CEP Assignment

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Human Artificial Leg Manipulator

Task Assigned:

Assume a human like artificial leg including foot (foot in single or two parts) attached to fixed hip. The artificial leg should be able to produce the human-like motion.

a) Introduction:

Why we need to design artificial legs?

According to the different surveys, the increase in the persons who are getting aged above 60 is seen which results in the development of spinal cord diseases and other neurological disorders. These disorders or weakness due to aging make a person dependent on others. Moreover, the increase in accidents every year is increasing which results in breaking of leg or arms or spinal cord etc. To overcome all these issues an exe-skeleton manipulator is designed, so that the patients can walk normally and can improve their quality of life by not depending on others. For different parts, different design is used i.e. for arm we will have to design an exo-skeleton arm manipulator and for leg we will design an exo-skeleton leg manipulator.

Kinematic Chain Model:

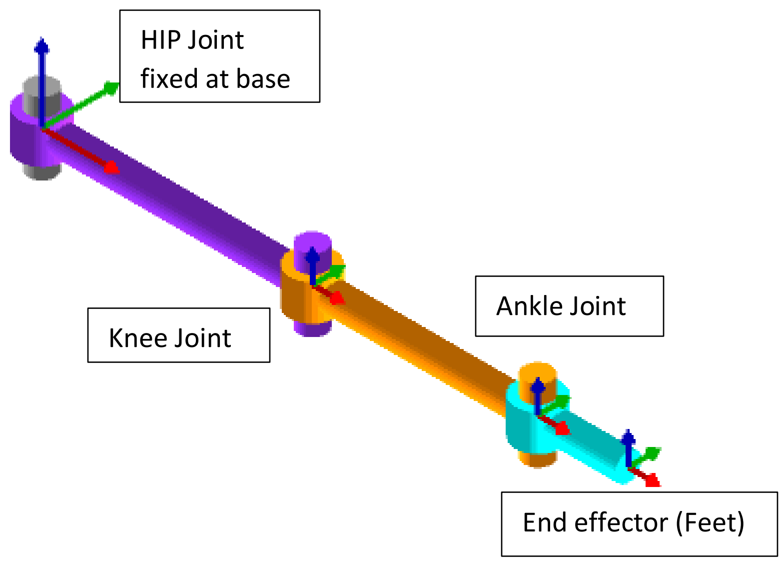

Fig 1: Kinematic chain model

Design:

In the present case, I have designed a three revolute joint dependent structure for leg (3R manipulator) with link lengths between my one joint to another. As we know our hip joint (revolute) can rotate through an angle of 130 degree fixed on base, knee joint(revolute) can also rotate by an angle of 130 degree while ankle joint(revolute) can rotate by an approximate angle of 25 degree at back and 45 at front which on rotating gives rotation by -20 degree. So, the whole design was based on these angles and link lengths which I assumed for myself.

DH table:

No. of links	Link length (a_i)	Joint offset(d_i)	Twist (α_i)	Joint Angle(Θ_i)
1	a1	0	0	Θ1
2	a2	0	0	Θ2
3	a3	0	0	Θ3

b) Kinematic Analysis:

Link Transformation Matrices:

$$\mathbf{A_0^1} = \begin{bmatrix} c1 & -s1 & 0 & a1c1 \\ s1 & c1 & 1 & a1s1 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\mathbf{A_1^2} = \begin{bmatrix} c2 & -s2 & 0 & a2c2 \\ s2 & c2 & 1 & a2s2 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\mathbf{A_2^3} = \begin{bmatrix} c3 & -s3 & 0 & a3c3 \\ s3 & c3 & 1 & a3s3 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Transformation Matrix:

$$T_0^3 = (A_0^1 . A_{1)}^2 . A_2^3$$

$$T_0^3 = \begin{bmatrix} c1c2 - s1s2 & -c1s2 - c2s1 & 0 & a1c1 + a2c1c2 \\ c1s2 + c2s1 & c1c2 - s1s2 & 1 & a1s1 + a2c1s2 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} . \begin{bmatrix} c3 & -s3 & 0 & a3c3 \\ s3 & c3 & 1 & a3s3 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$T_0^3 = \begin{bmatrix} c3(c1c2 - s1s2) - s3(c1s2 + c2s1) & -c3(c1s2 + c2s1) - s3(c1c2 - s1s2) & 0 & a1c1 + a2c1c2 + a3c3(c1c2 - s1s2) - a3s3(c1s2 + c2s1) \\ c3(c1s2 + c2s1) + s3(c1c2 - s1s2) & c3(c1c2 - s1s2) - s3(c1s2 + c2s1) & 1 & a1s1 + a2c1s2 + a3c3(c1s2 + c2s1) + a3s3(c1c2 - s1s2) \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Inverse Kinematic Analysis:

