Fundamentals of Robotics *

*Note: Robotics — Homework I

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***Abstract*—The current document contains the solutions to the first Robotics assignment, prepared for the class Robotics, 8106126-01 . Knowledge of Robotics is required for deep understanding of the materials presented in this report.**

***Index Terms*—Robotics, Euler NGKDGDH TO BE COMPLETED LATER**

I. Introduction

A. List of Problems

1) Robots vs. Waste: Smarter Cleanup
2) Get a Grip: Robotics in Action
3) Axis/Angle Representation
4) Yaw-Pitch-Roll
5) Homogeneous Transformation Matrix
6) Euler-Rodrigues Parameters

I don't know weather its the sky or my perception, but everything is grayish numb.

II. Problem 1— Robot vs. Waste: Smarter Cleanup

A. key Requirements for Robotic Waste Management Systems

Waste classification is one of the cornerstones of waste management and it is more often achieved through **Computer Vision** Modules. [1] To achieve physical manipulation of the waste, the designed robot must be fast, precise, and able to manipulate heavy objects as well as the light ones. In order to provide the mentioned functionalities and tolerate high payloads a **delta robot** is more suitable. A gripper is also required (which is discussed in the next problem), the use of vacuum technology provides a robust and low-cost solution for material transfer but might not handle heavy waste and have low payload. [2]

B. Types of Robots Required for The System

Zhihong et al. [10] used an industrial **KUKA manipulator** with a two-finger system to sort waste according to the vision-based classification of moving objects. Similarly, a robotic system is recently developed that accomplishes one sort per second, utilizing **delta robot** technology[3].

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Fig. 1. Cortex sorting system from the company AMP with a suction cup (AMP Robotics, 2019)

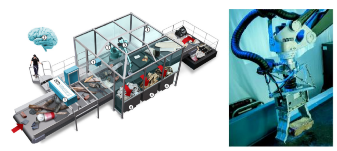

Fig. 2. Left: Scheme of ZenRobotics "Heavy Picker", 1 : Sensors, 2: Control unit ZenRobotics Brain, 3: Industrial robot arm, 4: Container for sorted fractions; Right: ZenRobotics "Smart Gripper" (Lukka et al.,2014).

C. Waste Categories

Waste classification principles vary and may involve categorization based on the waste's **material, state, or source.** [5] Based on the waste sources, research has demonstrated that industrial waste is the primary source of waste (Gaur et al. 2020). This waste is mainly composed of volatile compounds, wastewater, slag, and scrap generated during industrial production, which contain many hazardous substances, such as heavy metals, organic pollutants, and radioactive materials, leading to severe environmental pollution. [5]

According to the waste states, waste can be divided into **solid waste (Jha et al. 2022), hazardous waste (Jha et al. 2022), liquid waste (Mekonnen 2012), organic waste** (Sharma et al. 2019), and **recyclable waste** (Ren et al. 2018). **Solid waste** is mainly generated from human activities such as manufacturing, agriculture, and mining, and the treatment methods include recycling, incineration, and landfill (Bhatt et al. 2018). **Hazardous waste** contains toxic, flammable, combustible, radioactive, and corrosive waste, mostly from electronic and biomedical waste (Akpan and Olukanni 2020). Hexavalent chromium liquid, mercury liquid waste, corrosive and alkaline liquid waste, cyanide liquid waste, and heavy metal liquid waste are all examples of **liquid waste**. **Recy-**

clable waste is refuse that can be removed from the waste stream and used as a raw material to create new products like paper, glass bottles, and ceramics (Fenta 2017). Some refuse recycling techniques include biological re-treatment, energy recovery, and physical retreatment (Waheeg et al. [5]

I can't help but notice the gray area in this question, classification is quite dependent on the goal and the provided data since that is used for training the model (perhaps through CNN). One can use a basic database including the classes: **aluminum (first row), paper and cardboard (second row), PET bottles (third row), and nylon (fourth row) to separate such recyclable items.**

D. Required Sensors for Garbage Classification

To identify the objects and their materials, the system can be implemented with different sensors and cameras (**such as VIS-, NIR-, metal-, 3D-laser sensors and RGB cameras**) the data of which is is sent to the control software. [4]

