PAINTING THE METAVERSE

KCGS 2021

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이화여자대학교 컴퓨터공학과

모바일 매니퓰레이터 로봇을 이용한 TSP 펜아트
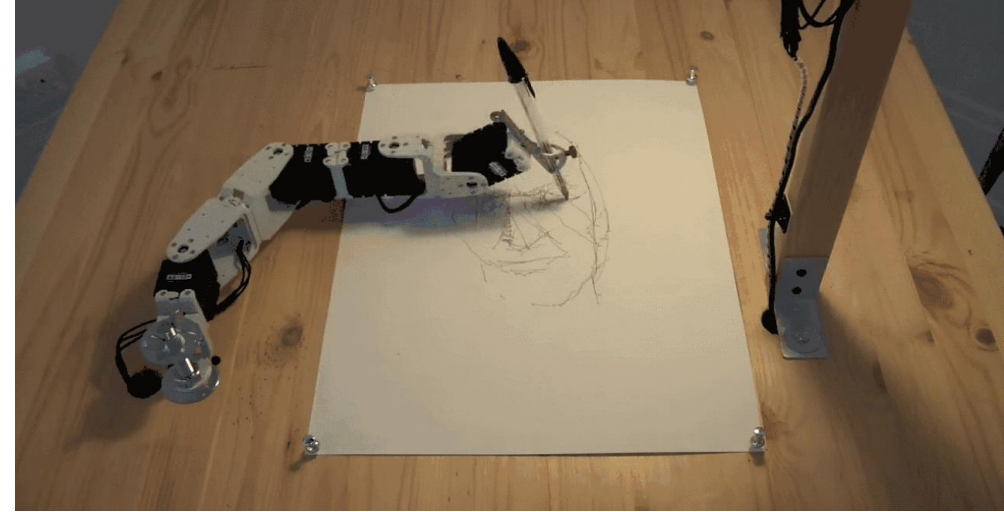
Introduction - **Robotic Drawing**

[Line us, online]

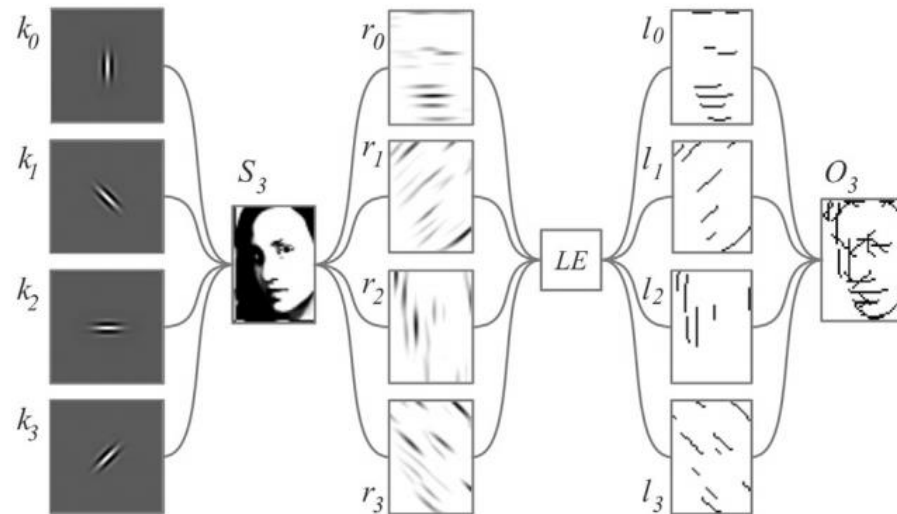[Tresset et al., C&G13]

[Cloud Painter, online]

Introduction - Related Works

[Lu et al., ASME09]

[Song et al., ICRA18]

[Tresset et al., C&G13]

Introduction - **Challenges**

- Limited drawing canvas size and workspace due to fixed base
  - Use of mobile base robot to relax the constraint

- Weak replication of image on physical space
  - Convert raster images to vector set for robot drawing
  - Express details(e.g. brightness, color) using TSP art

