## 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 ??

unknown

unknowz

# 3 Design

This is the Design of the final report.

## 3.1 Methodology

### 3.1.1 Forward Kinematics

The manipulator consists of four sections, 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 sections are shown in Equations 1, 2, and 3.

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

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

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

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 $node_5$.

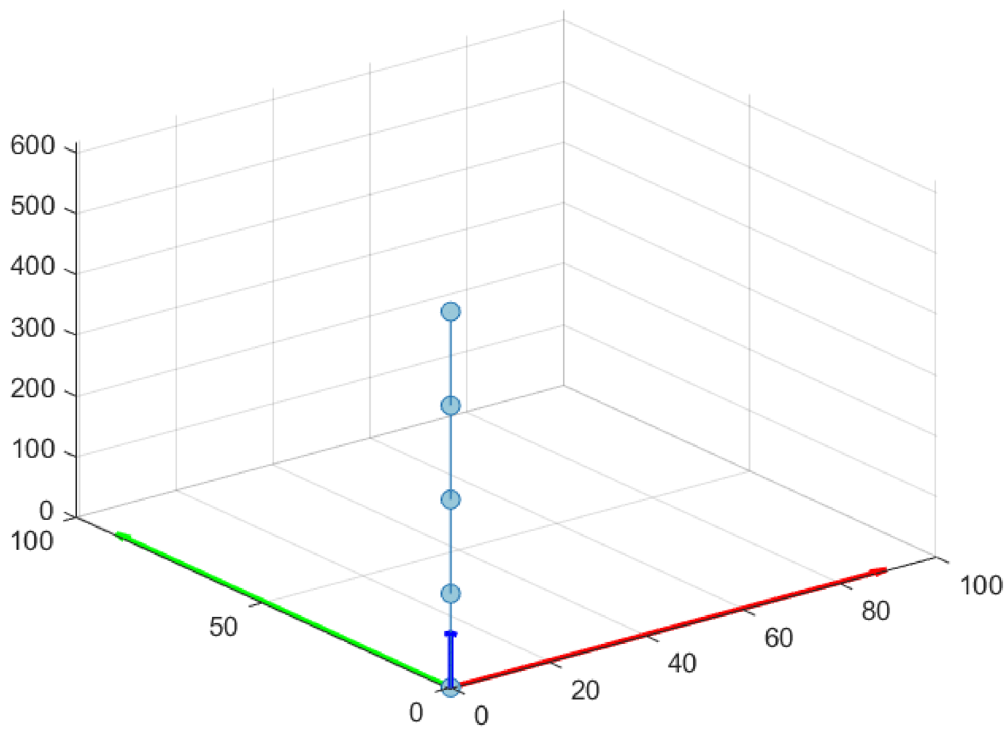
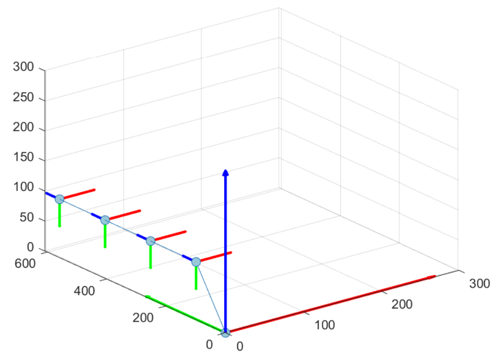
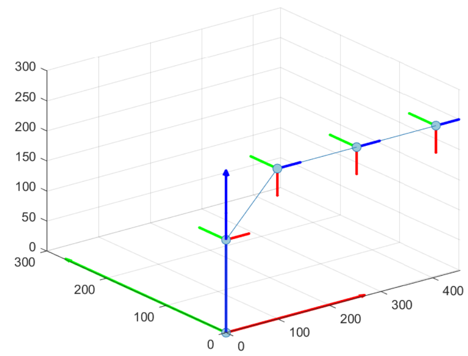



**Figure 1:** ***The kinematics model of manipulator in initial position.***

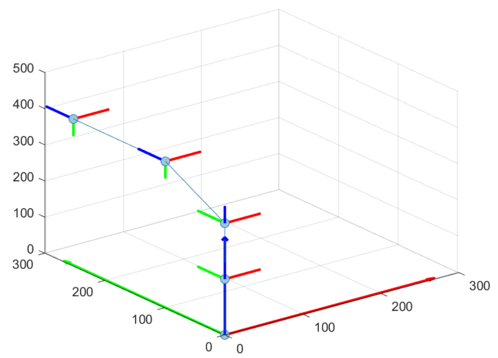
The unit 1 is restricted to bending in the y-z plane of the coordinate system where $node_1$ serves as the origin, while the unit 2 is restricted to bending in the x-z plane of the coordinate system where $node_2$ serves as the origin. Similarly, the unit 3 and unit 4 are subject to the same constraints. The bending angles for these units are defined as $\alpha_1$, $\alpha_2$, $\alpha_3$, and $\alpha_4$, respectively. The positions of the manipulator model in the base coordinate system after bending each unit by 90° are illustrated in Figure 2.