E. Waste Management Pipeline

Okay, here's an overview of the waste management pipeline, including collection, sorting, and disposal, with a focus on how soft robotics is starting to play a role:

****1. Waste Collection****

Description: This initial stage involves gathering waste from various sources like residential areas, commercial establishments, and industrial facilities. Collection methods vary depending on location and type of waste. Common methods include curbside pickup, drop-off centers, and collection events. **Traditional Methods**: Typically involves manual labor and automated trucks with mechanical lifting arms. **Soft Robotics Role (Emerging): Adaptable Grippers for Varied Waste:** Soft robotic grippers can conform to irregular shapes and fragile items more effectively than traditional rigid grippers, reducing damage and improving handling efficiency (see reference on soft robotics grippers below). **Waste Collection in Complex Environments:** Soft robots could potentially navigate cluttered or difficult-to-access areas for waste collection.

****2. Waste Sorting****

Description: Sorting separates recyclable materials (paper, plastic, glass, metal) from non-recyclable waste. This is crucial for resource recovery and reducing landfill waste. **Traditional Methods**: Historically, this was a manual process, but Material Recovery Facilities (MRFs) now use automated systems involving conveyor belts, screens, magnets, and eddy current separators. However, manual sorting is still often required for quality control and to remove contaminants. **Soft Robotics Role (Growing): Gentle Handling of Recyclables:** Soft grippers can pick up delicate or easily damaged recyclables (e.g., thin plastic films, oddly shaped containers) without crushing them, maintaining material quality. **Improved Dexterity in Sorting:** Soft robotic hands can potentially mimic the dexterity of human sorters, identifying and separating different materials with greater accuracy and speed. **Adaptive Sorting Based on Object **3. Waste Processing Treatment****

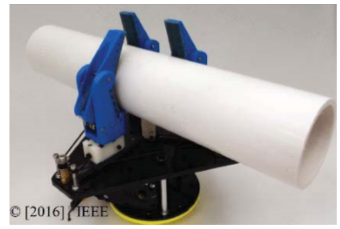

Fig. 3. Adaptive three-fingered gripper

Description: This stage prepares different waste streams for final disposal or resource recovery. Processes include: **Compaction**: Reducing the volume of waste for landfill disposal. **Shredding/Crushing**:Preparing waste for further processing (e.g., incineration). **Composting**: Biologically decomposing organic waste. **Anaerobic Digestion:** Breaking down organic waste in the absence of oxygen to produce biogas. **Incineration:** Burning waste at high temperatures, often to generate energy (Waste-to-Energy plants). **Soft Robotics Role (Potential): Handling Difficult Waste Streams**:Soft robots could be used to manipulate hazardous or bulky waste materials within processing facilities. **Automated Feeding of Processing Equipment**:Soft robotic arms could precisely load waste into shredders, compactors, or other processing machinery.

****4. Waste Disposal****

Description: The final stage involves the safe and responsible disposal of waste that cannot be recycled or processed. **Methods**: **Landfilling**: Waste is buried in engineered landfills designed to minimize environmental contamination. **Incineration (with energy recovery)**:Burning waste to reduce its volume and generate electricity or heat. **Soft Robotics Role** (Limited, but Possible): **Landfill Compaction Assistance**: Potentially, soft robotic systems could assist in compacting waste within landfills, though this is a challenging application. **Hazardous Waste Handling**: Soft robots could be deployed in specialized facilities to handle and dispose of highly hazardous waste materials.

III. Problem 2— Get a Grip: Robotics in Action

A. Different Types of Robotic Gripper

Based on the number of fingers and configurations of each gripper, various types of grippers are presented according to [7], [8] and [9].