For a 3R manipulator we can perform the inverse kinematic analysis by using a simple method called “Piper’s solution”. Piper’s solution provides the analytical method to find the inverse kinematic analysis solution up to 3 joints.

c) Velocity Kinematic Analysis:

For the velocity kinematic analysis, the Jacobian matrix of the kinematic system which is as follows.

$$\mathbf{J}=\begin{bmatrix} z0x(O3-O0) & z1x(O3-O1) & z2x(O3-O2) \\ z0 & z1 & z2 \end{bmatrix}$$

We find:

$$\mathbf{T_1^0}=\begin{bmatrix} c1 & -s1 & 0 & a1c1 \\ s1 & c1 & 1 & a1s1 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}; \mathbf{T_2^0}=\begin{bmatrix} c12 & -s12 & 0 & a1c1+a2c12 \\ s12 & c12 & 1 & a1s1+s2s12 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\mathbf{T_3^0}=\begin{bmatrix} c123 & -s123 & 0 & a1c1+a2c12+a3c123 \\ s123 & c123 & 1 & a1s1+s2s12+a3s123 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Origins:

$$O0=\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}; O1=\begin{bmatrix} a1c1 \\ a1s1 \\ 0 \end{bmatrix}; O2=\begin{bmatrix} a1c1+a1c12 \\ a1s1+a2s2 \\ 0 \end{bmatrix}; O3=\begin{bmatrix} a1c1+a2c12+a3c123 \\ 0a1s1+a2s12+a3s123 \\ 0 \end{bmatrix}$$

z-vectors:

$$z0=z1=z2=z3=\begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$$

$$z0x(O3-O0)=z0xO3=\begin{bmatrix} -a1s1-a2s12-a3s123 \\ a1c1+a2c12+a3c123 \\ 0 \end{bmatrix}$$

$$O3-O1=\begin{bmatrix} a2c12+a3c123 \\ a2s12+a3s123 \\ 0 \end{bmatrix}$$

$$z1x(O3-O1)=\begin{bmatrix} -a2s12-a3s123 \\ a2c12+a3c123 \\ 0 \end{bmatrix}$$

$$(O3-O2)=\begin{bmatrix} a3c123 \\ a3s123 \\ 0 \end{bmatrix}$$

$$z2x(O3-O2)=\begin{bmatrix} -a3s123 \\ a3c123 \\ 0 \end{bmatrix}$$

$$
J=\begin{bmatrix} -a1s1-a2s12-a3s123 & -a2s12-a3s123 & -a3s123 \\ a1c1+a2s12+a3s123 & a2c12+a2c123 & a3c123 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix}
$$

d) Workspace:

I took the link lengths of my body, i.e.

a1=Link Length Between Hip and Knee= 0.42

a2=Link Length Between Knee and Ankle= 0.33

a3=Link Length Between Ankle and foot tip= 0.17

Angle limits were selected as per human can move his particular joint. i.e.

ϴ1= 0 to 130; ϴ2= 0 to 130; ϴ3= 0 to -20

Robo-Analyzer DH parameter section:

D-H Parameters

Robot

Select DOF: 3

Select Robot: 3R

Joint No	Joint Type	Joint Offset (b) m	Joint Angle (theta) deg	Link Length (a) m	Twist Angle (alpha) deg	Initial Value (JV) deg or m	Final Value (JV) deg or m
1	Revolute	0	Variable	0.42	0	0	130
2	Revolute	0	Variable	0.33	0	0	130
3	Revolute	0	Variable	0.17	0	0	-20

Fig 2: DH parameters set on Robo-Analyzer

Workspace provided after setting parameters of link lengths and angle limits:

