MECH0064 MSc Group Design Project

Compact Continuum Robotic Manipulator Platform

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Abstract

This is the Abstract of the final report.

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test for github

Key Words: Continuum Robotic e.g.

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1 Introduction

This is the Introduction of the final report.[1]

Introduction including market survey.

Introduction including market survey.

1.1 Background

This is the background part.

1.2 Motivation

This is the motivation part.

2 Literature Review

This is the Literature Review of the final report.

2.1 part ??

unknown

2.2 part ??

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unknowz

3 Design

This is the Design of the final report.

3.1 Methodology

3.1.1 Forward Kinematics

The manipulator consists of four units, and the backbones of each section are perpendicular to each other. To derive the workspace of the manipulator for further analysis, the forward kinematics formula need to be conducted. According to the fishbone continuum robot[2], the forward kinematics formula of two perpendicular units are shown in Equations 1, 2, and 3.

$$\begin{aligned} x = & -\frac{S_r r}{\Delta S_1} + \frac{S_r r}{\Delta S_1}\cos\left(\frac{\Delta S_l}{r}\right) - d_1 \sin\left(\frac{\Delta S_l}{r}\right) \\ & - \frac{S_r r}{\Delta S_3}\sin\left(\frac{\Delta S_1}{r}\right)\sin\left(\frac{\Delta S_3}{r}\right) \\ & - d_2 \sin\left(\frac{\Delta S_1}{r}\right)\cos\left(\frac{\Delta S_3}{r}\right) \end{aligned} \tag{1}$$

$$y = -\frac{S_r r}{\Delta S_3} + \frac{S_r r}{\Delta S_3}\cos\left(\frac{\Delta S_3}{r}\right) - d_2 \sin\left(\frac{\Delta S_3}{r}\right) \tag{2}$$

$$\begin{aligned} \mathrm{Z} = & \frac{S_r r}{\Delta S_1}\sin\left(\frac{\Delta S_l}{r}\right) + d_1 \cos\left(\frac{\Delta S_l}{r}\right) \\ & + \frac{S_r r}{\Delta S_3}\sin\left(\frac{\Delta S_3}{r}\right)\cos\left(\frac{\Delta S_1}{r}\right) \\ & + d_2 \cos\left(\frac{\Delta S_1}{r}\right)\cos\left(\frac{\Delta S_3}{r}\right). \end{aligned} \tag{3}$$

However, calculating the centroid directly using the above formula becomes complex while there are four units in the manipulator. Additionally, the inverse kinematics part also requires the derivation of corresponding matrices for subsequent calculations using the composite coordinate transformation formula. Therefore, The relevant matrices for subsequent calculations need to be derived.

According to the design specifications, the manipulator comprises four units.

The backbones of the units are vertically aligned. The base coordinate system can be established with the centroid of base disk upper surface serving as the origin. The x-axis of the coordinate system is aligned with the backbone of the unit nearest to the base disk. Consequently, the backbones of units 1 and 3 are parallel to the x-axis, while those of units 2 and 4 are parallel to the y-axis. The positions of the five centroids in the base coordinate system when the manipulator is in the initial position are shown in Figure 1. The centroids of the five disc upper surfaces are designated as $node_1$, $node_2$, $node_3$, $node_4$, and $node_5$.

