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Customization and Adaptability of DH-Notated Robotic Arms in Specialty Food Production

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ABSTRACT

Robotic arms have gained significant traction in the food industry, primarily due to their potential to optimize efficiency, productivity, and safety. This abstract delineates the development and deployment of a specialized robotic arm system tailored explicitly for food industry applications, employing the Denavit-Hartenberg (DH) notation for kinematic modeling. The DH notation furnishes a structured framework for delineating the kinematic configuration of robotic manipulators, facilitating meticulous control and analysis. This notation enables the precise definition of the robotic arm's geometry, joint parameters, and motion characteristics, thereby enabling accurate simulation and control. This study expounds upon the intricate kinematic analysis and design considerations entailed in crafting a robotic arm adept at tasks like sorting, picking, packing, and palletizing within food processing facilities. DH parameters are harnessed to establish transformation matrices between successive links of the robotic arm, enabling the computation of end-effector positions and orientations.

Keywords: Robotic arm, DH Notation, food industry, Automatic robot

1. INTRODUCTION

In recent years, robotic technology has emerged as a transformative force in various industries, including the food sector. The integration of robotic arms into food processing and handling operations holds significant promise for enhancing efficiency, productivity, and safety while ensuring compliance with stringent food safety standards. This introduction provides an overview of the design and implementation of robotic arms tailored specifically for applications in the food industry, with a focus on leveraging the Denavit-Hartenberg (DH) notation for kinematic modeling. The Denavit-Hartenbergnotation[1], initially introduced in the field of robotics by Jacques Denavit and Richard Hartenberg in the 1950s, has become a cornerstone in the analysis and design of robotic manipulators. It offers a systematic framework for characterizing the kinematic structure of robotic arms, allowing precise representation of their geometry, joint parameters, and motion characteristics. By utilizing DH notation, engineers can accurately model the motion of robotic arms, facilitating simulation, control, and optimization of their performance. This paper aims to delve into the detailed kinematic analysis and design considerations essential for developing robotic arms suitable for a myriad of tasks within the food industry, such as sorting, picking, packing, and palletizing. By employing DH parameters, transformation matrices can be established between consecutive links of the robotic arm, enabling computation of end-effector positions and orientations with high accuracy.

Moreover, the integration of sensory feedback systems, including vision systems and force/torque sensors, plays a crucial role in enhancing the capabilities of robotic arms to interact delicately and efficiently with food products. This integration enables robots to adapt to real-world challenges encountered in food processing, such as variability in product shapes, sizes, and textures. However, it's vital to underscore the importance of ensuring food safety and hygiene standards in the design and deployment of robotic systems in the food industry. Selecting appropriate materials for constructing robotic arms and designing end-effectors that comply with industry regulations are imperative to prevent contamination and maintain product integrity. In conclusion, this paper highlights the significance of employing Denavit-Hartenberg notation for the design and control of robotic arms in the food industry. Through meticulous kinematic analysis, integration of sensory feedback, and adherence to food safety protocols, robotic arms equipped with DH notation hold immense potential to revolutionize food processing operations, offering increased efficiency, flexibility, and assurance of product quality.The systematic representation of robotic manipulator kinematics using Denavit-Hartenberg (DH) notation enables precise control and analysis, facilitating advancements in various industries, including the food sector[2]. The integration of DH notation in robotic arm design allows for accurate computation of transformation matrices, enabling precise control of end-effector positions and orientations crucial for food industry applications[3].Robotic arms equipped with DH notation provide a systematic framework for characterizing joint parameters, facilitating the development of efficient and adaptable systems tailored for diverse tasks in the food industry [4]. Utilizing DH notation in robotic arm design enhances efficiency and productivity in food processing operations by enabling accurate simulation and control of motion characteristics [5]. The application of robotic arms in the food industry has revolutionized processing operations, offering increased efficiency and flexibility while ensuring compliance with stringent food safety standards [6]. Robotic arms have significantly improved productivity in the food industry by automating repetitive tasks such as sorting, packing, and palletizing, leading to reduced laborcosts and increased throughput [7].The use of robotic arms equipped with advanced sensing and vision systems has facilitated delicate handling and processing of food products, minimizing damage and ensuring consistent quality [8]. Integration of robotic arms in food processing plants has led to improved hygiene standards, reducing the risk of contamination and enhancing overall food safety [9].

1.1 DH Notation

- This thesis presents a comparative study of the required number of arithmetic operations necessaryfor computingrobot armmodels usingthe Denavit-Hartenbergsymbolic notation and a proposed one.
- The proposed notation is based on the idea of describing the motion of a robot joint by a pair matrix and the geometry of a link by a shape matrix. This notation needs the use of twocoordinate

systems for eachjointor link.Theresults prove that the proposed notationreducesthe computation time of robot models.