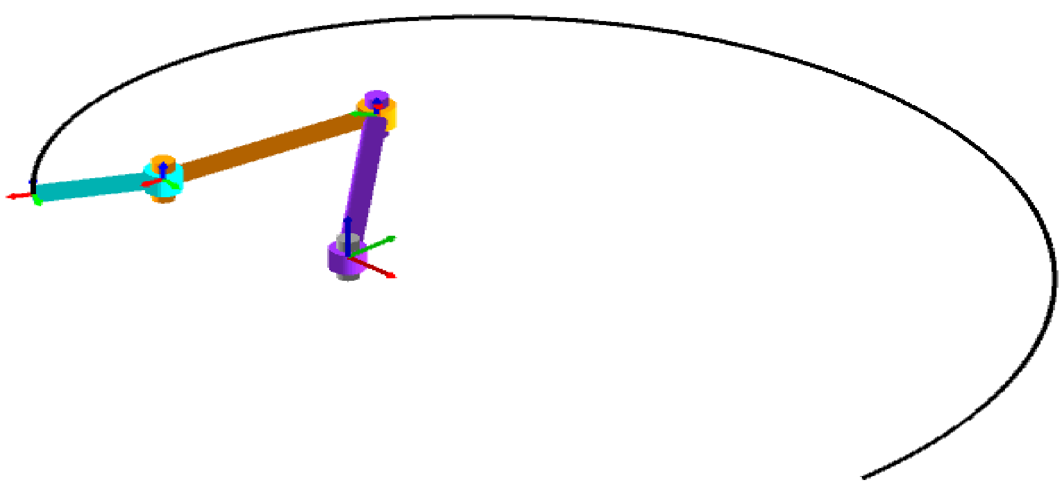

Fig 3: Workspace

As per proposed kinematic model, the model contains three revolute joints which means in physical modelling we will use three stepper motors.

In one of our control system 1 assignment, we were assigned a task in which we had to perform PID controlling of a motor. I applied the same method on tunning the stepper to get the specified response. Transfer function is as follows;

$$\text{Transfer Function= T.F} = \frac{0.068}{0.0012s^2+0.009s+0.0196}$$

Control system for the following three stepper motors can be done by using PID tunning in “SISOTOOL”. For each motor we’ll tune it in PID tunning to get the desired response i.e.: adjusting the rise time by tunning P, adjusting the maximum overshoots and settling time for the movement by tunning D and I. MATLAB code is as follows;

```
clear
close
clc
num = [0.068];
den = [0.0012 0.009 0.019624];
G = tf(num,den)
sisotool(G);
```

Fig 4: Code

PID tunning:

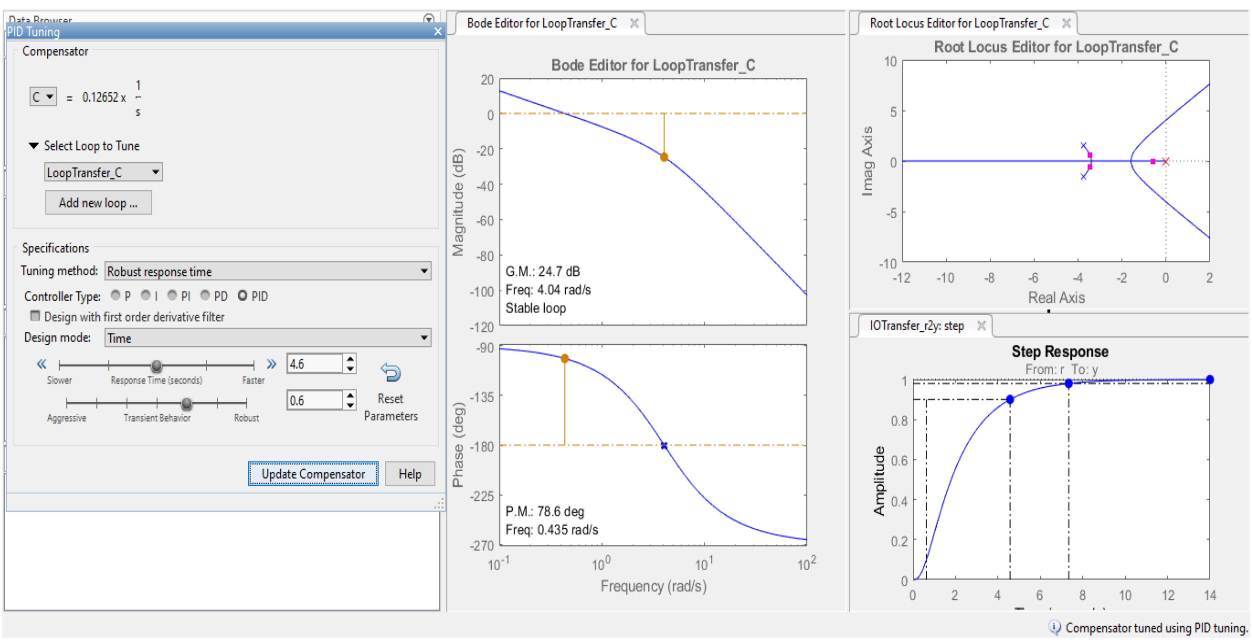

Fig 5: PID tunning

Conclusion:

In conclusion, the analysis and solution development for the complex engineering problem presented in this report required a thorough understanding of the underlying principles and mathematical models involved. The problem was approached systematically, starting with the development of a mathematical model to describe the system's behavior and dynamics. The model was then used to analyze the system's performance and identify the root cause of the problem. Afterwards we solved the system at hand efficiently.