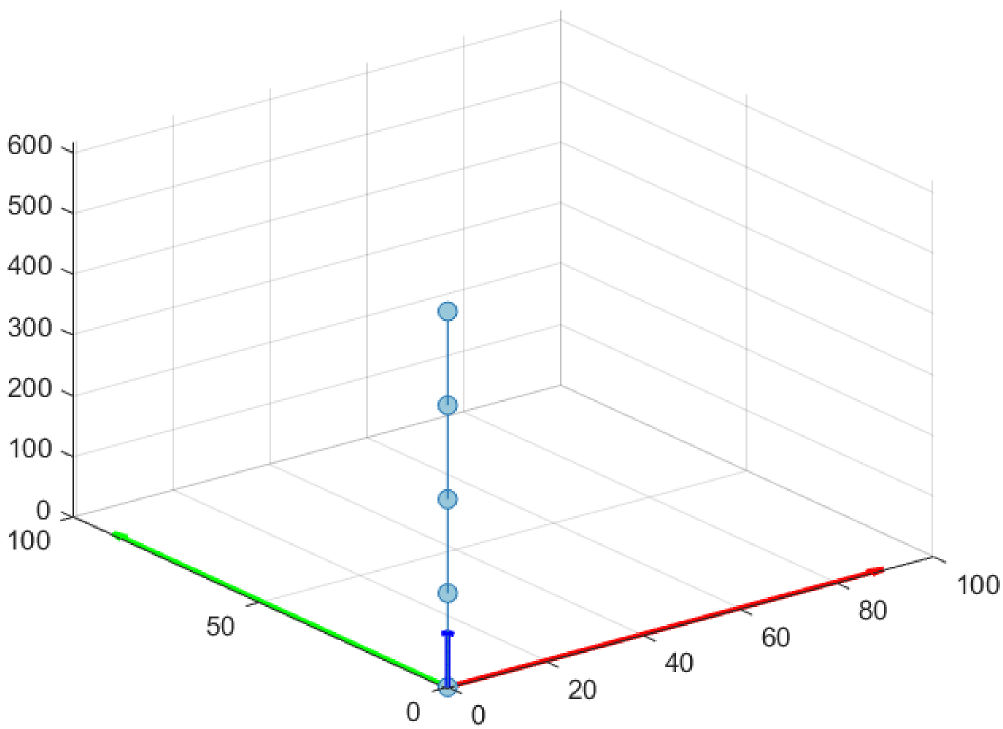
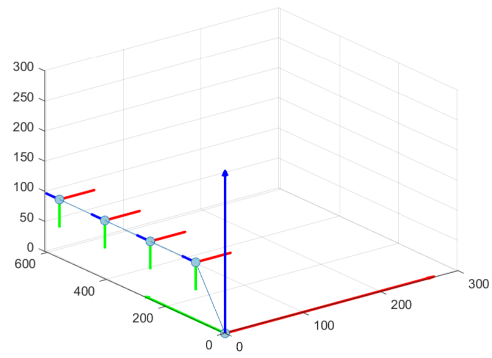
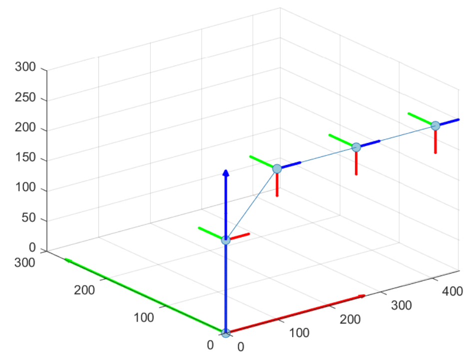


Figure 1: ***The kinematics model of manipulator in initial position.***

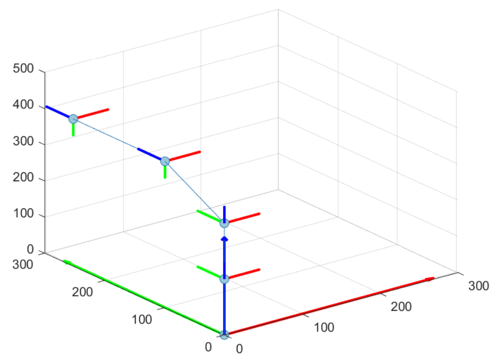
The unit 1 is restricted to bending in the y-z plane of the coordinate system where $node_1$ serves as the origin, while the unit 2 is restricted to bending in the x-z plane of the coordinate system where $node_2$ serves as the origin. Similarly, the unit 3 and unit 4 are subject to the same constraints. The bending angles for these units are defined as α_1, α_2, α_3, and α_4, respectively. The positions of the manipulator model in the base coordinate system after bending each unit by 90° are illustrated in Figure 2.



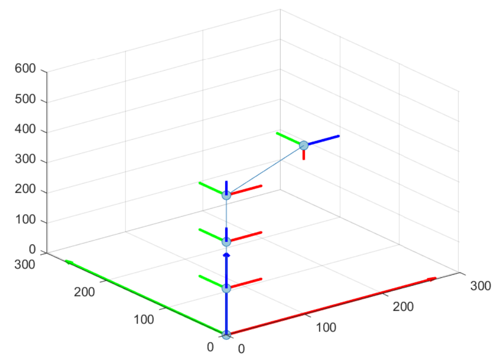
(a) $\alpha_1 = 90°, \alpha_2 = 0, \alpha_3 = 0, \alpha_4 = 0$



