1 = y1';

end

% ===== MODULE FUNCTIONS ========

% Map Minimum and Maximum Input Processing Function

function y = mapminmax\_apply(x,settings)

y = bsxfun(@minus,x,settings.xoffset);

y = bsxfun(@times,y,settings.gain);

y = bsxfun(@plus,y,settings.ymin);

end

% Remove Constants Input Processing Function

function y = removeconstantrows\_apply(x,settings)

y = x(settings.keep,:);

end

% Sigmoid Symmetric Transfer Function

function a = tansig\_apply(n,~)

a = 2 ./ (1 + exp(-2\*n)) - 1;

end

% Map Minimum and Maximum Output Reverse-Processing Function

function x = mapminmax\_reverse(y,settings)

x = bsxfun(@minus,y,settings.ymin);

x = bsxfun(@rdivide,x,settings.gain);

x = bsxfun(@plus,x,settings.xoffset);

end

1.3005521620413602601 -0.44931081149188273338 0.53650433842372602378;0.61995816208229315158 0.52769693902332259761 -0.11147363037098317884 -0.40021705870471946387 1.0085796040348402602 0.99535905456443152239 0.27485120837793514115 1.440832908584177785 -0.012514710405709178129 -0.9938581256057108515;0.24999340639517103613 0.26978411516927913727 -1.0663547258719145994 -0.37170787540979505215 0.98805721297810555903 1.0071053175649362643 0.30389369199784610487 1.451511768850543227 0.018060409800917262557 0.52925685038483560874;0.52887453573930964801 0.68558761014970370784 0.56915146132686567082 -0.40144275569567677842 1.0209857049536934515 0.97523297222884797186 0.287888801644097303 1.4320203802240094593 -0.38291979771049183823 -1.0041207837805592451;0.84834836060750107301 0.38267713533469399634 -0.5383587257556029515 -0.60377416536702799288 0.97962595835942389844 1.1146599218376702645 -0.084047106178881850203 1.2939483727443104044 -0.40861535423225486818 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-0.16388314738346390631 0.26944608760076582676 0.49701771422858764815 0.72700772315596029483 1.0740156282486958972 1.6664987721305224433 0.27656455727066803219 -0.027735290388858201832;0.37338658504881083733 -0.28977057583856841161 0.17124664225042898758 0.1170100204231538793 0.59043013424875123718 0.82417451216220627419 0.91032090374599383686 1.6685141270565784222 -1.0359738693012068289 0.29467335783669518223;0.56052544815552018953 -0.15771366714853335411 -0.24756510830833486358 -0.32577785285619076383 0.85087643019842185144 0.95193007530691620133 0.38248976976191073618 1.5411929822717769234 -0.24970973181617692194 0.16416121001063396778;0.0094909698596854861347 0.77216662318109430263 -0.044905473087330484427 -0.19689311499473996503 0.77768690242774030086 0.93179555158734272968 0.54758316831823705684 1.6095632386087430632 -0.23427422449232912505 -0.18133010971839838565;0.91829377544633972175 0.35961922548832847557 -1.0693527732870604652 -0.12124111894027565783 0.76028067565193691024 0.86108433704242648421 0.68163858333775562137 1.6484662411800259374 0.10177948549205460826 0.056199994209798147249;-0.031501501995131436784 0.010052250354338652591 -0.94310428105422106082 -0.1794645582711489884 0.80677140292620119766 0.88447896714443652311 0.60260437393871535416 1.6276273756937347237 -0.47144678371756820745 -0.30334763429651884215;-0.59589737462372449617 0.92851796562070443297 -0.58389285269436885795 -0.31286983457521633234 0.86936017770668061466 0.92657252413253055057 0.41742376281010512562 1.5577027510357084328 0.10733915589268047674 -1.0932604160677448224;0.74245989652152788452 0.40657067919107436893 -0.030911946065721923604 -0.71380514483412949023 1.0139945991680949788 1.0763417963983217263 -0.24511060209046467429 1.242093452557286426 0.044742644401023115575 -0.55307970122974370319;0.046444285533173826352 0.45058450257500692882 0.051708223951609739999 -0.6537936207516741316 0.98763552055294945298 1.047404751395025313 -0.11301041569191103142 1.3149338208867922262 -0.63392526304119911629 -0.0060294115798133710721;-0.24833941939010381605 0.71056752155228508627 -0.43949697482509841873 -0.6078442779513356653 0.98609962482994195643 1.0267011175007096924 -0.029579280312307342643 1.3544323757950069709 -0.22540019174081821207 -0.34634944443486326282;0.1745038632512841692 0.78063944485863678846 0.14157697393514687145 -0.6649860792650695851 0.96725541399355230432 1.0754435029302740201 -0.14865011520553078617 1.3054657530746698324 0.37058023773979753557 -0.7736925138335324359;-0.31470426896772668579 0.54008218518632267191 -0.0090800779837170216696 -0.73874662941552515782 0.97674525602930073465 1.1272825223914557657 -0.3184745780091697287 1.2154948782597811974 -0.3553344437934319866 0.29930469946004689685];

% Output 1

y1\_step1.ymin = -1;

y1\_step1.gain = [2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2];

y1\_step1.xoffset = [0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0];

% ===== SIMULATION ========

% Dimensions

Q = size(x1,1); % samples

% Input 1

x1 = x1';

xp1 = removeconstantrows\_apply(x1,x1\_step1);

xp1 = mapminmax\_apply(xp1,x1\_step2);

% Layer 1

a1 = tansig\_apply(repmat(b1,1,Q) + IW1\_1\*xp1);

% Layer 2

a2 = repmat(b2,1,Q) + LW2\_1\*a1;