Introduction - Research Goal

Robotic Drawing System using a Mobile Manipulator

- Large drawing canvas

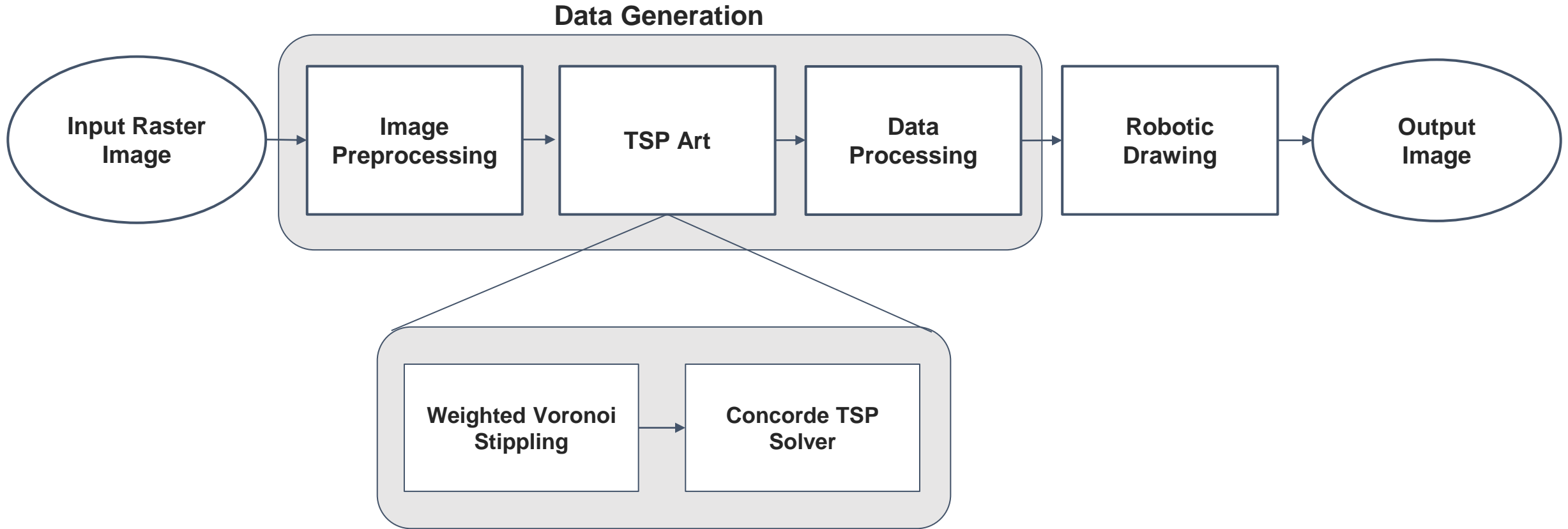- Complicated and detailed drawing

Introduction - TSP Art

- ## Traveling Salesman Problem(TSP) Art

  : Single-stroke drawing generated by solving a TSP on the image

  - Can easily be converted into continuous robot

    trajectories

  - Can express details of input image with many

    pixels, colors, contrast

[Robert Bosch, online]

System Overview

Image Preprocessing

- Color Channel Separation into CMYK
  - Use of four-color painting to reproduce the input color space in the physical space
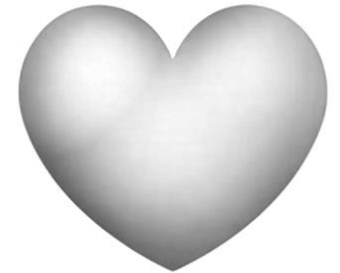

Input Image   **Cyan**   **Magenta**   **Yellow**   **Black**
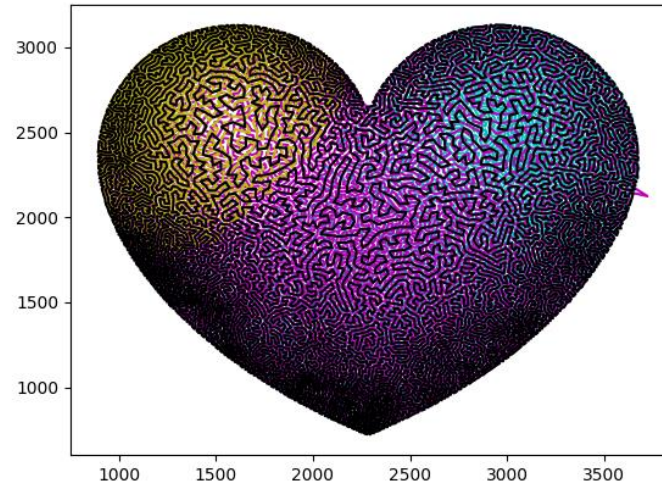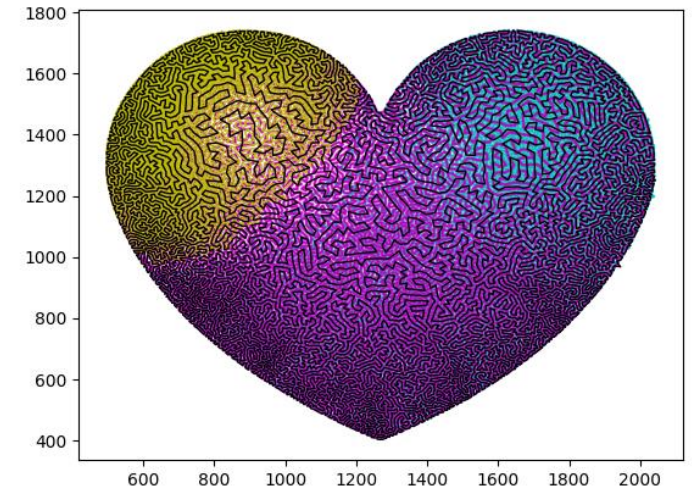
Image Preprocessing

- Color Thresholding
  - To reduce the "blackness" that dominates other color channels when drawn on canvas