(b) $\alpha_1 = 0, \alpha_2 = 90°, \alpha_3 = 0, \alpha_4 = 0$



(c) $\alpha_1 = 0, \alpha_2 = 0, \alpha_3 = 90°, \alpha_4 = 0$



(d) $\alpha_1 = 0, \alpha_2 = 0, \alpha_3 = 0, \alpha_4 = 90°$

Figure 2: ***The kinematics model of manipulator with respective bending units.***

While the units bend to the positive direction of x-axis or y-axis, the bending angles α are positive. Owing to the distinct properties of the four units, different calculation methods are required for analysis. The unit i have a base node $node_i$ and an end effector node $node_{i+1}$. To further calculate the position of $node_{i+1}$ in the base coordinate system, these matrices can be employed in the Equation 4.

$$\mathbf{P}_{i+1}^{base} = \mathbf{B}_i \times \mathbf{P}_{i+1}^{i} + \mathbf{P}_{i}^{base} \tag{4}$$

$\mathbf{P}_{i+1}^{base}$: The position of $node_{i+1}$ in the base coordinate system.

$\mathbf{B}_i$: The rotational matrix tranforms the base coordinate system into coordinate system i, which is the coordinate system with origin $node_i$.

$\mathbf{P}_{i+1}^{i}$: The position of $node_{i+1}$ in coordinate system i.

$\mathbf{P}_{i}^{base}$: The position of $node_i$ in the base coordinate system.

- Unit 1

  For Unit 1, the relationship between the relative position matrix of $node_1$ and $node_2$ $\mathbf{P}_2^1$ and α_1 is shown in Equation 5.

$$\mathbf{P}_2^1 = \begin{bmatrix} 0 \\ sgn(\alpha_1) \cdot (R_1 \cdot (1 - \cos(|\alpha_1|)) + d_2 \cdot \sin(|\alpha_1|)) \\ (R_1 \cdot \sin(|\alpha_1|) + d_2 \cdot \cos(|\alpha_1|)) \end{bmatrix} \tag{5}$$

$$(hint: \ R_1 = Sr_1/\alpha_1)$$

  R_1 is the radius of the Unit 1 bending curve, Sr_1 is the length of the Unit 1 backbone, and d_2 is the thickness of the disc whose centroid is $node_2$. Meanwhile, the rotational matrix $\mathbf{B}_1$ and the position matrix of $node_1$ $\mathbf{P}_1^{base}$ are shown in Equations 6 and 7.

$$\mathbf{B}_1 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{6}$$

$$\mathbf{P}_1^{base} = \begin{bmatrix} 0 & 0 & 0 \end{bmatrix}^{\mathbf{T}} \tag{7}$$

  According to the Equations 5, 6, and 7, the position matrix of $node_2$ in the base coordinate system $\mathbf{P}_2^{base}$ can be calculated in Equation 8.

$$\begin{aligned} \mathbf{P}_2^{base} &= \mathbf{B}_1 \times \mathbf{P}_2^1 + \mathbf{P}_1^{base} \\ &= \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} 0 \\ sgn(\alpha_1) \cdot (R_1 \cdot (1 - \cos(|\alpha_1|)) + d_2 \cdot \sin(|\alpha_1|)) \\ (R_1 \cdot \sin(|\alpha_1|) + d_2 \cdot \cos(|\alpha_1|)) \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \\ &= \begin{bmatrix} 0 \\ sgn(\alpha_1) \cdot (R_1 \cdot (1 - \cos(|\alpha|)) + d \cdot \sin(|\alpha|)) \\ (R_1 \cdot \sin(|\alpha|) + d \cdot \cos(|\alpha|)) \end{bmatrix} \end{aligned} \tag{8}$$

- Unit 2

  For Unit 2, the relationship between the relative position matrix of $node_2$

and $node_3$ $\mathbf{P}_3^2$ and α_2 is shown in Equation 9.

$$\mathbf{P}_3^2 = \begin{bmatrix} sgn(\alpha_2) \cdot (R_2 \cdot (1 - \cos(|\alpha_2|)) + d_3 \cdot \sin(|\alpha_2|)) \\ 0 \\ (R_2 \cdot \sin(|\alpha_2|) + d_3 \cdot \cos(|\alpha_2|)) \end{bmatrix} \tag{9}$$

$$(hint: \; R_2 = Sr_2/\alpha_2)$$

R_2 is the radius of the Unit 2 bending curve, Sr_2 is the length of the Unit 2 backbone, and d_3 is the thickness of the disc whose centroid is $node_3$. Meanwhile, the rotational matrix $\mathbf{B}_2$ and the position matrix of $node_2$ $\mathbf{P}_2^{base}$ are shown in Equations 10 and 8.

