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**Lab: Industrial Networks and Power Electronics Laboratory (INPEL)**

Class: MECHANICS AND CONTROL OF ROBOT MANIPULATORS

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Home Work 3

1. Program Forward Kinematics for Puma 560 robot with your assumed values for DRW00001f0442de and DRW00001f0442e0=> DRW00001f0442e2 then, when DRW00001f0442e4=[ 30 deg 90 90 30 30 30], Find DRW00001f0442e6
2. Program Inverse Kinematics for Puma 560 robot. Find the 8 solution sets corresponding to the DRW00001f0442e8of prob. 1. and make sure that one among your solution sets must be [ 30deg 90 90 30 30 30].

Solutions

1. Program Forward Kinematic for Puma 560 robot with the assumed value of a2, a3, d3 and d4 as below:

When

The result of matrix as below:



Matlab code is presented as the following:

|  |
| --- |
| clc;clear all; close all;  %%%%%%Input%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%  % theta1=pi/6  % theta2=pi/2  % theta3=pi/2  % theta4=pi/6  % theta5=pi/6  % theta6=pi/6  theta1=0.5236  theta2=1.5708  theta3=1.5708  theta4=0.5236  theta5=0.5236  theta6=0.5236    %%%%%%D\_H\_PARAMETERS%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%  anpha0=0;  anhpha1=-pi/2;  anpha2=0;  anpha3=-pi/2;  anpha4=pi/2;  anpha5=-pi/2;  a0=0;  a1=0;  a2=0.5813;%  a3=0.0655;  a4=0;  a5=0;  d1=0;  d2=0;  d3=0.1579;%  d4=0.5442;%  d5=0;  d6=0;  %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%  %%Forward kinematic  %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%  c23=cos(theta2)\*cos(theta3)-sin(theta2)\*sin(theta3)  s23=cos(theta2)\*sin(theta3)+sin(theta2)\*cos(theta3);    r11=cos(theta1)\*(c23\*(cos(theta4)\*cos(theta5)\*cos(theta6)-sin(theta4)\*sin(theta6))-s23\*sin(theta5)\*cos(theta6))+sin(theta1)\*(sin(theta4)\*cos(theta5)\*cos(theta6)+cos(theta4)\*sin(theta6));  r21=sin(theta1)\*(c23\*(cos(theta4)\*cos(theta5)\*cos(theta6)-sin(theta4)\*sin(theta6))-s23\*sin(theta5)\*cos(theta6))-cos(theta1)\*(sin(theta4)\*cos(theta5)\*cos(theta6)+cos(theta4)\*sin(theta6));  r31=-s23\*(cos(theta4)\*cos(theta5)\*cos(theta6)-sin(theta4)\*sin(theta6))-c23\*sin(theta5)\*cos(theta6);    r12=cos(theta1)\*(c23\*(-cos(theta4)\*cos(theta5)\*sin(theta6)-sin(theta4)\*cos(theta6))+s23\*sin(theta5)\*sin(theta6))+sin(theta1)\*(cos(theta4)\*cos(theta6)-sin(theta4)\*cos(theta5)\*sin(theta6));  r22=sin(theta1)\*(c23\*(-cos(theta4)\*cos(theta5)\*sin(theta6)-sin(theta4)\*cos(theta6))+s23\*sin(theta5)\*sin(theta6))-cos(theta1)\*(cos(theta4)\*cos(theta6)-sin(theta4)\*cos(theta5)\*sin(theta6));  r32=-s23\*(-cos(theta4)\*cos(theta5)\*sin(theta6)-sin(theta4)\*cos(theta6))+c23\*sin(theta5)\*sin(theta6);    r13=-cos(theta1)\*(c23\*cos(theta4)\*sin(theta5)+s23\*cos(theta5))-sin(theta1)\*sin(theta4)\*sin(theta5);  r23=-sin(theta1)\*(c23\*cos(theta4)\*sin(theta5)+s23\*cos(theta5))+cos(theta1)\*sin(theta4)\*sin(theta5);  r33=s23\*cos(theta4)\*sin(theta5)-c23\*cos(theta5);    px=cos(theta1)\*(a2\*cos(theta2)+a3\*c23-d4\*s23)-d3\*sin(theta1);  py=sin(theta1)\*(a2\*cos(theta2)+a3\*c23-d4\*s23)+d3\*cos(theta1);  pz=-a3\*s23-a2\*sin(theta2)-d4\*c23;    T\_0\_6=[r11 r12 r13 px;  r21 r22 r23 py;  r31 r32 r33 pz;  0 0 0 1]    T\_6\_t=[1 0 0 1;  0 1 0 1;  0 0 1 2;  0 0 0 1]  T\_0\_t=T\_0\_6\*T\_6\_t |