% Output 1

y1 = mapminmax\_reverse(a2,y1\_step1);

y1 = y1';

end

% ===== MODULE FUNCTIONS ========

% Map Minimum and Maximum Input Processing Function

function y = mapminmax\_apply(x,settings)

y = bsxfun(@minus,x,settings.xoffset);

y = bsxfun(@times,y,settings.gain);

y = bsxfun(@plus,y,settings.ymin);

end

% Remove Constants Input Processing Function

function y = removeconstantrows\_apply(x,settings)

y = x(settings.keep,:);

end

% Sigmoid Symmetric Transfer Function

function a = tansig\_apply(n,~)

a = 2 ./ (1 + exp(-2\*n)) - 1;

end

% Map Minimum and Maximum Output Reverse-Processing Function

function x = mapminmax\_reverse(y,settings)

x = bsxfun(@minus,y,settings.ymin);

x = bsxfun(@rdivide,x,settings.gain);

x = bsxfun(@plus,x,settings.xoffset);

end

0.093459018435617643994 0.55337756463208698232 0.37692006815873801973 0.29308721925423097954 0.74883972767118722746 0.96598518049255177598 1.4332743750441043762 -0.77307226599296385849 -0.70635414416186348419;-0.55044819866906491423 -0.26327894689028508157 -0.3909799119262499234 0.40065555490705928587 0.3780494029723844851 0.68761671238868671274 1.099624588948536319 1.5289023884267478604 -0.59369558624794149804 -0.77525712296809456969;0.015401175491335076378 1.1381542282646324171 0.66702399567532977276 0.30342379276199343829 0.48819552530920284905 0.77855834045482164019 1.0431251822241656146 1.6050326441466453709 -0.096762438893696983699 -0.5058441100895872955;-0.57016306668682203984 0.5331600276517811654 -0.41127844393321616456 0.010997054021869109852 0.75220027707611603063 0.86621501552595481233 0.82873715023122951351 1.682115029214195312 0.28134077182926869876 -0.94997532924230509987;0.83243457769214335151 0.22947419700417645561 0.041210815437348426171 0.15791822696100882295 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0.29669984671808974364 -0.016842244692237492293 0.58493355620956899443 0.56189571776199886965 0.91077153607241856381 0.11289616945084603172 -0.17611541125416932396;0.19615254511105340018 0.76868943668711298134 0.38167506492864000656 0.36821407233714775753 0.15154025202322785049 0.69728590874875751027 0.83713227227383646412 1.2650325390537253689 0.37904774855564465907 -0.046021441571447808949;-0.29587838592967002915 0.3404595990029418151 -0.0038333192124644505094 0.34811676375851174914 0.34536416449537016282 0.70008621807306492535 1.0601624656076154007 1.5516985217747407688 -0.85213040038343712546 0.1358665330128047688;0.77857117768247618983 -0.23086246148021311031 -0.13715622848400940703 0.41036905390425448825 0.33654007402447849717 0.59601430379459618969 1.0805165377607066635 1.4447367279969900444 -0.57373796775609653409 0.062943296642337845381;-1.0861817796064345831 -0.1115696932332351371 -0.45121295685892642835 0.37234346747979174541 0.2264995001617856607 0.6841804545336155341 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% Output 1

y1\_step1.ymin = -1;

y1\_step1.gain = [2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2];

y1\_step1.xoffset = [0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0];

% ===== SIMULATION ========

% Dimensions

Q = size(x1,1); % samples

% Input 1

x1 = x1';

xp1 = removeconstantrows\_apply(x1,x1\_step1);

xp1 = mapminmax\_apply(xp1,x1\_step2);

% Layer 1

a1 = tansig\_apply(repmat(b1,1,Q) + IW1\_1\*xp1);

% Layer 2

a2 = repmat(b2,1,Q) + LW2\_1\*a1;

% Output 1

y1 = mapminmax\_reverse(a2,y1\_step1);

y1 = y1';

end

% ===== MODULE FUNCTIONS ========

% Map Minimum and Maximum Input Processing Function

function y = mapminmax\_apply(x,settings)

y = bsxfun(@minus,x,settings.xoffset);

y = bsxfun(@times,y,settings.gain);

y = bsxfun(@plus,y,settings.ymin);

end

% Remove Constants Input Processing Function

function y = removeconstantrows\_apply(x,settings)

y = x(settings.keep,:);

end

% Sigmoid Symmetric Transfer Function

function a = tansig\_apply(n,~)

a = 2 ./ (1 + exp(-2\*n)) - 1;

end

% Map Minimum and Maximum Output Reverse-Processing Function

function x = mapminmax\_reverse(y,settings)

x = bsxfun(@minus,y,settings.ymin);

x = bsxfun(@rdivide,x,settings.gain);

x = bsxfun(@plus,x,settings.xoffset);