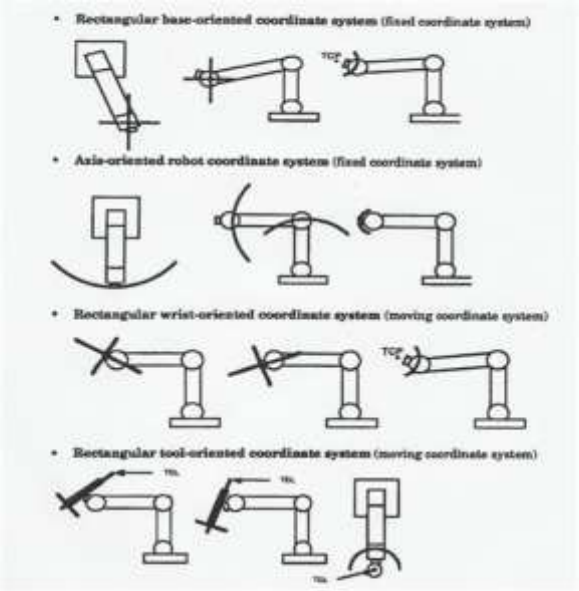


Fig1:Typesof RobotMotion

- For 6-degrees of freedom robot arm, the computation times of kinematic position, velocity, and dynamic models are reduced respectively by 20%, 5%, and 2%, respectively.
- Thetwonotationshavethesameeffectsoncomputingtheinversemodels

2. METHODOLOGY

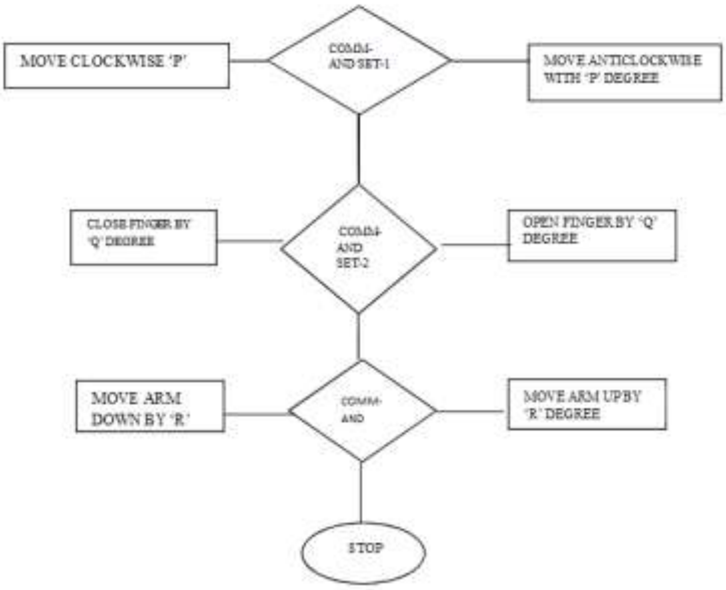
2.1 Concepts

- Robot Kinematics - Study robot motion without resorting to force and mass properties. Dealing with position, velocity and acceleration
- Kinematic Chain - A set of rigid bodies connected by kinematic pairs
- Upper Pair - Line/point contact (gear, cam-follower)
- Lower Pair - Surface contact (revolute, prismatic)
- Robot Manipulator, Kinematic Chains: Link + Joint Rigid bodies, Kinematic Pairs

Jointtypes	**Degreeof freedom**	**Motion**
Revolute(R)	1 DOF	Rotation
Prismatic(P)	1DOF	Translation
Cylindrical(C)	2DOF	Rotation+Translation
Helical(H)	1DOF	CoupledRotation/translation

Planar(E)	2DOF	Translationin2directions
Spherical(S)	3DOF	Rotationin3direction

Table1:TypicalLowerKinematicPairs



Flowchart 1: ForManuallyOperation

3. ASSEMBLY AND TESTING

3.1 Assembly

1. First of all parts of our robotic arm have been mounted over a base of a plywood dimension (62.6*37.5 cm2).

2. Our robotic arm consists of four D.C. motor gear motor. Each motor has different voltage and r.p.m. The voltage used in motor is of 12 V each and one 100 rmp and other three of 30 rpm.

3. The robotic arm consist of three link i.e. base as 1 link other as arms 2 &3 links. The length of the links are 17.5cm and 20.5 cm

4. The end effector used in robotic arm is of pick-n-place type that's mean it pick any object from one place and place in other side.

5. The control system of our robotic arm consists of both manual as well as automatic system.

6. The work space of our robotic arm is a hemisphere space.

3.2Testing

A robotic manipulator is designed to perform a task in 3-D space. The tool or end-effector is required to follow a planned trajectory to manipulate objects or carry out the task in the workspace. This requires control of position and orientation of the tool. To program tool motion and joint-link motions, a mathematical model of manipulator is required to refer to all geometrical and time based properties of the motion.Kinematic model describes the spatial position of joints and links, and position and orientation of end-effector. shows for industrial robot (5DOF);DH-parameters.