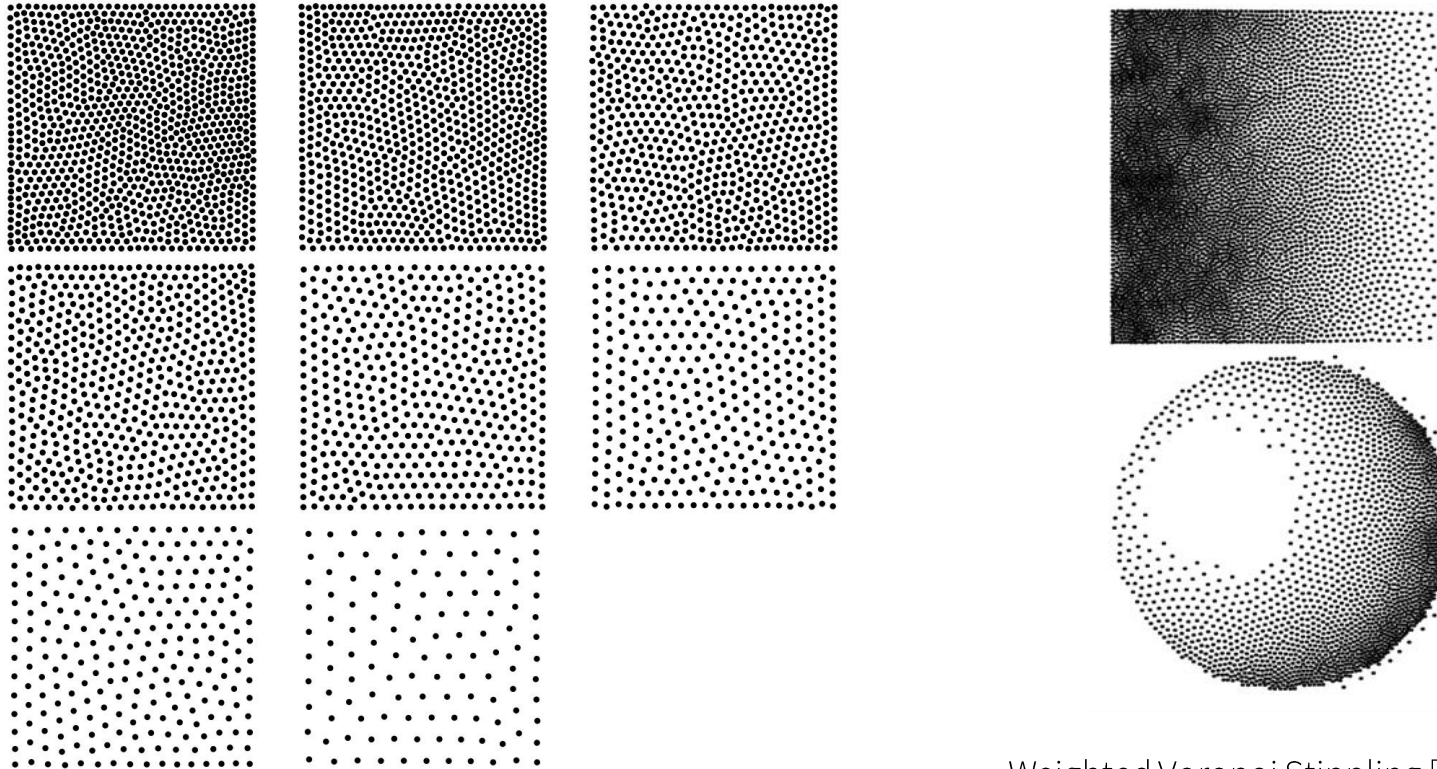**Input Image**

Without Threshold and Saturation

With Threshold and Saturation

- Generate stipple drawings from grayscale images using weighted centroidal Voronoi diagrams [Secord, NPAR 02]
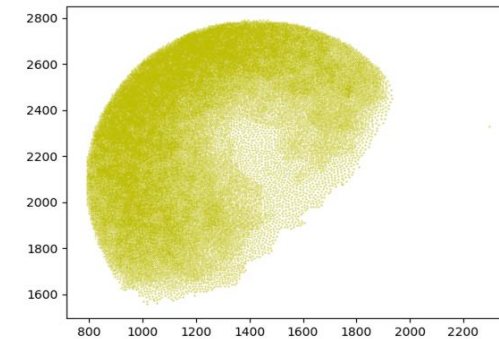

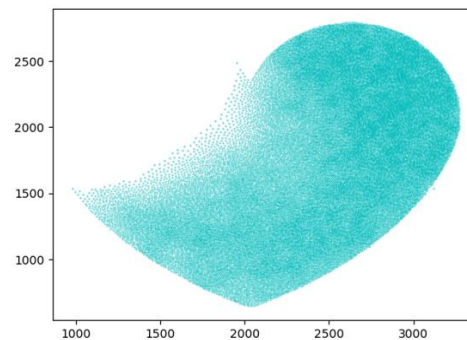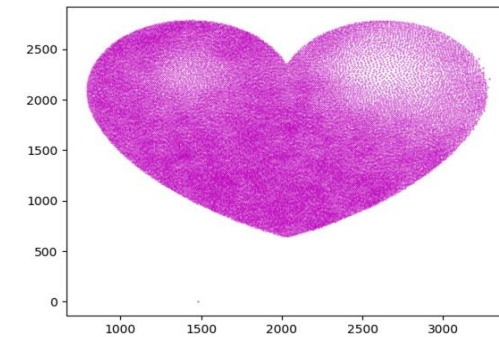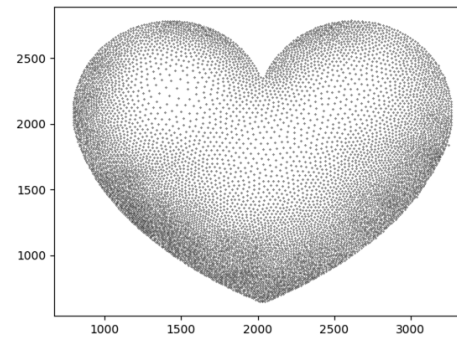Weighted Voronoi Stippling [Secord 02]

TSP Art - Weighted Voronoi Stippling

- Generate stipple drawings from grayscale images using weighted centroidal Voronoi diagrams [Secord, NPAR 02]