1. Program Inverse Kinematic for Puma 560. Among 8 solution sets, the first set is the given set

The result is shown as below:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Item |  |  |  |  |  |  |
| Solution set 1 | 0.5236 | -4.7124 | 1.5708 | 0.5236 | 0.5236 | 0.5236 |
| Solution set 2 | 1.3100 | -0.5401 | 1.5708 | -0.2569 | 2.6049 | 0.0727 |
| Solution set 3 | 1.3100 | -4.7124 | 1.8104 | -0.4579 | 0.2982 | 0.7350 |
| Solution set 4 | 0.5236 | -2.6015 | 1.8104 | 2.8763 | 1.8764 | -2.2359 |
| Solution set 5 | 0.5236 | -4.7124 | 1.5708 | 3.6652 | -0.5236 | 3.6652 |
| Solution set 6 | 1.3100 | -0.5401 | 1.5708 | 2.8847 | -2.6049 | 3.2142 |
| Solution set 7 | 1.3100 | -4.7123 | 1.8104 | 2.6837 | -0.2982 | 3.8766 |
| Solution set 8 | 0.5236 | -2.6015 | 1.8104 | 6.0179 | -1.8764 | 0.9057 |

In which -4.7124 = pi\*2 – 2\*pi

Matlab code:

|  |
| --- |
| %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%  %%Inverse manipulator kinematics  %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%  A=T\_0\_t\*T\_6\_t^-1  K=((A(1,4)^2+A(2,4)^2+A(3,4)^2)-a2^2-a3^2-d3^2-d4^2)/(2\*a2);  %%%%%%%% solutions set #1:%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%  tt1=atan2(A(2,4),A(1,4))-atan2(d3,-sqrt(A(2,4)^2+A(1,4)^2-d3^2)) %-  tt3=atan2(a3,d4)-atan2(K,sqrt(a3^2+d4^2-K^2)) %+  tt23=atan2((-a3-a2\*cos(tt3))\*A(3,4)-(cos(tt1)\*A(1,4)+sin(tt1)\*A(2,4))\*(d4-a2\*sin(tt3)),(a2\*sin(tt3)-d4)\*A(3,4)+(a3+a2\*cos(tt3))\*(cos(tt1)\*A(1,4)+sin(tt1)\*A(2,4)))  tt2=tt23-tt3  c4s5=-A(1,3)\*cos(tt1)\*cos(tt23)-A(2,3)\*sin(tt1)\*cos(tt23)+A(3,3)\*sin(tt23);  s4s5=-A(1,3)\*sin(tt1)+A(2,3)\*cos(tt1);  if and(abs(c4s5)<10^-8,abs(s4s5)<10^-8)  tt5=0  tt4=0.1  s6=-A(1,1)\*(cos(tt1)\*cos(tt23)\*sin(tt4)-sin(tt1)\*cos(tt4))-A(2,1)\*(sin(tt1)\*cos(tt23)\*sin(tt4)+cos(tt1)\*cos(tt4))+A(3,1)\*(sin(tt23)\*sin(tt4))  c6=A(1,1)\*((cos(tt1)\*cos(tt23)\*cos(tt4)+sin(tt1)\*sin(tt4))\*cos(tt5)-cos(tt1)\*sin(tt23)\*sin(tt5))+A(2,1)\*((sin(tt1)\*cos(tt23)\*cos(tt4)-cos(tt1)\*sin(tt4))\*cos(tt5)-sin(tt1)\*sin(tt23)\*sin(tt5))-A(3,1)\*(sin(tt23)\*cos(tt4)\*cos(tt5)+cos(tt23)\*sin(tt5))  