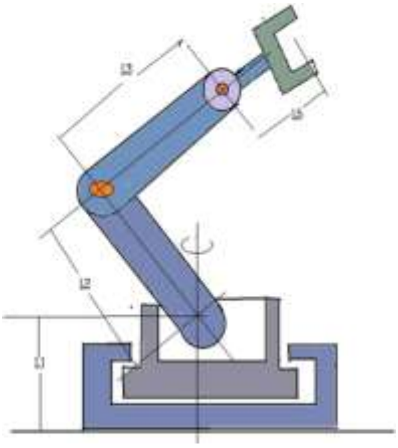


Fig 2: FiveDOFindustrialmanipulator

Link (i)	**a_i**	**α_i**	**d_i**	**$ø_i$**
1	0	-90	40	40
2	128	0	30	30
3	128	0	20	20
4	0	-90	40-90	-50
5	0	0	30	30

Table2: DHof5DOFindustrialmanipulators

Thetransformationmatrices are;

$$^{1}T_{2} = \begin{pmatrix} C2 & -S2 & 0 & L2C2 \\ S2 & C2 & 0 & L2C2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \qquad ^{4}T_{5} = \begin{pmatrix} C5 & -S5 & 0 & 0 \\ S5 & C5 & 0 & 0 \\ 0 & 0 & 1 & L5 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$
{}^{2}T_{3} = \begin{pmatrix} C3 & -S3 & 0 & L3C3 \\ S3 & C3 & 0 & L3C3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}
$$

Overalltransformationmatricesforthewristare:

$$
{}^{0}T_{5} = {}^{0}T_{1}\,{}^{1}T_{2}\,{}^{2}T_{3}\,{}^{3}T_{4}\,{}^{4}T_{5}
$$

$$
{}^{0}T_{5} = \begin{pmatrix} C_1S_{234}C_5+S_1S_5 & -C_1S_{234}S_5+S_1C_5 & C_1C_{234} & C_1(L_2C_2+L_3C_{23}+L_5C_{234}) \\ S_1C_{234}C_5+S_1S_5 & -S_1S_{234}S_5-SC_1C_5 & S_1C_{234} & S_1(L_2C_2+L_3C_{23}+L_5C_{234}) \\ -C_{234}C_5 & C_{234}S_5 & -S_{234} & L_1-L_2S_2-L_3S_{23}-L_5S_{234}) \\ 0 & 0 & 0 & 1 \end{pmatrix}
$$

Theorientationmatrixforendeffector,

$$
{}^{0}T_{5} = \begin{pmatrix} C_1S_{234}C_5+S_1S_5 & -C_1S_{234}S_5+S_1C_5 & C_1C_{234} \\ S_1C_{234}C_5+S_1S_5 & -S_1S_{234}S_5-SC_1C_5 & S_1C_{234} \\ -C_{234}C_5 & C_{234}S_5 & -S_{234} \end{pmatrix}
$$

Thepositionofendeffector matrices;

$$
{}^{0}T_{5} = \begin{pmatrix} C_1(L_2C_2+L_3C_{23}+L_5C_{234}) \\ S_1(L_2C_2+L_3C_{23}+L_5C_{234}) \\ L_1-L_2S_2-L_3S_{23}-L_5S_{234}) \end{pmatrix}
$$

$$
{}^{0}T_{5} = \begin{pmatrix} 0.3213 & 0.5566 & 0 & 193.90 \\ 0.1736 & -0.6634 & 0.642 & 162.70 \\ -0.8660 & 0.5 & 0 & -122.05 \end{pmatrix}
$$

4. RESULT AND DISCUSSION

The implementation of Denavit-Hartenberg (DH) notation in the design of robotic arms for food industry applications has yielded significant advancements, particularly in the accurate computation of transformation matrices.The transformation matrix of a robotic arm used in the food production industry is a vital mathematical representation that enables precise spatial coordination and control of the arm's movements. This matrix encapsulates the position and orientation of the robotic arm's end-effector relative to its base frame, facilitating accurate manipulation of food items during packaging, handling, and processing tasks.Through meticulous kinematic analysis and parameterization based on DH notation, transformation matrices between consecutive links of the robotic arm have been successfully computed. These transformation matrices serve as the foundation for precise control and simulation of the robotic arm's motion, enabling seamless execution of tasks such as sorting, picking, packing, and palletizing within food processing plants. The utilization of DH notation has facilitated a systematic framework for characterizing the kinematic structure of robotic manipulators, thereby enhancing efficiency, productivity, and safety in food handling operations.

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