Input Image

Stippling results of each C, M, Y, K split images

TSP Art - **Concorde TSP Solver**

- Iteratively solve relaxed linear programming of TSP using cutting-plane method [Applegate, Princeton University Press 06]

  - The cutting plane method eliminates flawed fractional solutions until an optimal solution is reached
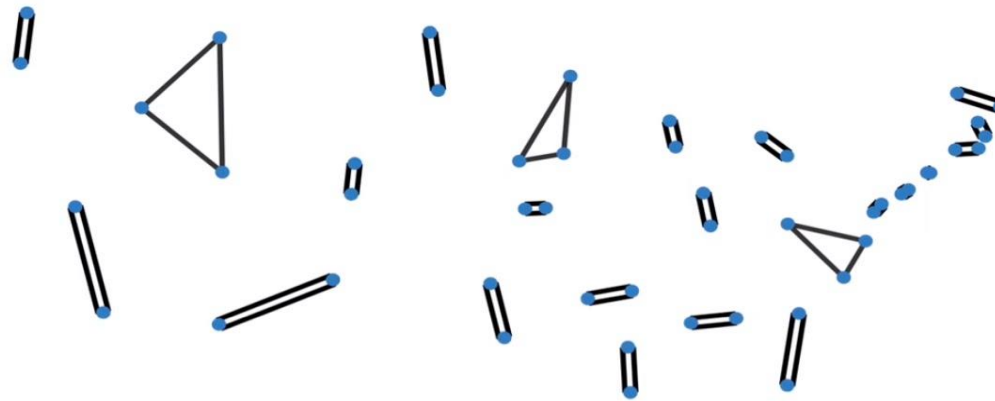