tt6=atan2(s6,c6)  else  tt4=atan2(s4s5,c4s5)  s5=-A(1,3)\*(cos(tt1)\*cos(tt23)\*cos(tt4)+sin(tt1)\*sin(tt4))-A(2,3)\*(sin(tt1)\*cos(tt23)\*cos(tt4)-cos(tt1)\*sin(tt4))+A(3,3)\*(sin(tt23)\*cos(tt4))  c5=A(1,3)\*(-cos(tt1)\*sin(tt23))+A(2,3)\*(-sin(tt1)\*sin(tt23))+A(3,3)\*(-cos(tt23))  tt5=atan2(s5,c5)  s6=-A(1,1)\*(cos(tt1)\*cos(tt23)\*sin(tt4)-sin(tt1)\*cos(tt4))-A(2,1)\*(sin(tt1)\*cos(tt23)\*sin(tt4)+cos(tt1)\*cos(tt4))+A(3,1)\*(sin(tt23)\*sin(tt4))  c6=A(1,1)\*((cos(tt1)\*cos(tt23)\*cos(tt4)+sin(tt1)\*sin(tt4))\*cos(tt5)-cos(tt1)\*sin(tt23)\*sin(tt5))+A(2,1)\*((sin(tt1)\*cos(tt23)\*cos(tt4)-cos(tt1)\*sin(tt4))\*cos(tt5)-sin(tt1)\*sin(tt23)\*sin(tt5))-A(3,1)\*(sin(tt23)\*cos(tt4)\*cos(tt5)+cos(tt23)\*sin(tt5))  tt6=atan2(s6,c6)  end  %%%%%%%%% solutions set #2 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%    tt1\_1=atan2(A(2,4),A(1,4))-atan2(d3,sqrt(A(2,4)^2+A(1,4)^2-d3^2)) %+  tt3\_1=atan2(a3,d4)-atan2(K,sqrt(a3^2+d4^2-K^2)) %+  tt23\_1=atan2((-a3-a2\*cos(tt3\_1))\*A(3,4)-(cos(tt1\_1)\*A(1,4)+sin(tt1\_1)\*A(2,4))\*(d4-a2\*sin(tt3\_1)),(a2\*sin(tt3\_1)-d4)\*A(3,4)+(a3+a2\*cos(tt3\_1))\*(cos(tt1\_1)\*A(1,4)+sin(tt1\_1)\*A(2,4)))  tt2\_1=tt23\_1-tt3\_1  c4s5\_1=-A(1,3)\*cos(tt1\_1)\*cos(tt23\_1)-A(2,3)\*sin(tt1\_1)\*cos(tt23\_1)+A(3,3)\*sin(tt23\_1);  s4s5\_1=-A(1,3)\*sin(tt1\_1)+A(2,3)\*cos(tt1\_1);  if and(abs(c4s5\_1)<10^-8,abs(s4s5\_1)<10^-8)  tt5\_1=0  tt4\_1=0.1  s6\_1=-A(1,1)\*(cos(tt1\_1)\*cos(tt23\_1)\*sin(tt4\_1)-sin(tt1\_1)\*cos(tt4\_1))-A(2,1)\*(sin(tt1\_1)\*cos(tt23\_1)\*sin(tt4\_1)+cos(tt1\_1)\*cos(tt4\_1))+A(3,1)\*(sin(tt23\_1)\*sin(tt4\_1))  c6\_1=A(1,1)\*((cos(tt1\_1)\*cos(tt23\_1)\*cos(tt4\_1)+sin(tt1\_1)\*sin(tt4\_1))\*cos(tt5\_1)-cos(tt1\_1)\*sin(tt23\_1)\*sin(tt5\_1))+A(2,1)\*((sin(tt1\_1)\*cos(tt23\_1)\*cos(tt4\_1)-cos(tt1\_1)\*sin(tt4\_1))\*cos(tt5\_1)-sin(tt1\_1)\*sin(tt23\_1)\*sin(tt5\_1))-A(3,1)\*(sin(tt23\_1)\*cos(tt4\_1)\*cos(tt5\_1)+cos(tt23\_1)\*sin(tt5\_1))  