1)
Configuration-based Classification:

1) Robot Grippers with 2 Fingers
2) Robot Grippers with 3 Fingers
3) Grippers with Flexible Fingers
4) Multi-Finger and Adaptive Grippers
5) Grain-Filled Flexible Ball Grippers
6) Bellows Grippers
7) O-ring Grippers

2)
Actuation-Based Classification:

1) Cable-Driven Grippers

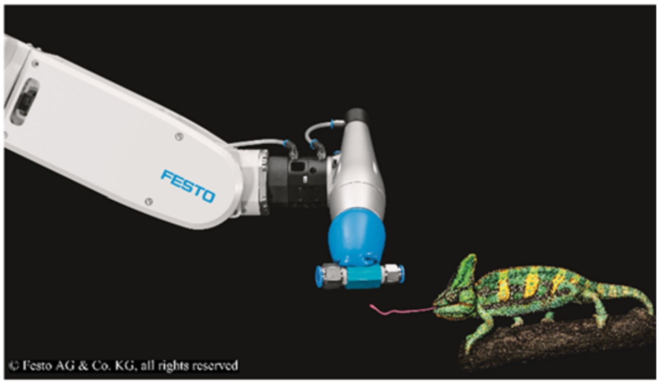

Fig. 4. Flex-Shape Gripper

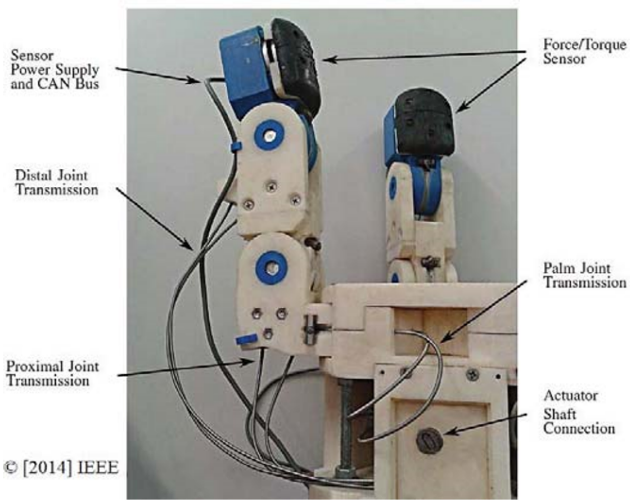

Fig. 5. Cable-driven gripper

2) Vacuum Grippers
3) Pneumatic Grippers
4) Hydraulic Grippers
5) Servo-Electric Grippers

3)
Application-based Classification:

1) Surgical Application
2) Assistive Application
3) Industrial Application
4) Underwater Application

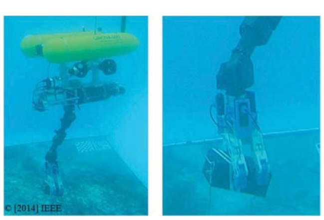

Fig. 6. Underwater gripper

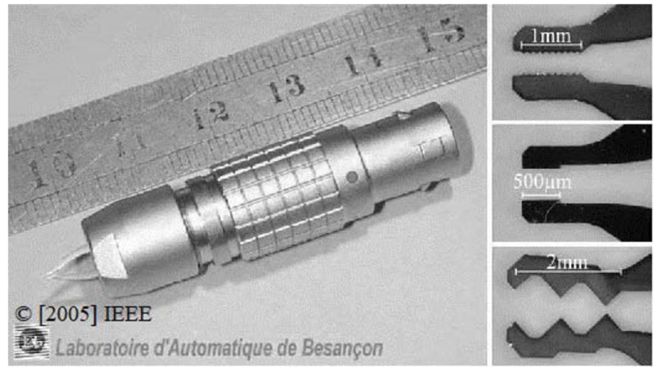

Fig. 7. Micro-gripper (left) and finger tips (right)

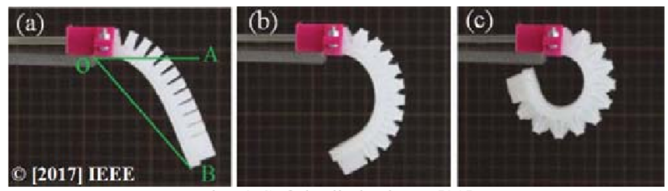

Fig. 8. Soft-bodied gripper

4) Size-based Classification: Robotic tools attached to the end-effector of the robotic manipulators are designed and manufactured in different sizes, from miniature and micro size to huge grippers. Their size is determined based on manipulation scale, accuracy, and precision needed. For example, for surgery, pick and place or other delicate tasks, accuracy of hundreds of micrometers is needed. At these scales, surface forces become dominating in comparison with other forces. Big robot grippers are commonly used for industrial purposes and suitable for bulky objects.