end

0.97739734971367719929 1.1451775465783564645 -0.35748218004389242797 1.1665688452081024451 -0.47568673173384612429 0.23884754608435176948;-0.54578345002016670495 -0.13649587260673842759 -0.64196229024512563299 -0.81775756539005195478 0.98217796801708456833 1.1989895051473999921 -0.52077791106001591892 1.0707837345145707619 0.0054483654352273170121 -1.1849402874701355781;0.67676206014703665925 -0.40405397233875628427 -0.29114640079010517537 0.37663400165833571531 0.17138728099150779549 0.66943750304753146807 0.86858628634105072841 1.2735978688920535085 -0.69537987199136541694 -0.41678157905593338217;-0.070426893130506346141 -0.62898918595300390422 0.015853973401605572086 0.29870320230443697662 -0.014348419283018578468 0.57477688835447571236 0.56848046018316600314 0.91244548779535816774 -0.37093997462135530618 -0.77651782287796111692;0.81764006183960280527 0.28850792736074815092 0.88878563600714821646 0.25337641648847736286 -0.038903916475402706976 0.53402198084494412189 0.43423065143643885255 0.75863092458525438477 0.58269320239811117634 -0.58307491132743693996;-0.41869118819593142966 -0.76148441690321688746 -0.84376910446949171529 0.29669984671808974364 -0.016842244692237492293 0.58493355620956899443 0.56189571776199886965 0.91077153607241856381 0.11289616945084603172 -0.17611541125416932396;0.19615254511105340018 0.76868943668711298134 0.38167506492864000656 0.36821407233714775753 0.15154025202322785049 0.69728590874875751027 0.83713227227383646412 1.2650325390537253689 0.37904774855564465907 -0.046021441571447808949;-0.29587838592967002915 0.3404595990029418151 -0.0038333192124644505094 0.34811676375851174914 0.34536416449537016282 0.70008621807306492535 1.0601624656076154007 1.5516985217747407688 -0.85213040038343712546 0.1358665330128047688;0.77857117768247618983 -0.23086246148021311031 -0.13715622848400940703 0.41036905390425448825 0.33654007402447849717 0.59601430379459618969 1.0805165377607066635 1.4447367279969900444 -0.57373796775609653409 0.062943296642337845381;-1.0861817796064345831 -0.1115696932332351371 -0.45121295685892642835 0.37234346747979174541 0.2264995001617856607 0.6841804545336155341 0.90170072472721818357 1.3232975917782019426 -0.58665788137251007051 -0.7326707370481149173;0.77597173784599859925 -0.15497097287874025962 -0.36110153016255902569 0.34368746556079776688 0.24107884248084018863 0.73721729290092663511 0.88459912572358390115 1.3712216695555627943 -0.40335921649521216947 0.43752360600229001086;0.58558348487527789317 -0.064614179760463935631 0.02022979772091780884 0.36603131084095413827 0.37420469299396585949 0.65209084835458119844 1.1168824120175804282 1.5661818053291827191 -0.63878309873814020925 0.46818302902052311154;0.37993141441217720411 0.58600354570908652629 -0.49157099048349045534 0.10175871847225813338 0.62582969208650329751 0.83516703978616424475 0.90430577006673995566 1.6760166360894288573 0.47628020356291944637 -0.29492339193072913961;-0.34357665914099844162 0.19509525136902811093 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1.00771348386146542 0.25350202517037789818 1.5081107692876651871 -0.64513261116772113724 -0.61116643265855641332;0.6421159241267382356 0.11899367042594123645 -0.30207834504640118656 -0.23203102439263498247 0.82162828394942533095 0.91090210122390324887 0.52500914634998363528 1.5974238225667807267 -0.68536277373807608093 -0.20442688168934483595;-0.14887106915830017329 -0.013269041974663303707 -0.21886910692482550167 -0.19276791110166802135 0.7788246566726887421 0.93247633329841372873 0.55170344121757119993 1.6062931648190563738 -0.65796230380293219131 -0.49986619878242743997;-0.37898665860531455252 -0.13784210745766181661 -0.53716229643799595639 -0.24466012730224140359 0.80141542192183923277 0.94271029826702112953 0.48571426416881957611 1.5857084752110990333 -0.74349857928596985168 -0.54903700095789331748;-0.26043053694817841492 1.2688495123439571532 0.27131477204711346163 -0.38081435285279791048 0.88644221091504826759 0.95578842130492169815 0.31375595926393906598 1.5170289869729813859 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0.66728931505709776495 0.76584247913353420412 1.1846053682544419594 -0.15933927554200016941 -0.83309997130526047826;-0.52491754444596905316 -0.0084382279434236286825 -1.1843261568071226097 0.36047598950905224147 0.30784594242670809683 0.68664506270578817837 1.0417908573636736058 1.5025353230164788521 0.095721721369064025065 -1.1209739341495315035;-0.40550669556289470341 0.17922203030749603303 -0.17860594949115946029 0.35662867587527874447 0.20259543857049261417 0.70494278948376631888 0.87539184067674924439 1.3245773250041681379 -0.65268256955240755435 -0.029304514863034196448;-0.62967730061970750288 0.02907065375780544525 -0.34078374863344557122 0.34598881074213566622 0.13724628445450029468 0.71309826642256790574 0.79952584925415803863 1.2483444691318741349 -0.39590824545689312641 -0.50493160878606457853;-0.13648875608896843259 0.91641477961471118352 -0.95031754692774406124 0.38682173903315258956 0.25004635934044622259 0.64394385907832463189 0.9640062985236442783 1.3538360694479394386 0.1128947840634397376 0.16803161498593044421;-0.16844759569688616541 0.88162887349667284909 -0.90266524230357458869 0.35594746374152319568 0.30210133275548595178 0.69555830892067638249 1.0291689976585540744 1.4956996984874963985 0.10886600172753702065 0.48038630054298359084;-0.18272150433548439707 1.041714899103027836 -0.26298933854231598684 0.11211800193666927872 0.58291587934156952056 0.8368578935579173983 0.89371181952047618058 1.663376924812262958 0.008130043994939510979 -0.37641314369174250221;-0.55596570641515574707 0.89657887438595573748 -0.97655196643350183905 0.27846016028363185235 0.52350340109458559645 0.68885252442861444333 1.1125463699082334124 1.6712327835855302904 -0.23285379874286835089 0.081438772334270256859;1.0392599752688767012 0.14757011839237835216 -0.056666992573614058393 0.30400997747206465194 0.4826347387670635869 0.66303551569616014927 1.1322515534496200296 1.6450580199928164227 -0.76003510950118102762 0.30541742854187509115;0.97160247859661663661 0.56847886603274344619 -0.16388314738346390631 0.26944608760076582676 0.49701771422858764815 0.72700772315596029483 1.0740156282486958972 1.6664987721305224433 0.27656455727066803219 -0.027735290388858201832;0.37338658504881083733 -0.28977057583856841161 0.17124664225042898758 0.1170100204231538793 0.59043013424875123718 0.82417451216220627419 0.91032090374599383686 1.6685141270565784222 -1.0359738693012068289 0.29467335783669518223;0.56052544815552018953 -0.15771366714853335411 -0.24756510830833486358 -0.32577785285619076383 0.85087643019842185144 0.95193007530691620133 0.38248976976191073618 1.5411929822717769234 -0.24970973181617692194 0.16416121001063396778;0.0094909698596854861347 0.77216662318109430263 -0.044905473087330484427 -0.19689311499473996503 0.77768690242774030086 0.93179555158734272968 0.54758316831823705684 1.6095632386087430632 -0.23427422449232912505 -0.18133010971839838565;0.91829377544633972175 0.35961922548832847557 -1.0693527732870604652 -0.12124111894027565783 0.76028067565193691024 0.86108433704242648421 0.68163858333775562137 1.6484662411800259374 0.10177948549205460826 0.056199994209798147249;-0.031501501995131436784 0.010052250354338652591 -0.94310428105422106082 -0.1794645582711489884 0.80677140292620119766 0.88447896714443652311 0.60260437393871535416 1.6276273756937347237 -0.47144678371756820745 -0.30334763429651884215;-0.59589737462372449617 0.92851796562070443297 -0.58389285269436885795 -0.31286983457521633234 0.86936017770668061466 0.92657252413253055057 0.41742376281010512562 1.5577027510357084328 0.10733915589268047674 -1.0932604160677448224;0.74245989652152788452 0.40657067919107436893 -0.030911946065721923604 -0.71380514483412949023 1.0139945991680949788 1.0763417963983217263 -0.24511060209046467429 1.242093452557286426 0.044742644401023115575 -0.55307970122974370319;0.046444285533173826352 0.45058450257500692882 0.051708223951609739999 -0.6537936207516741316 0.98763552055294945298 1.047404751395025313 -0.11301041569191103142 1.3149338208867922262 -0.63392526304119911629 -0.0060294115798133710721;-0.24833941939010381605 0.71056752155228508627 -0.43949697482509841873 -0.6078442779513356653 0.98609962482994195643 1.0267011175007096924 -0.029579280312307342643 1.3544323757950069709 -0.22540019174081821207 -0.34634944443486326282;0.1745038632512841692 0.78063944485863678846 0.14157697393514687145 -0.6649860792650695851 0.96725541399355230432 1.0754435029302740201 -0.14865011520553078617 1.3054657530746698324 0.37058023773979753557 -0.7736925138335324359;-0.31470426896772668579 0.54008218518632267191 -0.0090800779837170216696 -0.73874662941552515782 0.97674525602930073465 1.1272825223914557657 -0.3184745780091697287 1.2154948782597811974 -0.3553344437934319866 0.29930469946004689685];