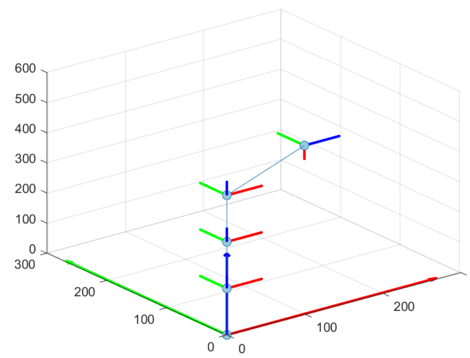

**(a)** $\alpha_1 = 90°, \alpha_2 = 0, \alpha_3 = 0, \alpha_4 = 0$




**(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.***

Owing to the distinct properties of the four units, different calculation methods are required for analysis. Therefore, the units are divided into odd and even groups for separate 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
- Unit 2
- Unit 3
- Unit 4

The position of the end effector at the section whose backbone is parallel to the x-axis, which is $\mathbf{P}_{end}$ can be derived based on the bending angle matrix $\mathbf{B}$, mechanism parameters, the position of the end effector in the base coordinate system $\mathbf{P}_{base}^{end}$ and the position of the base at the section $\mathbf{P}_{base}$. The composite coordinate transformation is a combination of rotation and translation. The equations are shown in Equations 5 and 6. $P_{horizontal}$ and $P_{vertical}$ are the horizontal and vertical position of end effector at the section in the base coordinate system, respectively. The sign of $P_{horizontal}$ in matrix $\mathbf{P}_{base}^{end}$ consistent with the the sign of $\alpha$.

$$\mathbf{P}_{end} = \mathbf{B} \times \mathbf{P}_{base} + \mathbf{P}_{base}^{end} \tag{5}$$

$$\begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\alpha) & \sin(\alpha) \\ 0 & -\sin(\alpha) & \cos(\alpha) \end{bmatrix} \times \begin{bmatrix} x \\ y \\ z \end{bmatrix} + \begin{bmatrix} 0 \\ \pm P_{\text{horizontal}} \\ P_{\text{vertical}} \end{bmatrix} \tag{6}$$

$$P_{horizontal} = R \cdot (1 - cos(\alpha) + d \cdot cos(\alpha))$$

$$P_{vertical} = R \cdot sin(\alpha) + d \cdot sin(\alpha)$$

The composite transfermation matrix of the first section whose backbone is parallel to x-axis is derived in Equations 7 and 8.

$$\mathbf{P}_{end,1} = \begin{bmatrix} \mathbf{B}_1 & \mathbf{P}_{base,1}^{end} \\ \mathbf{0} & 1 \end{bmatrix} \mathbf{P}_{base,1} \tag{7}$$

$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & cos(\alpha 1) & sin(\alpha 1) & \pm P_{horizontal,1} \\ 0 & -sin(\alpha 1) & cos(\alpha 1) & P_{vertical,1} \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} \tag{8}$$

The composite transfermation matrix of the second section whose backbone is parallel to y-axis is derived in Equations 9 and 10. ($\mathbf{P}_{base,2}$ is equivalent to $\mathbf{P}_{end,1}$)

$$\mathbf{P}_{end,2} = \begin{bmatrix} \mathbf{B}_2 & \mathbf{P}^{end}_{base,2} \\ \mathbf{0} & 1 \end{bmatrix} \mathbf{P}_{base,2}\ (\mathbf{P}_{end,1}) \tag{9}$$

$$\begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} = \begin{bmatrix} cos(\alpha 2) & 0 & sin(\alpha 2) & \pm P_{horizontal,2} \\ 0 & 1 & 0 & 0 \\ -sin(\alpha 2) & 0 & cos(\alpha 2) & P_{vertical,2} \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} \tag{10}$$

The manipulator consists of four sections. Therefore, the coordinates of the base and end effector of the manipulator can be expressed through the following forward kinematics matrices in Equation 11.

$$\mathbf{P}_{end,4} = \begin{bmatrix} \mathbf{B}_4 & \mathbf{P}^{end}_{base,4} \\ \mathbf{0} & 1 \end{bmatrix} \begin{bmatrix} \mathbf{B}_3 & \mathbf{P}^{end}_{base,3} \\ \mathbf{0} & 1 \end{bmatrix} \begin{bmatrix} \mathbf{B}_2 & \mathbf{P}^{end}_{base,2} \\ \mathbf{0} & 1 \end{bmatrix} \begin{bmatrix} \mathbf{B}_1 & \mathbf{P}^{end}_{base,1} \\ \mathbf{0} & 1 \end{bmatrix} \mathbf{P}_{base,1} \tag{11}$$

### 3.2 part ??

unknown

### 3.3 part ??

unknown

# 4 Result and Discussion

This is the Result and Discussion of the final report.

## 4.1 part ??

unknown

## 4.2 part ??

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## 4.3 part ??

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## 4.4 part ??

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## 4.5 part ??

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## 4.6 part ??

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## 4.7 part ??

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### 4.9 part ??

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### 4.10 part ??

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### 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.