$$\mathbf{B}_2 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\alpha_1) & \sin(\alpha_1) \\ 0 & -\sin(\alpha_1) & \cos(\alpha_1) \end{bmatrix} \tag{10}$$

According to the Equations 8, 9, and 10, the position matrix of $node_3$ in the base coordinate system $\mathbf{P}_3^{base}$ can be calculated in Equation 11.

$$\begin{aligned} \mathbf{P}_3^{base} &= \mathbf{B}_1 \times \mathbf{B}_2 \times \mathbf{P}_3^2 + \mathbf{P}_2^{base} \\ &= \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \times \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\alpha_1) & \sin(\alpha_1) \\ 0 & -\sin(\alpha_1) & \cos(\alpha_1) \end{bmatrix} \\ &\times \begin{bmatrix} 0 \\ sgn(\alpha_2) \cdot (R_2 \cdot (1 - \cos(|\alpha_2|)) + d_3 \cdot \sin(|\alpha_2|)) \\ (R_2 \cdot \sin(|\alpha_2|) + d_3 \cdot \cos(|\alpha_2|)) \end{bmatrix} \\ &+ \begin{bmatrix} 0 \\ sgn(\alpha_1) \cdot (R_1 \cdot (1 - \cos(|\alpha_1|)) + d_2 \cdot \sin(|\alpha_1|)) \\ (R_1 \cdot \sin(|\alpha_1|) + d_2 \cdot \cos(|\alpha_1|)) \end{bmatrix} \end{aligned} \tag{11}$$

- Unit 3

For Unit 3, the relationship between the relative position matrix of $node_3$

and $node_4$ $\mathbf{P}_4^3$ and α_3 is shown in Equation 12.

$$\mathbf{P}_4^3 = \begin{bmatrix} 0 \\ sgn(\alpha_3) \cdot (R_3 \cdot (1 - \cos(|\alpha_3|)) + d_4 \cdot \sin(|\alpha_3|)) \\ (R_3 \cdot \sin(|\alpha_3|) + d_4 \cdot \cos(|\alpha_3|)) \end{bmatrix} \tag{12}$$

$$(hint: \ R_2 = Sr_2/\alpha_2)$$

R_3 is the radius of the Unit 3 bending curve, Sr_3 is the length of the Unit 3 backbone, and d_4 is the thickness of the disc whose centroid is $node_4$. Meanwhile, the rotational matrix $\mathbf{B}_3$ and the position matrix of $node_3$ $\mathbf{P}_3^{base}$ are shown in Equations 13 and 11.

$$\mathbf{B}_3 = \begin{bmatrix} \cos(\alpha_2) & 0 & \sin(\alpha_2) \\ 0 & 1 & 0 \\ -\sin(\alpha_2) & 0 & \cos(\alpha_2) \end{bmatrix} \tag{13}$$

According to the Equations 11, 12, and 13, the position matrix of $node_4$ in the base coordinate system $\mathbf{P}_4^{base}$ can be calculated in Equation 14.

$$\begin{aligned} \mathbf{P}_4^{base} &= \mathbf{B}_1 \times \mathbf{B}_2 \times \mathbf{B}_3 \times \mathbf{P}_4^3 + \mathbf{P}_3^{base} \\ &= \mathbf{B}_1 \times \mathbf{B}_2 \times \begin{bmatrix} \cos(\alpha_2) & 0 & \sin(\alpha_2) \\ 0 & 1 & 0 \\ -\sin(\alpha_2) & 0 & \cos(\alpha_2) \end{bmatrix} \\ &\times \begin{bmatrix} 0 \\ sgn(\alpha_3) \cdot (R_3 \cdot (1 - \cos(|\alpha_3|)) + d_4 \cdot \sin(|\alpha_3|)) \\ (R_3 \cdot \sin(|\alpha_3|) + d_4 \cdot \cos(|\alpha_3|)) \end{bmatrix} + \mathbf{P}_3^{base} \end{aligned} \tag{14}$$