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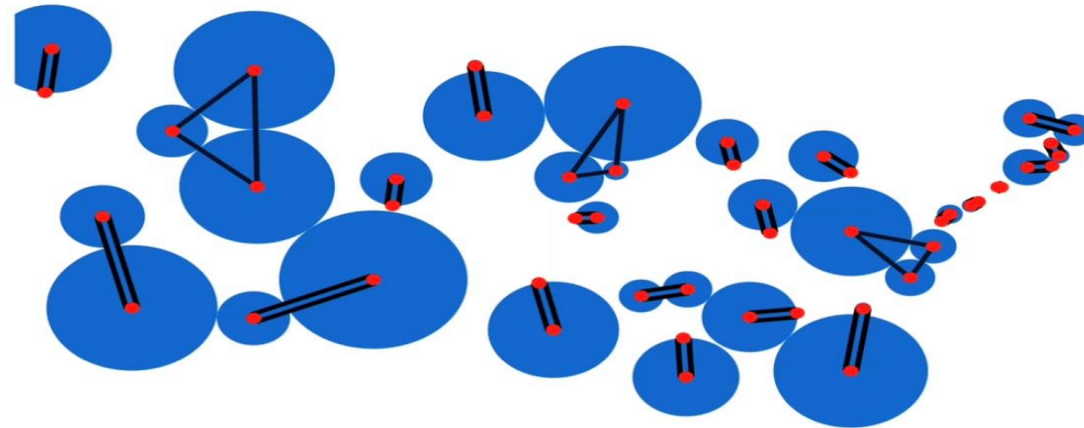
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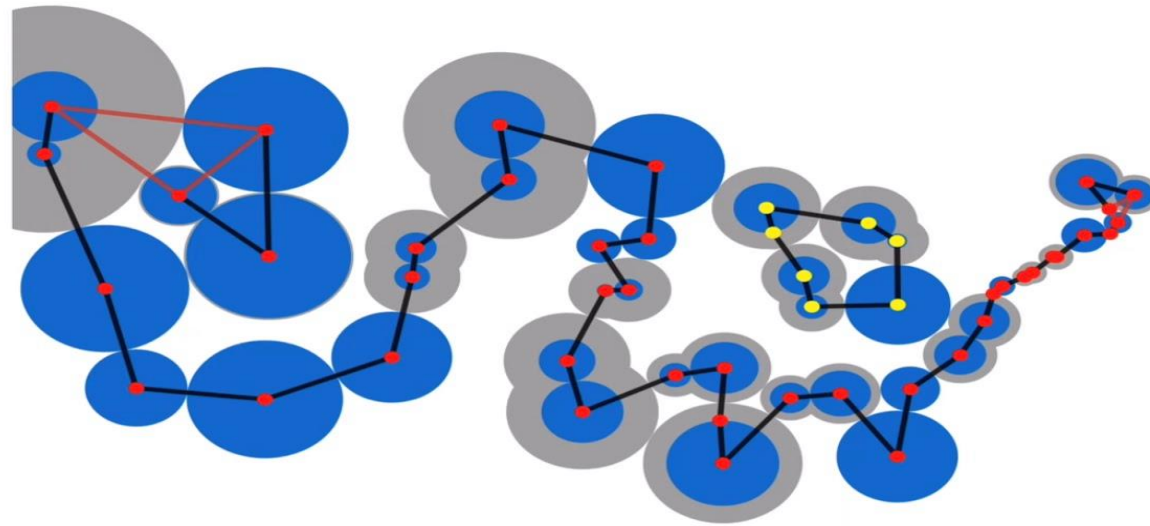
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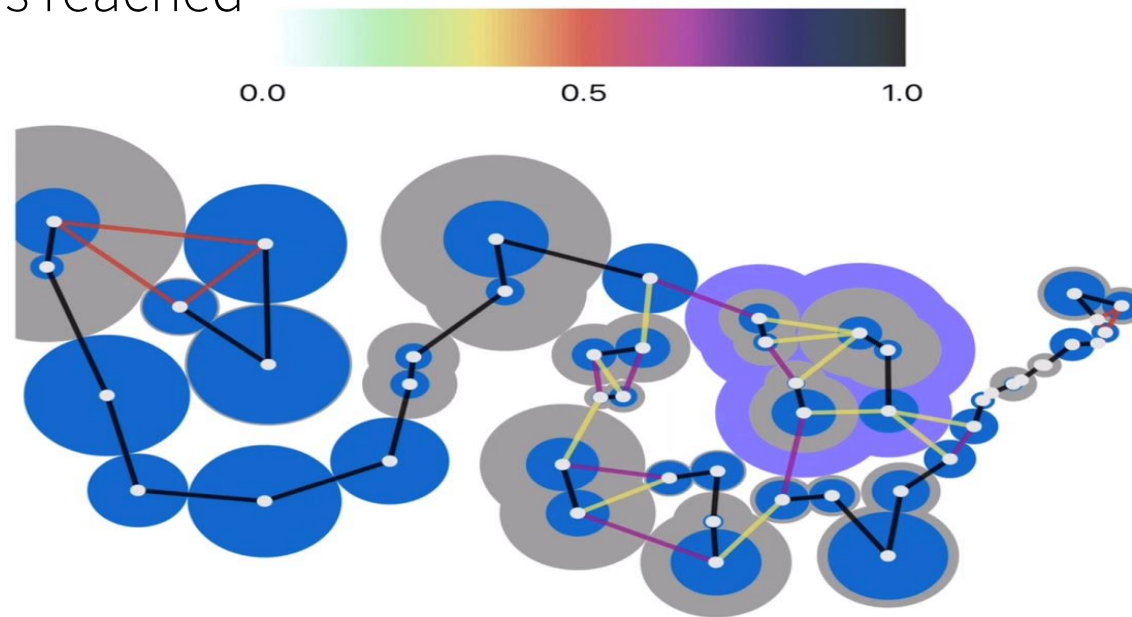
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