5)
Stiffness-based Classification:

1) Rigid Grippers
2) Soft Grippers

B. Grasping Technology

Grasping technology employs various methods, including:

Classical Grasping Data-Driven Grasping Analytical Grasping: Employs mathematical models and optimization techniques to plan grasps. **Reactive Grasping**: Reacts to sensory feedback in real-time to adjust the grasp. **Hybrid Approaches**:Combines multiple methods to leverage their individual strengths. **Deep Learning**: Utilizes neural networks to learn complex grasping policies directly from visual data. **Force Closure**: Aims to achieve a stable grasp by ensuring that the object is constrained against all external forces. **Form Closure**: Uses the shape of the hand and object to create a stable grasp, regardless of friction. **Underactuated Hands**: Simplifies control by using mechanical linkages to coordinate finger movements. **Soft Robotics**: Employs flexible materials to conform to object shapes and provide a more secure grasp.

C. Major Challenges in Robotic Grasping

Robotic grasping faces several significant challenges:

Object Variability: Handling diverse object shapes, sizes, weights, and materials remains difficult. **Uncertainty**: Real-world environments introduce uncertainty due to sensor noise, incomplete information, and unexpected disturbances. **Dexterity and Adaptability**: Achieving human-level dexterity and adapting grasps in real-time to changing conditions is complex. **Robustness**: Ensuring reliable grasping under various conditions and despite potential errors is crucial. **Perception**:Accurately perceiving and interpreting the environment to identify graspable objects and plan appropriate grasps is challenging. **Planning and Contro**l: Generating efficient grasp plans and controlling the robot hand to execute them precisely is computationally intensive.

D. Future Prospects in This Area

The future prospects for grippers are looking bright, with advancements happening across several key areas:

Soft Robotics: Grippers are becoming more adaptable and gentle, useful for handling delicate or irregularly shaped objects. **AI and Machine Learning**: Integration of AI allows grippers to learn and improve their grasping techniques, making them more autonomous. **Customization**: 3D printing enables the creation of grippers tailored to specific tasks, increasing efficiency. Materials: New materials are making grippers stronger, lighter, and more resistant to wear and tear.

E. Advantages and Disadvantages of Each Gripper Type

TABLE I. COMPARISION OF DIFFERENT ACTUATION METHODS

Gripper type	Advantages	Disadvantages
Cable-driven	Optimal weight and space	Control Complexity
Vacuum	Highly flexible Clean	Some operational issue
Pneumatic	Small dimension Low weight Clean	Not precise enough High operating cost
Hydraulic	High force	Not clean enough high maintenance cost
Servo-Electric	Highly flexible Low maintenance cost Easily controllable Clean	Low force

IV. PROBLEM 3— AXIS/ANGLE REPRESENTATION

A rigid body rotates from an initial orientation Ri to a final orientation Rf as specified by:

$$R_i = \begin{bmatrix} 0 & 1 & 0 \\ 0.5 & 0 & \frac{\sqrt{3}}{2} \\ \frac{\sqrt{3}}{2} & 0 & -0.5 \end{bmatrix}, \quad R_f = \begin{bmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{bmatrix} \tag{1}$$

To find the axis/ angle representation of the rotation, the rotation matrix Q is derived as such:

$$Q = R_f R_i^{-1} = \begin{bmatrix} 0 & 0.5 & \frac{\sqrt{3}}{2} \\ -1 & 0 & 0 \\ 0 & -\frac{\sqrt{3}}{2} & 0.5 \end{bmatrix} \tag{2}$$

The axis/angle representation is as follows:

$$Vect(Q) = \begin{bmatrix} -\frac{\sqrt{3}}{2} \\ \frac{\sqrt{3}}{2} \\ -1.5 \end{bmatrix}$$

(3)

$$\phi = cos^{-1}(\frac{tr(Q)-1}{2}) = 1.824 \textit{ (rad)}, \tag{4}$$

$$\mathbf{e} = \frac{Vect(Q)}{sin(\phi)} = \begin{bmatrix} -\frac{\sqrt{3}}{2} \\ \frac{\sqrt{3}}{2} \\ -1.549 \end{bmatrix} \tag{5}$$