% Output 1

y1\_step1.ymin = -1;

y1\_step1.gain = [2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2];

y1\_step1.xoffset = [0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0];

% ===== SIMULATION ========

% Dimensions

Q = size(x1,1); % samples

% Input 1

x1 = x1';

xp1 = removeconstantrows\_apply(x1,x1\_step1);

xp1 = mapminmax\_apply(xp1,x1\_step2);

% Layer 1

a1 = tansig\_apply(repmat(b1,1,Q) + IW1\_1\*xp1);

% Layer 2

a2 = repmat(b2,1,Q) + LW2\_1\*a1;

% Output 1

y1 = mapminmax\_reverse(a2,y1\_step1);

y1 = y1';

end

% ===== MODULE FUNCTIONS ========

% Map Minimum and Maximum Input Processing Function

function y = mapminmax\_apply(x,settings)

y = bsxfun(@minus,x,settings.xoffset);

y = bsxfun(@times,y,settings.gain);

y = bsxfun(@plus,y,settings.ymin);

end

% Remove Constants Input Processing Function

function y = removeconstantrows\_apply(x,settings)

y = x(settings.keep,:);

end

% Sigmoid Symmetric Transfer Function

function a = tansig\_apply(n,~)

a = 2 ./ (1 + exp(-2\*n)) - 1;

end

% Map Minimum and Maximum Output Reverse-Processing Function

function x = mapminmax\_reverse(y,settings)

x = bsxfun(@minus,y,settings.ymin);

x = bsxfun(@rdivide,x,settings.gain);

x = bsxfun(@plus,x,settings.xoffset);

end

0.66728931505709776495 0.76584247913353420412 1.1846053682544419594 -0.15933927554200016941 -0.83309997130526047826;-0.52491754444596905316 -0.0084382279434236286825 -1.1843261568071226097 0.36047598950905224147 0.30784594242670809683 0.68664506270578817837 1.0417908573636736058 1.5025353230164788521 0.095721721369064025065 -1.1209739341495315035;-0.40550669556289470341 0.17922203030749603303 -0.17860594949115946029 0.35662867587527874447 0.20259543857049261417 0.70494278948376631888 0.87539184067674924439 1.3245773250041681379 -0.65268256955240755435 -0.029304514863034196448;-0.62967730061970750288 0.02907065375780544525 -0.34078374863344557122 0.34598881074213566622 0.13724628445450029468 0.71309826642256790574 0.79952584925415803863 1.2483444691318741349 -0.39590824545689312641 -0.50493160878606457853;-0.13648875608896843259 0.91641477961471118352 -0.95031754692774406124 0.38682173903315258956 0.25004635934044622259 0.64394385907832463189 0.9640062985236442783 1.3538360694479394386 0.1128947840634397376 0.16803161498593044421;-0.16844759569688616541 0.88162887349667284909 -0.90266524230357458869 0.35594746374152319568 0.30210133275548595178 0.69555830892067638249 1.0291689976585540744 1.4956996984874963985 0.10886600172753702065 0.48038630054298359084;-0.18272150433548439707 1.041714899103027836 -0.26298933854231598684 0.11211800193666927872 0.58291587934156952056 0.8368578935579173983 0.89371181952047618058 1.663376924812262958 0.008130043994939510979 -0.37641314369174250221;-0.55596570641515574707 0.89657887438595573748 -0.97655196643350183905 0.27846016028363185235 0.52350340109458559645 0.68885252442861444333 1.1125463699082334124 1.6712327835855302904 -0.23285379874286835089 0.081438772334270256859;1.0392599752688767012 0.14757011839237835216 -0.056666992573614058393 0.30400997747206465194 0.4826347387670635869 0.66303551569616014927 1.1322515534496200296 1.6450580199928164227 -0.76003510950118102762 0.30541742854187509115;0.97160247859661663661 0.56847886603274344619 -0.16388314738346390631 0.26944608760076582676 0.49701771422858764815 0.72700772315596029483 1.0740156282486958972 1.6664987721305224433 0.27656455727066803219 -0.027735290388858201832;0.37338658504881083733 -0.28977057583856841161 0.17124664225042898758 0.1170100204231538793 0.59043013424875123718 0.82417451216220627419 0.91032090374599383686 1.6685141270565784222 -1.0359738693012068289 0.29467335783669518223;0.56052544815552018953 -0.15771366714853335411 -0.24756510830833486358 -0.32577785285619076383 0.85087643019842185144 0.95193007530691620133 0.38248976976191073618 1.5411929822717769234 -0.24970973181617692194 0.16416121001063396778;0.0094909698596854861347 0.77216662318109430263 -0.044905473087330484427 -0.19689311499473996503 0.77768690242774030086 0.93179555158734272968 0.54758316831823705684 1.6095632386087430632 -0.23427422449232912505 -0.18133010971839838565;0.91829377544633972175 0.35961922548832847557 -1.0693527732870604652 -0.12124111894027565783 0.76028067565193691024 0.86108433704242648421 0.68163858333775562137 1.6484662411800259374 0.10177948549205460826 0.056199994209798147249;-0.031501501995131436784 0.010052250354338652591 -0.94310428105422106082 -0.1794645582711489884 0.80677140292620119766 0.88447896714443652311 0.60260437393871535416 1.6276273756937347237 -0.47144678371756820745 -0.30334763429651884215;-0.59589737462372449617 0.92851796562070443297 -0.58389285269436885795 -0.31286983457521633234 0.86936017770668061466 0.92657252413253055057 0.41742376281010512562 1.5577027510357084328 0.10733915589268047674 -1.0932604160677448224;0.74245989652152788452 0.40657067919107436893 -0.030911946065721923604 -0.71380514483412949023 1.0139945991680949788 1.0763417963983217263 -0.24511060209046467429 1.242093452557286426 0.044742644401023115575 -0.55307970122974370319;0.046444285533173826352 0.45058450257500692882 0.051708223951609739999 -0.6537936207516741316 0.98763552055294945298 1.047404751395025313 -0.11301041569191103142 1.3149338208867922262 -0.63392526304119911629 -0.0060294115798133710721;-0.24833941939010381605 0.71056752155228508627 -0.43949697482509841873 -0.6078442779513356653 0.98609962482994195643 1.0267011175007096924 -0.029579280312307342643 1.3544323757950069709 -0.22540019174081821207 -0.34634944443486326282;0.1745038632512841692 0.78063944485863678846 0.14157697393514687145 -0.6649860792650695851 0.96725541399355230432 1.0754435029302740201 -0.14865011520553078617 1.3054657530746698324 0.37058023773979753557 -0.7736925138335324359;-0.31470426896772668579 0.54008218518632267191 -0.0090800779837170216696 -0.73874662941552515782 0.97674525602930073465 1.1272825223914557657 -0.3184745780091697287 1.2154948782597811974 -0.3553344437934319866 0.29930469946004689685];