tt6\_1=atan2(s6\_1,c6\_1)  else  tt4\_1=atan2(s4s5\_1,c4s5\_1)  s5\_1=-A(1,3)\*(cos(tt1\_1)\*cos(tt23\_1)\*cos(tt4\_1)+sin(tt1\_1)\*sin(tt4\_1))-A(2,3)\*(sin(tt1\_1)\*cos(tt23\_1)\*cos(tt4\_1)-cos(tt1\_1)\*sin(tt4\_1))+A(3,3)\*(sin(tt23\_1)\*cos(tt4\_1))  c5\_1=A(1,3)\*(-cos(tt1\_1)\*sin(tt23\_1))+A(2,3)\*(-sin(tt1\_1)\*sin(tt23\_1))+A(3,3)\*(-cos(tt23\_1))  tt5\_1=atan2(s5\_1,c5\_1)  s6\_1=-A(1,1)\*(cos(tt1\_1)\*cos(tt23\_1)\*sin(tt4\_1)-sin(tt1\_1)\*cos(tt4\_1))-A(2,1)\*(sin(tt1\_1)\*cos(tt23\_1)\*sin(tt4\_1)+cos(tt1\_1)\*cos(tt4\_1))+A(3,1)\*(sin(tt23\_1)\*sin(tt4\_1))  c6\_1=A(1,1)\*((cos(tt1\_1)\*cos(tt23\_1)\*cos(tt4\_1)+sin(tt1\_1)\*sin(tt4\_1))\*cos(tt5\_1)-cos(tt1\_1)\*sin(tt23\_1)\*sin(tt5\_1))+A(2,1)\*((sin(tt1\_1)\*cos(tt23\_1)\*cos(tt4\_1)-cos(tt1\_1)\*sin(tt4\_1))\*cos(tt5\_1)-sin(tt1\_1)\*sin(tt23\_1)\*sin(tt5\_1))-A(3,1)\*(sin(tt23\_1)\*cos(tt4\_1)\*cos(tt5\_1)+cos(tt23\_1)\*sin(tt5\_1))  tt6\_1=atan2(s6\_1,c6\_1)  end  %%%%%%%%% solutions set #3 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%      tt1\_2=atan2(A(2,4),A(1,4))-atan2(d3,sqrt(A(2,4)^2+A(1,4)^2-d3^2)) %+  tt3\_2=atan2(a3,d4)-atan2(K,-sqrt(a3^2+d4^2-K^2)) %-  tt23\_2=atan2((-a3-a2\*cos(tt3\_2))\*A(3,4)-(cos(tt1\_2)\*A(1,4)+sin(tt1\_2)\*A(2,4))\*(d4-a2\*sin(tt3\_2)),(a2\*sin(tt3\_2)-d4)\*A(3,4)+(a3+a2\*cos(tt3\_2))\*(cos(tt1\_2)\*A(1,4)+sin(tt1\_2)\*A(2,4)))  tt2\_2=tt23\_2-tt3\_2  c4s5\_2=-A(1,3)\*cos(tt1\_2)\*cos(tt23\_2)-A(2,3)\*sin(tt1\_2)\*cos(tt23\_2)+A(3,3)\*sin(tt23\_2);  s4s5\_2=-A(1,3)\*sin(tt1\_2)+A(2,3)\*cos(tt1\_2);  tt4\_2=atan2(s4s5\_2,c4s5\_2)  if and(abs(c4s5\_2)<10^-8,abs(s4s5\_2)<10^-8)  tt5\_2=0  tt4\_2=0.1  s6\_2=-A(1,1)\*(cos(tt1\_2)\*cos(tt23\_2)\*sin(tt4\_2)-sin(tt1\_2)\*cos(tt4\_2))-A(2,1)\*(sin(tt1\_2)\*cos(tt23\_2)\*sin(tt4\_2)+cos(tt1\_2)\*cos(tt4\_2))+A(3,1)\*(sin(tt23\_2)\*sin(tt4\_2))  