V. PROBLEM 4— YAW - PITCH - ROLL

A. Part 1

Since R is generated by a rotation of α about z_0 followed by a rotation of β about y_1 followed by a rotation of γ about x_2. (in local coordination)

$$R = Q_{z_0}(\alpha).Q_{y_1}(\beta).Q_{x_2}(\gamma) = \tag{6}$$

$$\begin{pmatrix} \cos(a)\cos(b) & \cos(a)\sin(b)\sin(y) - \sin(a)\cos(y) & \sin(a)\sin(y) + \cos(a)\sin(b)\cos(y) \\ \cos(b)\sin(a) & \sin(a)\sin(b)\sin(y) - \cos(a)\cos(y) & \cos(a)\sin(y) + \sin(a)\sin(b)\cos(y) \\ -\sin(b) & \cos(b)\sin(y) & \cos(b)\cos(y) \end{pmatrix}$$

B. Part 2

The rotation matrix has two main features, one is that the determinant of R is one, the other feature is that $RR^T = 1$.

$$R_1 R_1^T = 1, \ det(R_1) = 1 \tag{7}$$

Consequently **R1** is a possible answer.

C. Part 3

$$\beta = \begin{pmatrix} \frac{\pi}{6} \\ \frac{\pi}{6} \\ \frac{5\pi}{6} \\ \frac{5\pi}{6} \end{pmatrix}, \alpha = \begin{pmatrix} 2.0074 \\ 1.1342 \\ 4.2758 \\ -1.1342 \end{pmatrix},$$

$$\gamma = \begin{pmatrix} 3.1240 \\ 0.0176 \\ 3.1591 \\ -0.0176 \end{pmatrix}$$

(8)

VI. Problem 5—Homogeneous Transformation Matrix

A. Part 1

A rotation by about the current x-axis:

$$R_x = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & cos(\alpha) & -sin(\alpha) & 0 \\ 0 & sin(\alpha) & cos(\alpha) & 1 \end{bmatrix} \tag{9}$$

B. Part 2

A translation of b units along the current x-axis:

$$T_x = \begin{bmatrix} 1 & 0 & 0 & b \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{10}$$

C. Part 3

A translation of d units along the current z-axis.

$$T_z = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{11}$$

D. Part 4

A rotation by about the current z-axis.

$$R_z = \begin{bmatrix} cos(\theta) & -sin(\theta) & 0 & 0 \\ sin(\theta) & cos(\theta) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{12}$$

Consequently:

$$H = R_x T_x T_z R_z = \tag{13}$$

$$\begin{pmatrix} \cos(\mathrm{th}) & -\sin(\mathrm{th}) & 0 & b \\ \cos(a)\,\sin(\mathrm{th}) & \cos(a)\,\cos(\mathrm{th}) & -\sin(a) & -d\,\sin(a) \\ \sin(a)\,\sin(\mathrm{th}) & \sin(a)\,\cos(\mathrm{th}) & \cos(a) & d\,\cos(a) \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

VII. Problem 6— Euler-Rodrigues Parameters

The rotation of 120 degrees about the axis u = $\frac{1}{\sqrt{14}}(1, 2, 3)$ is considered,

A. Part 1

The Euler-Rodrigues parameters.

$$\mathbf{r} = sin(\frac{\phi}{2})\mathbf{u},\ r_0 = cos(\frac{\phi}{2}) \tag{14}$$

Computing with Matlab we get:

$$\mathbf{r} = \begin{bmatrix} 0.2315 \\ 0.4629 \\ 0.6944 \end{bmatrix},\ r_0 = 0.5 \tag{15}$$

B. Part 2

The corresponding rotation matrix:

$$Q = (r_0^2 - \mathbf{r}.\mathbf{r})I + 2\mathbf{r}\mathbf{r}^T + 2\mathbf{r}.R \tag{16}$$

Q =

```
Q = 3×3
   -0.3929   -0.4801    0.7843
    0.9087   -0.0714    0.4114
   -0.1415    0.8743    0.4643

ans = 3×3
    1.0000   -0.0000   -0.0000
   -0.0000    1.0000   -0.0000
   -0.0000   -0.0000    1.0000

ans = 1
```

C. Part 3

Show that the obtained rotation matrix is a valid one. det(Q) =1 and QQT = 1

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