% Output 1

y1\_step1.ymin = -1;

y1\_step1.gain = [2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2;2];

y1\_step1.xoffset = [0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0];

% ===== SIMULATION ========

% Dimensions

Q = size(x1,1); % samples

% Input 1

x1 = x1';

xp1 = removeconstantrows\_apply(x1,x1\_step1);

xp1 = mapminmax\_apply(xp1,x1\_step2);

% Layer 1

a1 = tansig\_apply(repmat(b1,1,Q) + IW1\_1\*xp1);

% Layer 2

a2 = repmat(b2,1,Q) + LW2\_1\*a1;

% Output 1

y1 = mapminmax\_reverse(a2,y1\_step1);

y1 = y1';

end

% ===== MODULE FUNCTIONS ========

% Map Minimum and Maximum Input Processing Function

function y = mapminmax\_apply(x,settings)

y = bsxfun(@minus,x,settings.xoffset);

y = bsxfun(@times,y,settings.gain);

y = bsxfun(@plus,y,settings.ymin);

end

% Remove Constants Input Processing Function

function y = removeconstantrows\_apply(x,settings)

y = x(settings.keep,:);

end

% Sigmoid Symmetric Transfer Function

function a = tansig\_apply(n,~)

a = 2 ./ (1 + exp(-2\*n)) - 1;

end

% Map Minimum and Maximum Output Reverse-Processing Function

function x = mapminmax\_reverse(y,settings)

x = bsxfun(@minus,y,settings.ymin);

x = bsxfun(@rdivide,x,settings.gain);

x = bsxfun(@plus,x,settings.xoffset);

end

% Layer 2

a2 = repmat(b2,1,Q) + LW2\_1\*a1;

% Output 1

y1 = mapminmax\_reverse(a2,y1\_step1);

y1 = y1';

end

% ===== MODULE FUNCTIONS ========

% Map Minimum and Maximum Input Processing Function

function y = mapminmax\_apply(x,settings)

y = bsxfun(@minus,x,settings.xoffset);

y = bsxfun(@times,y,settings.gain);

y = bsxfun(@plus,y,settings.ymin);

end

% Remove Constants Input Processing Function

function y = removeconstantrows\_apply(x,settings)

y = x(settings.keep,:);

end

% Sigmoid Symmetric Transfer Function

function a = tansig\_apply(n,~)

a = 2 ./ (1 + exp(-2\*n)) - 1;

end

% Map Minimum and Maximum Output Reverse-Processing Function

function x = mapminmax\_reverse(y,settings)

x = bsxfun(@minus,y,settings.ymin);

x = bsxfun(@rdivide,x,settings.gain);

x = bsxfun(@plus,x,settings.xoffset);

end

try

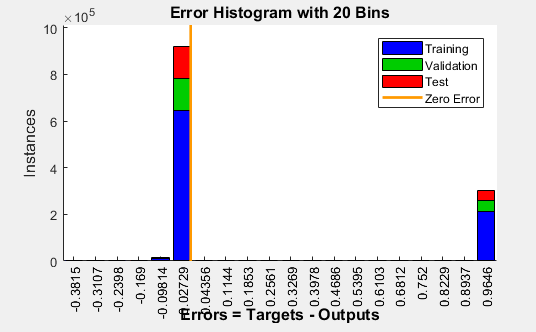
[~,vol]=convhull(performanceVector(:,1),performanceVector(:,2),performanceVector(:,3));

hullV=horzcat(hullV,vol);

catch

hullV=horzcat(hullV,0);