c6\_2=A(1,1)\*((cos(tt1\_2)\*cos(tt23\_2)\*cos(tt4\_2)+sin(tt1\_2)\*sin(tt4\_2))\*cos(tt5\_2)-cos(tt1\_2)\*sin(tt23\_2)\*sin(tt5\_2))+A(2,1)\*((sin(tt1\_2)\*cos(tt23\_2)\*cos(tt4\_2)-cos(tt1\_2)\*sin(tt4\_2))\*cos(tt5\_2)-sin(tt1\_2)\*sin(tt23\_2)\*sin(tt5\_2))-A(3,1)\*(sin(tt23\_2)\*cos(tt4\_2)\*cos(tt5\_2)+cos(tt23\_2)\*sin(tt5\_2))  tt6\_2=atan2(s6\_2,c6\_2)  else  s5\_2=-A(1,3)\*(cos(tt1\_2)\*cos(tt23\_2)\*cos(tt4\_2)+sin(tt1\_2)\*sin(tt4\_2))-A(2,3)\*(sin(tt1\_2)\*cos(tt23\_2)\*cos(tt4\_2)-cos(tt1\_2)\*sin(tt4\_2))+A(3,3)\*(sin(tt23\_2)\*cos(tt4\_2))  c5\_2=A(1,3)\*(-cos(tt1\_2)\*sin(tt23\_2))+A(2,3)\*(-sin(tt1\_2)\*sin(tt23\_2))+A(3,3)\*(-cos(tt23\_2))  tt5\_2=atan2(s5\_2,c5\_2)  s6\_2=-A(1,1)\*(cos(tt1\_2)\*cos(tt23\_2)\*sin(tt4\_2)-sin(tt1\_2)\*cos(tt4\_2))-A(2,1)\*(sin(tt1\_2)\*cos(tt23\_2)\*sin(tt4\_2)+cos(tt1\_2)\*cos(tt4\_2))+A(3,1)\*(sin(tt23\_2)\*sin(tt4\_2))  c6\_2=A(1,1)\*((cos(tt1\_2)\*cos(tt23\_2)\*cos(tt4\_2)+sin(tt1\_2)\*sin(tt4\_2))\*cos(tt5\_2)-cos(tt1\_2)\*sin(tt23\_2)\*sin(tt5\_2))+A(2,1)\*((sin(tt1\_2)\*cos(tt23\_2)\*cos(tt4\_2)-cos(tt1\_2)\*sin(tt4\_2))\*cos(tt5\_2)-sin(tt1\_2)\*sin(tt23\_2)\*sin(tt5\_2))-A(3,1)\*(sin(tt23\_2)\*cos(tt4\_2)\*cos(tt5\_2)+cos(tt23\_2)\*sin(tt5\_2))  tt6\_2=atan2(s6\_2,c6\_2)  end  %%%%%%%%% solutions set #4%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%    tt1\_3=atan2(A(2,4),A(1,4))-atan2(d3,-sqrt(A(2,4)^2+A(1,4)^2-d3^2)) %-  tt3\_3=atan2(a3,d4)-atan2(K,-sqrt(a3^2+d4^2-K^2)) %-  tt23\_3=atan2((-a3-a2\*cos(tt3\_3))\*A(3,4)-(cos(tt1\_3)\*A(1,4)+sin(tt1\_3)\*A(2,4))\*(d4-a2\*sin(tt3\_3)),(a2\*sin(tt3\_3)-d4)\*A(3,4)+(a3+a2\*cos(tt3\_3))\*(cos(tt1\_3)\*A(1,4)+sin(tt1\_3)\*A(2,4)))  tt2\_3=tt23\_3-tt3\_3  c4s5\_3=-A(1,3)\*cos(tt1\_3)\*cos(tt23\_3)-A(2,3)\*sin(tt1\_3)\*cos(tt23\_3)+A(3,3)\*sin(tt23\_3);  s4s5\_3=-A(1,3)\*sin(tt1\_3)+A(2,3)\*cos(tt1\_3);  if and(abs(c4s5\_3)<10^-8,abs(s4s5\_3)<10^-8)  tt5\_3=0  tt4\_3=0.1  s6\_3=-A(1,1)\*(cos(tt1\_3)\*cos(tt23\_3)\*sin(tt4\_3)-sin(tt1\_3)\*cos(tt4\_3))-A(2,1)\*(sin(tt1\_3)\*cos(tt23\_3)\*sin(tt4\_3)+cos(tt1\_3)\*cos(tt4\_3))+A(3,1)\*(sin(tt23\_3)\*sin(tt4\_3))  