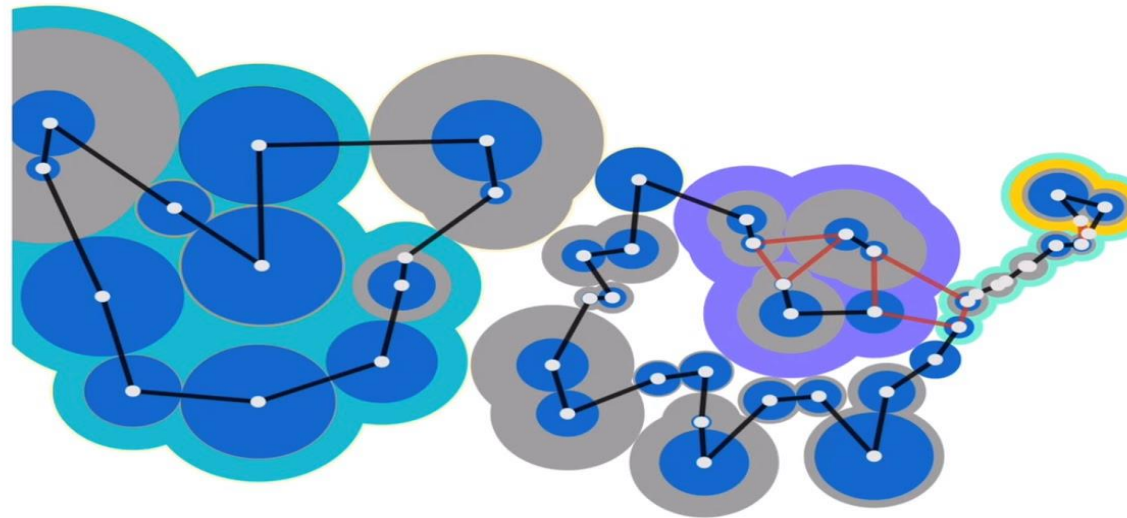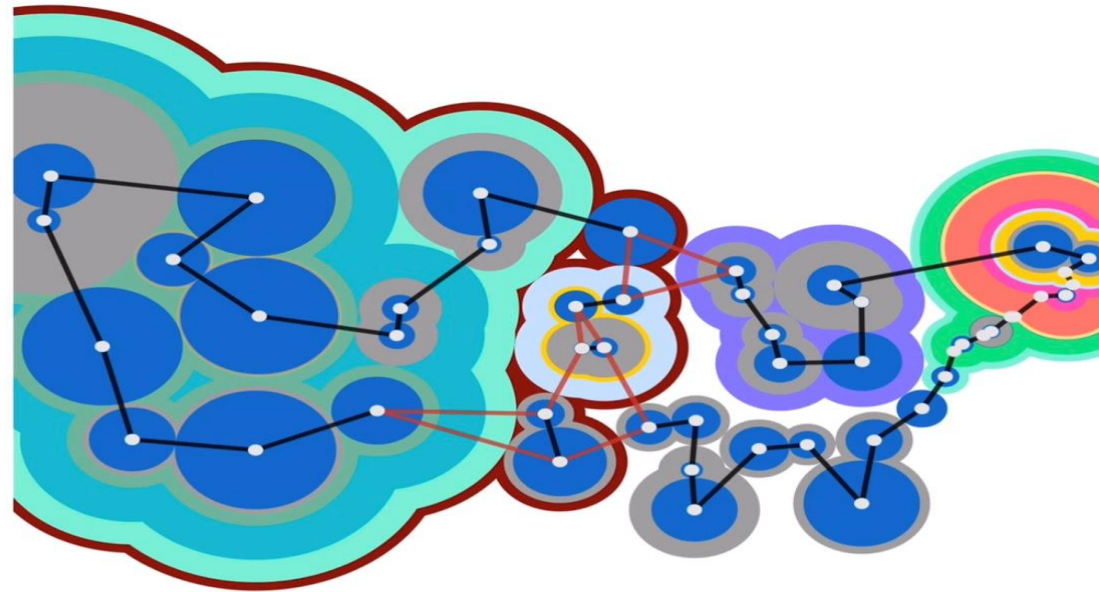
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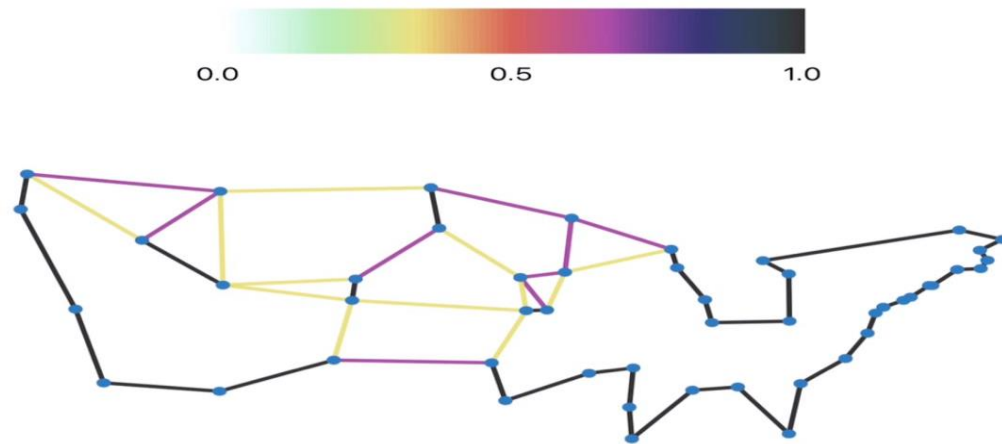
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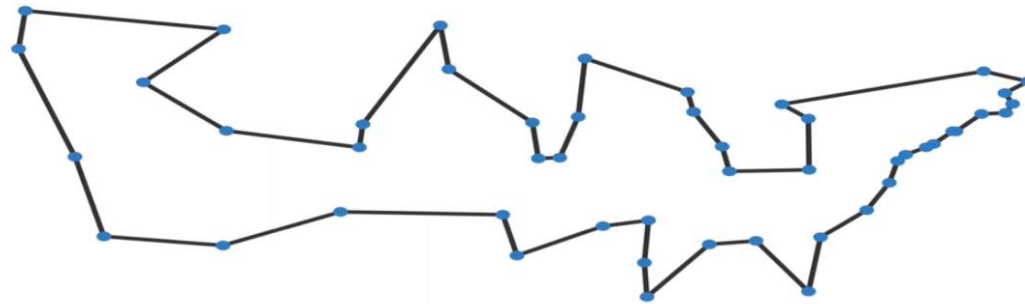
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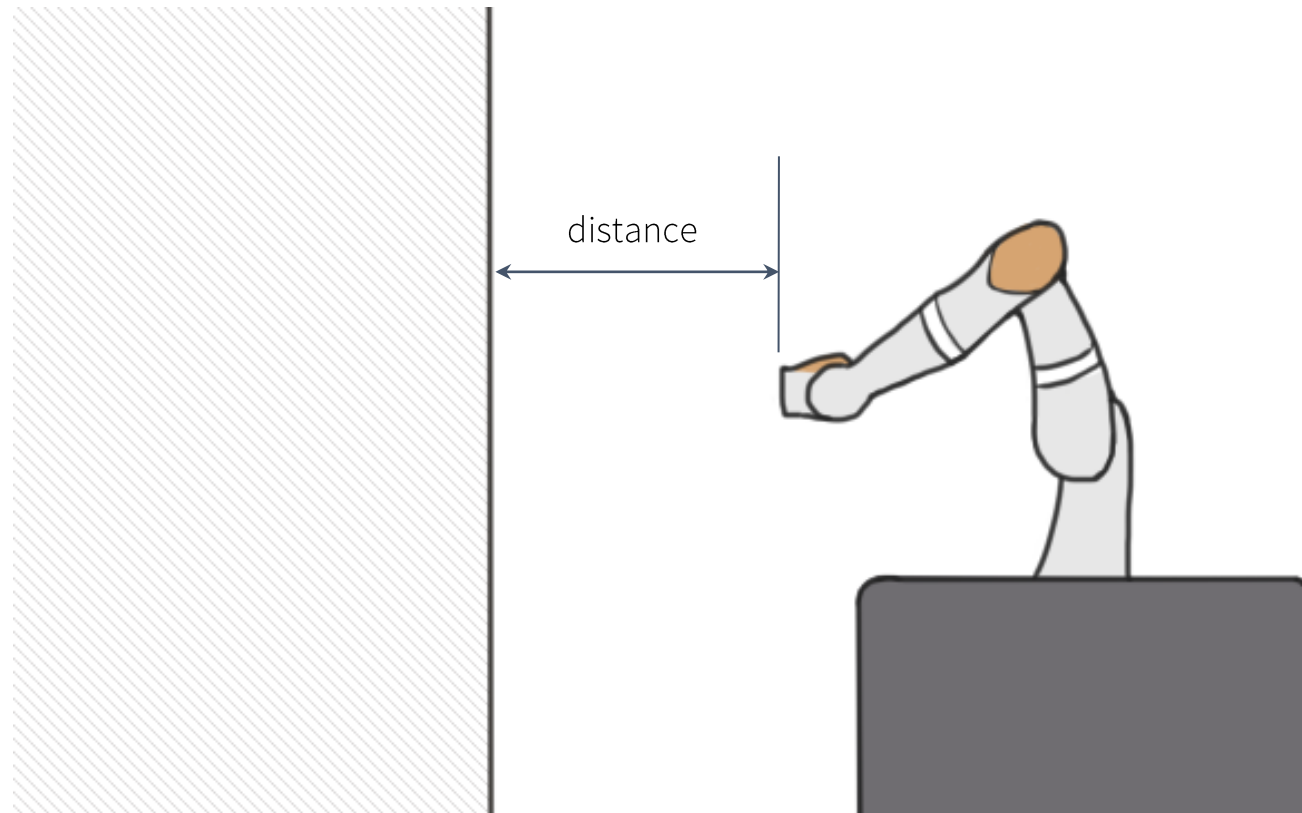
Data Processing