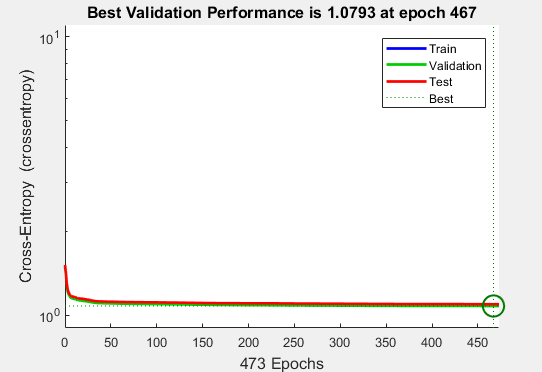
end



Error bin on

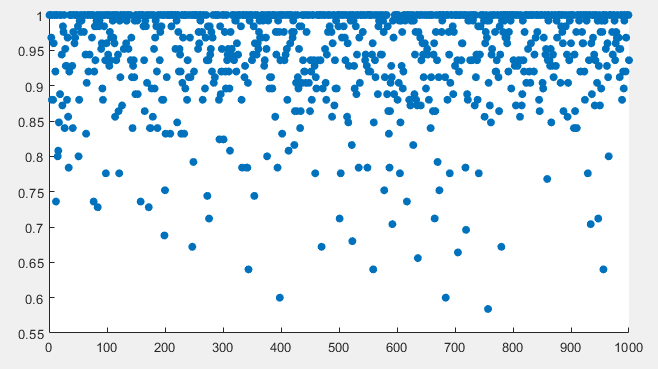
Test/Vlidation

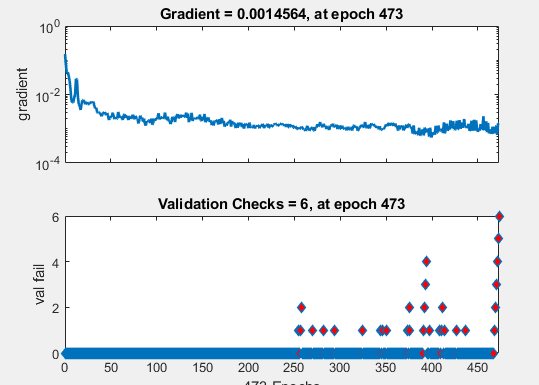
/Training set



Percentage

Accuracy of different test samples





14 models trained, including 3 manipulability prediction models

Date: 11/7/17

Alexander Liao

Idea 3 (final)

function [Y,Xf,Af] = mani1(X,~,~)

% ===== NEURAL NETWORK CONSTANTS =====

% Input 1

x1\_step1.keep = [1 2 3 4];

x1\_step2.xoffset = [5.90318136701325e-05;4.34334412752338e-05;2.14918317015145e-06;1.83852642646537e-05];

x1\_step2.gain = [2.00012319856925;2.00020952641606;2.00000738017723;20.0042458476643];

x1\_step2.ymin = -1;

% Layer 1

b1 = [-4.713067541036823016;-4.9660892040430857364;4.9324247896655419865;-4.2796050150304054682;-4.1527867817152710472;4.1092602798447703805;4.3503414943086431421;1.951995604841571641;2.3069944544242924067;1.9901552408222153989;-2.218309858103696186;1.3512562212215732949;2.7130290799187308792;-2.1955426525577927954;2.3149108347942837227;-2.3004754150013515535;-4.9139114683836417896;2.3060118954111303857;3.2447263360177083236;3.3512911878683309119;4.426767537418831111;-2.6257938978023518395;4.7619836099418160202;4.7903053232738210809;5.0582330954824383795];

IW1\_1 = [0.26076594092256100144 0.45151596560338186359 -0.0090912745291757499772 0.019242619922154199225;0.56141413401318052134 -0.040686596708401141786 0.07775059584977143945 -0.18376994426782558567;-0.4061644516726500842 0.63866112212746373178 0.35989850153301133906 0.2999143041717338698;0.39394161192424886897 -0.067574640477852887521 -0.38639228551105003762 -0.087611654548758507999;-1.2007644198204034947 -0.32397238063391708973 -0.46868377347124112742 -0.02527660432129228904;0.0030948079780288842086 0.29869525846305061689 0.65391939373766005961 0.29199727408844794452;-0.40113766891037055951 0.6095316973954718609 -0.21204908945373643347 -0.11777705598448984237;1.0631773075117163518 -0.56687363196025231105 -1.731254341488661419 0.12089782416520396258;1.1392095138780355956 -0.73768643401795974679 -1.5202259698570368407 0.12097230363830961675;1.0605603044034075388 -0.53575450765026144673 -1.8379517225337351771 0.11058008926656028026;-1.0305864260575905433 0.81090295668313627786 1.4783217556389101066 -0.10511319908764304998;1.2294357194387015575 -0.6014324957911670877 -0.91833620890129374903 0.036350994084469435974;1.4506955780285795132 -1.1170379431245025525 -1.7061446153113377644 0.069074452260570781692;-1.0649887121067400653 0.77661035788833854276 1.046897158505649017 -0.041696929845386823676;1.005389301601370855 -1.553904848771650693 -0.66503002953139778164 0.029024355950504083373;-1.1852805637601520061 1.0973262408930002376 1.2680846485082233333 -0.077030710942710425848;1.3498115799725622921 1.6497378695397222348 0.082528726628022811007 -0.055900989970307207733;1.0618420582198293545 -0.56592172116225658574 -1.3721379246999272361 0.02072450282693365925;1.258747209835081593 -0.85108674055901811784 -1.8426593266008148841 -0.0006959785748908459569;1.6007666553201387316 -1.4227837946842170069 -1.4681459579441193952 0.020306371481635322046;-0.19922186896266813605 0.18247082279179169251 0.12906582843319805431 -0.2722529116678262251;-1.9115004200958358727 -0.10428932154577447156 0.55521895984106861555 -0.049500602628398254756;0.16763286365645169163 -0.25400340555650280372 0.40342277229321121812 -0.06884854431630184346;0.12562891262526243441 -0.62979542488172601811 -0.12614291137617159033 -0.2255768045725881632;-0.50812561214958307243 0.14118350221406372746 0.61663239670249980762 -0.039450249300931820862];