c6\_3=A(1,1)\*((cos(tt1\_3)\*cos(tt23\_3)\*cos(tt4\_3)+sin(tt1\_3)\*sin(tt4\_3))\*cos(tt5\_3)-cos(tt1\_3)\*sin(tt23\_3)\*sin(tt5\_3))+A(2,1)\*((sin(tt1\_3)\*cos(tt23\_3)\*cos(tt4\_3)-cos(tt1\_3)\*sin(tt4\_3))\*cos(tt5\_3)-sin(tt1\_3)\*sin(tt23\_3)\*sin(tt5\_3))-A(3,1)\*(sin(tt23\_3)\*cos(tt4\_3)\*cos(tt5\_3)+cos(tt23\_3)\*sin(tt5\_3))  tt6\_3=atan2(s6\_3,c6\_3)  else    tt4\_3=atan2(s4s5\_3,c4s5\_3)  s5\_3=-A(1,3)\*(cos(tt1\_3)\*cos(tt23\_3)\*cos(tt4\_3)+sin(tt1\_3)\*sin(tt4\_3))-A(2,3)\*(sin(tt1\_3)\*cos(tt23\_3)\*cos(tt4\_3)-cos(tt1\_3)\*sin(tt4\_3))+A(3,3)\*(sin(tt23\_3)\*cos(tt4\_3))  c5\_3=A(1,3)\*(-cos(tt1\_3)\*sin(tt23\_3))+A(2,3)\*(-sin(tt1\_3)\*sin(tt23\_3))+A(3,3)\*(-cos(tt23\_3))  tt5\_3=atan2(s5\_3,c5\_3)  s6\_3=-A(1,1)\*(cos(tt1\_3)\*cos(tt23\_3)\*sin(tt4\_3)-sin(tt1\_3)\*cos(tt4\_3))-A(2,1)\*(sin(tt1\_3)\*cos(tt23\_3)\*sin(tt4\_3)+cos(tt1\_3)\*cos(tt4\_3))+A(3,1)\*(sin(tt23\_3)\*sin(tt4\_3))  c6\_3=A(1,1)\*((cos(tt1\_3)\*cos(tt23\_3)\*cos(tt4\_3)+sin(tt1\_3)\*sin(tt4\_3))\*cos(tt5\_3)-cos(tt1\_3)\*sin(tt23\_3)\*sin(tt5\_3))+A(2,1)\*((sin(tt1\_3)\*cos(tt23\_3)\*cos(tt4\_3)-cos(tt1\_3)\*sin(tt4\_3))\*cos(tt5\_3)-sin(tt1\_3)\*sin(tt23\_3)\*sin(tt5\_3))-A(3,1)\*(sin(tt23\_3)\*cos(tt4\_3)\*cos(tt5\_3)+cos(tt23\_3)\*sin(tt5\_3))  tt6\_3=atan2(s6\_3,c6\_3)  end  %%%%%%%% solutions set #5:%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%  tt1\_4=tt1  tt3\_4=tt3  tt2\_4=tt2  tt4\_4=tt4+pi  tt5\_4=-tt5  tt6\_4=tt6+pi  %%%%%%%% solutions set #6:%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%  tt1\_5=tt1\_1  tt3\_5=tt3\_1  tt2\_5=tt2\_1  tt4\_5=tt4\_1+pi  tt5\_5=-tt5\_1  tt6\_5=tt6\_1+pi  %%%%%%%% solutions set #7:%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%  tt1\_6=tt1\_2  tt3\_6=tt3\_2  tt2\_6=tt2\_2  tt4\_6=tt4\_2+pi  tt5\_6=-tt5\_2  tt6\_6=tt6\_2+pi  %%%%%%%% solutions set #8:%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%  tt1\_7=tt1\_3  tt3\_7=tt3\_3  tt2\_7=tt2\_3  tt4\_7=tt4\_3+pi  tt5\_7=-tt5\_3  tt6\_7=tt6\_3+pi  %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% |