- Add more drawing points in-between the connected TSP nodes for smooth robotic motion

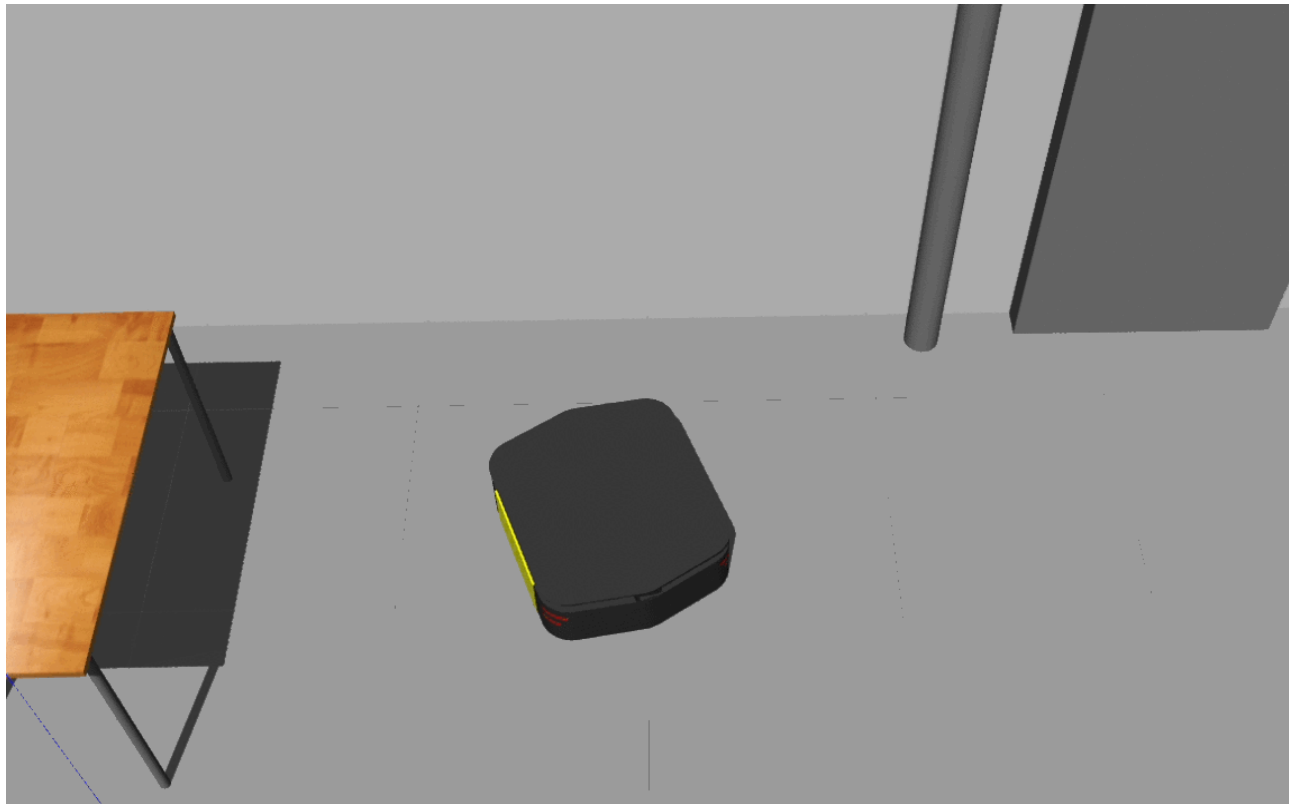- Separate the drawing points into subsections