% Layer 2

b2 = [-0.087534435932126009039;0.75745297311714299138;-0.034734034184943557433;0.1094782483108567156;0.17127588642366844973;-0.86443562121045136593;0.14312578712504031575;-0.16863373617828023021;-0.34937691052810904146;0.45765533653787321411;0.53357850609872703451;-0.64637170450360970086;0.18115925601907748033;0.85447370411766110365;-0.50289340934203052846;-0.68246619288928866975;-0.20581537366691168844;0.66283361517333727608;-0.061406740351640801134;-0.44634511782732011476;-0.10082393326863396676;0.031926213885077263377;-0.12983847836482298455;-1.0360292954841909818;-0.070097340490818740855;0.44843456220508381982;-0.075288531199642447223;-0.80493224934417728633;-0.058165341853377273973;-0.15924845532247455804;-0.25882506186977682905;0.59784586865750455331;-0.0026630029070452876545;-0.64675291970280346376;-0.48895472943977552616;-0.033324489605331450437;-0.4030164211131443408;1.0104407263271824036;-0.42818509252064812509;-0.50198158194903863549;-0.68161837578714812302;0.37207246943246680138;-0.94553858178483396468;0.89900468759395646412;-0.69990386817476990533;-0.89099908602035926553;0.33461859996211429369;-0.82291324509883945204;-0.39305788444920941593;0.058000254834281089744;0.72120111361538308259;0.72470755472875691972;0.20967849386603734652;-0.1806020753899459097;-0.38865491856682710115;0.040832166380138520956;-0.48067405496382664687;0.70564329628885502643;0.32692102941436784747;0.33988714577900475122;0.59270599428658521379;-0.19010495889633266531;-0.05431408061143302296;0.26686595296141241151;0.53623493274706213185;0.0037716606467446452816;0.22085710667604435686;0.2339671576392218233;0.01310106727538815595;-0.077892462052137567685;-0.33917618236935498377;0.50017542225070554807;-0.95068905538563697188;0.44046988625871713596;-1.2771726507064791178;0.095761722730170667495;-0.058202366932327644078;-0.8963381496109656954;0.53537945234832517993;0.15269569756215778389;0.27612419439928304055;-0.22878562674848912373;0.8109156978346950817;-0.092258431519165781665;0.81183612436903684895;0.28740043868867648502;-0.21358588615084789231;0.64876057360576444566;-0.23587592389460018683;0.21601659827309524498;-0.46127620020725895733;0.50880202845964528358;-0.66446634274570592904;-1.2791060204923647703;0.021851817114895834976;0.120548197266266921;0.56756652902575477349;-0.40699618394012099243;0.28268858360184384582;-0.48300415102230431774;-0.034231484630901240496;0.80407962923639886288;0.86130774427019196615;-0.75876535666190703111;0.19135304906112515777;-0.28257434723921642794;-0.0017083245270079197228;-0.56506302582551259928;0.52816655216523034078;0.69851761262198230895;-0.10389953721728524549;0.21049788111844597305;0.76102888155485570731;0.29211096913541312325;-0.16257418829536104954;-0.34815995196686189139;-0.0048552872457966536612;-0.69895255347776596988;-0.42622866275058118868;-0.74621845672644238068;-0.27829567718074937899;-0.48091744687139414971;0.47999559617730741534;-1.0143215074374059004;-0.40745797173596998153];

LW2\_1 = [-0.94979029035089168609 0.69493682878738316511 -0.073476634493424911043 -0.19068974410043029732 0.2710191414385506592 -0.26172528269225936448 -0.26260374907338684958 1.2235836825597681266 0.40860404258623844731 -0.35574088653212282418 -0.58103898384939534072 -1.0347446874594883326 0.22068722516999364491 0.0016177129902145183371 1.9783518714709864561 1.6849916649843104111 1.6364676129149542394 -0.19277607355899761821 -0.51376813051605985105 -1.7148448456832532383 -0.64496770957640958688 -0.11512780526029273154 1.2317777587068594602 0.36071623942677372154 1.1507681656535022618;0.51442331090957416073 -0.24732363649868807642 0.51299441794500433289 0.2833460290326118014 -0.11702553893170551669 -0.38617605215417000197 0.882856555076120042 0.50624278113478771157 1.0217805619160902353 0.02638672978961163762 0.14441185835024802908 -0.63900143112207208329 0.47567011487003690862 -0.24971159216394980818 1.1621682944835234341 1.4085190285730651016 0.68950018724920181246 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0.37018184318684660417 -0.6641524246000412024 -0.54022055184320005861 -0.18877714188424762898 0.93153344603785381839 0.89658741062384028631 0.17891649503911130625 -0.27534491827091683858 0.27333138338514012533 0.6231612102829977573 -0.48304351782773924384 0.81482084462815995707 -0.25841816134646578007 0.32264585133788836746 -0.55416136440674979013 0.33077532697231121217;0.37105284902144852754 -0.4067901001381964976 -1.0763601247309184661 -0.46975832536272033035 -0.50994274480090251433 -0.54665504221152971809 -0.95921628551816195962 0.025131832881001372332 0.42439543907671140044 0.50177304618150209148 0.21758025137437300711 -0.5632938056410462524 -0.56727685059369670206 0.36202406229127570558 0.59459549532531430494 0.17305062327435119518 -0.3709566840396719134 0.48689065509461387782 0.68071122268564232538 -0.78425029220922926054 -0.013343072327279614092 0.65283493919714230547 0.68642753369002806885 -0.78190986854649369153 0.20130054729530919011;-0.15738948181486717148 -0.32817733255650072266 -0.86662257150668275951 0.066766611402916342666 1.1306610490688417947 -0.61293465754065257212 0.1321079394086658032 0.73777121060075478987 -0.78931130849708663888 0.089962710797306333355 0.28908440380528982461 -1.0300995369966154946 -0.80932551811627095883 -0.19424439319126982073 1.2399861787671950797 0.23828599017660706538 -0.86715334055004622549 1.6264244511520502545 1.602434271560759349 -1.8189584910325162781 -0.73439631714259123729 0.10609492770291631403 -0.52291110454309353006 0.52651469969767450419 0.62460655765676798001;-0.14730103460340904231 -0.065526987146103721216 0.27997420662688815574 0.68775395196975896983 0.15705051575084066906 0.0089137987775522540407 0.1397262370409926846 0.24808276257922234898 -0.15658504269717185564 0.2550636734864452082 0.49319505578089301023 -0.9428344320018470226 -0.2770741690762351106 -0.58131287880311099947 0.89557468455428457244 0.56078948811278839237 -0.062102725746256547124 1.7578144601408487446 0.56739587255306678237 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% Output 1

y1\_step1.ymin = -1;