- Unit 4

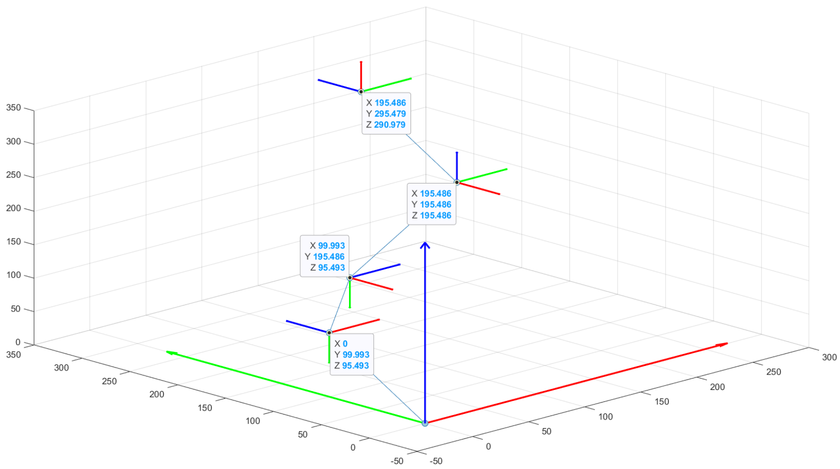
  In summary, the position matrix of $node_5$ in the base coordinate system P_5^{base}can be represented by Equation 15.

$$\mathbf{P}_5^{base} = \mathbf{B}_1 \times \mathbf{B}_2 \times \mathbf{B}_3 \times \mathbf{B}_4 \times \mathbf{P}_5^4 + \mathbf{P}_4^{base} \tag{15}$$

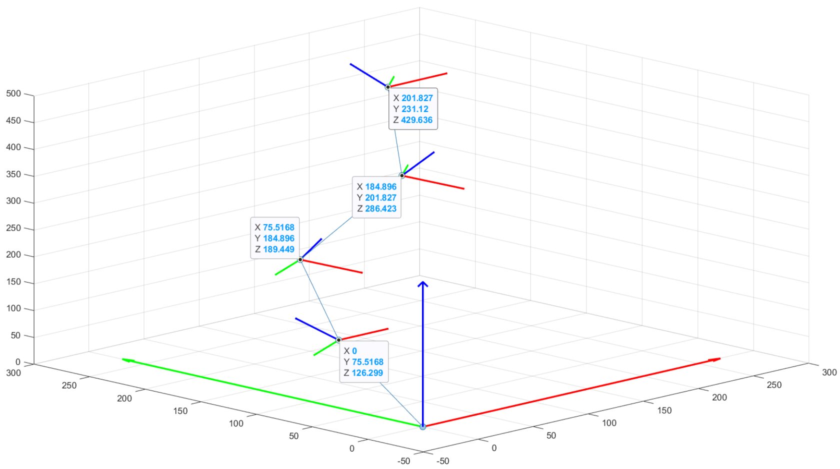
Applying the corresponding transformations to the Equation 4 reveals the patterns shown in Equation 17.

$$\mathbf{P}_{i+1}^{base} - \mathbf{P}_{i}^{base} = \prod_{n=1}^{i} \mathbf{B}_n \times \mathbf{P}_{i+1}^{i} \tag{16}$$

$$\mathbf{P}_{i+1}^{base} = \sum_{m=1}^{i} \left[\prod_{n=1}^{m} \mathbf{B}_n \times \mathbf{P}_{m+1}^{m} \right] \quad (\mathbf{P}_{1}^{base} = 0) \tag{17}$$



(a) $\alpha_1 = 90°, \alpha_2 = 90°, \alpha_3 = -90°, \alpha_4 = -90°$



(b) $\alpha_1 = 60°, \alpha_2 = 60°, \alpha_3 = -60°, \alpha_4 = -60°$

Figure 3: ***The kinematics model of manipulator with respective bending units.***

4 Result and Discussion

This is the Result and Discussion of the final report.

4.1 part ??

unknown

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4.6 part ??

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4.7 part ??

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4.8 part ??

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4.9 part ??

unknown

4.10 part ??

unknown

4.11 part ??

unknown

5 Conclusion

This is the Conclusion of the final report.

References

1. Benner, S. A. Synthetic biology: Act natural. *Nature* **421,** 118–118 (2003).
2. Zhou, P. *et al.* A bioinspired fishbone continuum robot with rigid-flexible-soft coupling structure. *Bioinspiration & Biomimetics* **17,** 066012 (2022).

Appendix A

TEST

This is the Appendix 1.

Appendix B

Test

This is the Appendix 2.