Data Processing

- Manipulator needs 3D paths as a necessary input trajectory
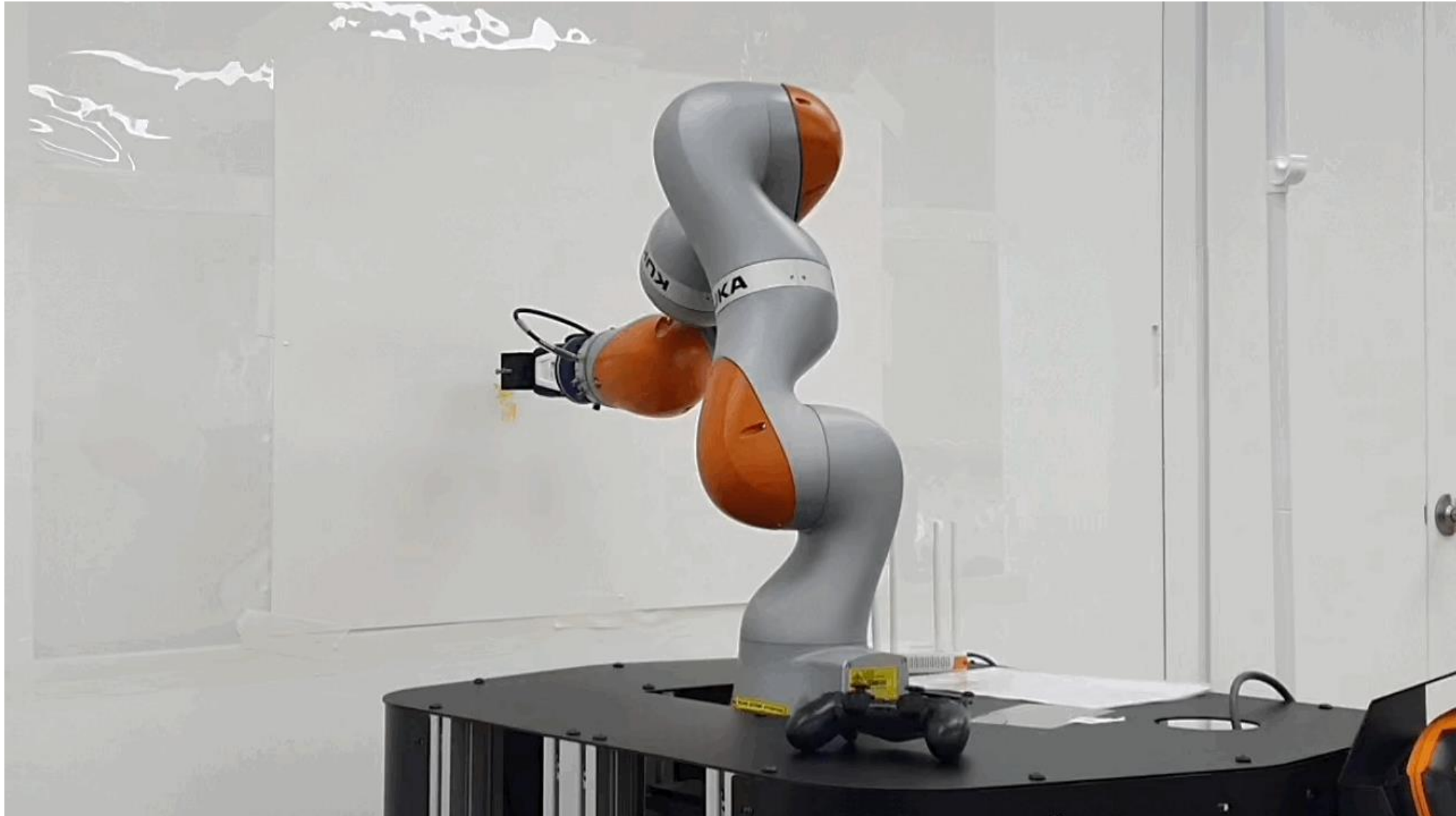 - Expand the 2D path to 3D by adding the wall-distance from the robot

distance

Robotic Drawing

- Orienting Robot toward the Canvas
  - Align the mobile base using the laser scanner

Robotic Drawing in Fastforward

Results

- Implementation Details

HW

KUKA IIWA 7 R800 (Manipulator)

Clearpath Robotics Ridgeback (Mobile base)

SW

Robot Operating System

Python Imaging Library (Pilow) for image processing

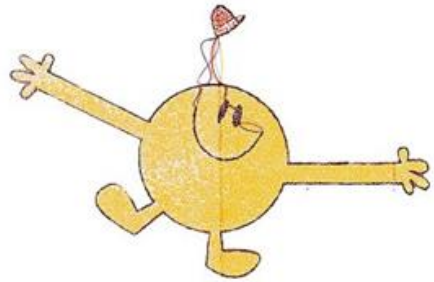Concorde TSP Solver for solving TSP
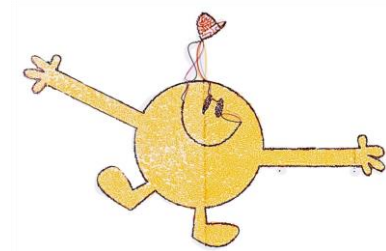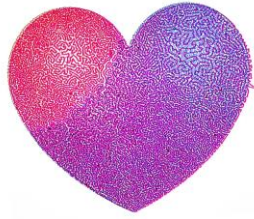
Results

Original

Drawing Result

Heart

Character

Flower

Results

	Heart	Character	Flower
Canvas Size (m)	0.40 × 0.35	0.60 × 0.40	0.85 × 0.30
Number of Points used for Stippling	34,849	31,151	95,155
TSP Time	6 min	36 min	97 min
Drawing Time	120 min	110 min	585 min

Conclusion

- Draw diverse images with Voronoi stippling and TSP Art

- Robotic drawing on large surfaces

Limitations and Future Work

1. Inaccurate Positioning
   - Localizing using robot vision

2. Minimial Human Intervention
   - Automated pen-switching

3. Diverse Drawing Style

Acknowledgement

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감사합니다

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