y1\_step1.gain = [19.8430846873881;25.1902297852514;28.0480043805873;25.1902297852515;19.8430846873881;15.4014213643285;17.587796255382;18.6052423789696;17.587796255382;15.4014213643285;12.8098359375956;13.6464356908205;14.0020385635065;13.6464356908205;12.8098359375956;11.1327961562979;11.5184475245726;11.6798900325227;11.5184475245726;11.132796156298;10.0263518607708;10.2529634177852;10.3501190645979;10.2529634177852;10.0263518607708;24.3085739439092;31.6367103728318;35.3669321427237;31.6367103728319;24.3085739439092;18.3591936694781;21.2323768325061;22.6071155078732;21.2323768325061;18.3591936694781;14.8716415185648;16.149707330217;16.5888266071274;16.149707330217;14.8716415185648;12.8000788732996;13.2510272096017;13.4449117424356;13.2510272096017;12.8000788732996;11.1531568910438;11.4425738999758;11.5685578032682;11.4425738999758;11.1531568910438;31.212296404562;42.6770051813765;48.1673283901317;42.6770051813765;31.212296404562;22.7659135886037;26.6947290312244;28.6742030350535;26.6947290312245;22.7659135886037;17.7529936793692;19.6008713201346;20.4390542768772;19.6008713201346;17.7529936793692;15.1439854378217;15.7923817259592;16.013075608594;15.7923817259592;15.1439854378217;12.7413370962304;13.0747835633085;13.2265692482126;13.0747835633085;12.7413370962304;41.8095072498824;61.0833904676167;72.2914102259972;61.0833904676167;41.8095072498824;29.8028292256988;35.065387557911;37.9256576261505;35.065387557911;29.8028292256988;21.9708633850535;24.2477557505819;25.3397138511227;24.247755750582;21.9708633850535;17.408378967788;19.688749848541;20.0505004696882;19.688749848541;17.408378967788;12.2289141323904;13.3119094529699;13.7159832833968;13.3119094529699;12.2289141323904;57.701581649538;89.7259104352578;113.152479033886;89.7259104352579;57.701581649538;32.8890905694871;45.3882853446809;51.7448296746395;45.388285344681;32.8890905694871;21.020850604828;24.7439973841522;26.3307882528371;24.7439973841522;21.020850604828;14.5909715722401;16.2399626504335;16.8762408799636;16.2399626504335;14.5909715722402;10.5359824104758;11.4247428707734;11.7571801183955;11.4247428707734;10.5359824104758];

y1\_step1.xoffset = [0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0;0];

% ===== SIMULATION ========

% Format Input Arguments

isCellX = iscell(X);

if ~isCellX

X = {X};

end

% Dimensions

TS = size(X,2); % timesteps

if ~isempty(X)

Q = size(X{1},1); % samples/series

else

Q = 0;

end

% Allocate Outputs

Y = cell(1,TS);

% Time loop

for ts=1:TS

% Input 1

X{1,ts} = X{1,ts}';

temp = removeconstantrows\_apply(X{1,ts},x1\_step1);

Xp1 = mapminmax\_apply(temp,x1\_step2);

% Layer 1

a1 = tansig\_apply(repmat(b1,1,Q) + IW1\_1\*Xp1);

% Layer 2

a2 = repmat(b2,1,Q) + LW2\_1\*a1;

% Output 1

Y{1,ts} = mapminmax\_reverse(a2,y1\_step1);

Y{1,ts} = Y{1,ts}';

end

% Final Delay States

Xf = cell(1,0);

Af = cell(2,0);

% Format Output Arguments

if ~isCellX

Y = cell2mat(Y);

end

end

% ===== MODULE FUNCTIONS ========

% Map Minimum and Maximum Input Processing Function

function y = mapminmax\_apply(x,settings)

y = bsxfun(@minus,x,settings.xoffset);

y = bsxfun(@times,y,settings.gain);

y = bsxfun(@plus,y,settings.ymin);

end

% Remove Constants Input Processing Function

function y = removeconstantrows\_apply(x,settings)

y = x(settings.keep,:);

end

% Sigmoid Symmetric Transfer Function

function a = tansig\_apply(n,~)

a = 2 ./ (1 + exp(-2\*n)) - 1;

end

% Map Minimum and Maximum Output Reverse-Processing Function

function x = mapminmax\_reverse(y,settings)

x = bsxfun(@minus,y,settings.ymin);

x = bsxfun(@rdivide,x,settings.gain);

x = bsxfun(@plus,x,settings.xoffset);

end

% Allocate Outputs

Y = cell(1,TS);

% Time loop

for ts=1:TS

% Input 1

X{1,ts} = X{1,ts}';

temp = removeconstantrows\_apply(X{1,ts},x1\_step1);

Xp1 = mapminmax\_apply(temp,x1\_step2);

% Layer 1

a1 = tansig\_apply(repmat(b1,1,Q) + IW1\_1\*Xp1);

% Layer 2

a2 = repmat(b2,1,Q) + LW2\_1\*a1;

% Output 1

Y{1,ts} = mapminmax\_reverse(a2,y1\_step1);

Y{1,ts} = Y{1,ts}';

end

% Final Delay States

Xf = cell(1,0);

Af = cell(2,0);

% Format Output Arguments

if ~isCellX

Y = cell2mat(Y);

end

end

% ===== MODULE FUNCTIONS ========

% Map Minimum and Maximum Input Processing Function

function y = mapminmax\_apply(x,settings)

y = bsxfun(@minus,x,settings.xoffset);

y = bsxfun(@times,y,settings.gain);

y = bsxfun(@plus,y,settings.ymin);

end

% Remove Constants Input Processing Function

function y = removeconstantrows\_apply(x,settings)

y = x(settings.keep,:);

end

% Sigmoid Symmetric Transfer Function

function a = tansig\_apply(n,~)

a = 2 ./ (1 + exp(-2\*n)) - 1;

end

% Map Minimum and Maximum Output Reverse-Processing Function

function x = mapminmax\_reverse(y,settings)

x = bsxfun(@minus,y,settings.ymin);

x = bsxfun(@rdivide,x,settings.gain);

x = bsxfun(@plus,x,settings.xoffset);

end

Trying to apply Convolution neural network to solve the mapping problem:

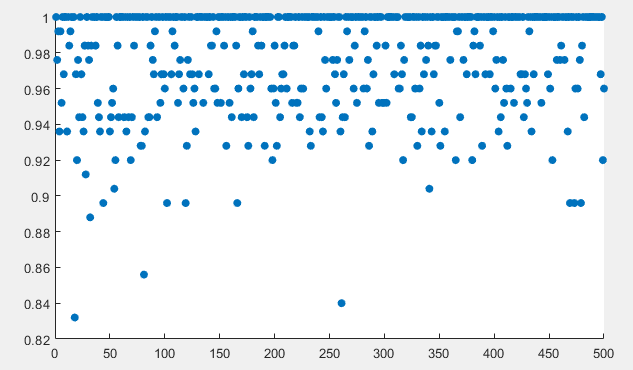
Date: 11/8/17

Alexander Liao

Idea 3 (final)

Abandoned due to the unwanted extra dimensionality that filters introduce

Extra precision achieved by increasing training set size and adjustments of model architecture



layers = [imageInputLayer([28 28 1])

convolution2dLayer(5,20)

reluLayer

maxPooling2dLayer(2,'Stride',2)

fullyConnectedLayer(10)

softmaxLayer

classificationLayer];