Fully Automated Dishwashing System

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***Abstract*—. In various high-capacity food establishments, such as large-scale restaurants and hostel canteens, ensuring prompt supply of kitchenware and swift service to customers presents a significant operational challenge. Even with an ample supply of plates and cutlery, the task of cleaning these items efficiently and without delay remains labor-intensive and demanding. This report presents a novel solution aimed at alleviating the burden of plate cleaning. Our proposed design approach revolves around the implementation of three automated systems. First, a robotic arm equipped with under actuated robotic hand securely grips and positions the plates onto a conveyor belt to approach the cleaning chamber. Subsequently, the specialized chamber which is an automated system, enables the performance from cleaning to drying accordingly. Notably, this intelligent device ensures precise and efficient usage of water and detergents and the careful draining of the dirty water while ensuring the proper cleaning of dishes. Finally, the cleaned dishes are gently retrieved from the chamber and strategically placed onto a designated rack for storage and subsequent use. Through the integration of these automated systems, we aim to streamline the dish washing process in high-volume food service settings, reducing manual labor requirements and expediting kitchen operations**

***Index Terms*—Automated systems,Robotic arm,Under actuated robotic hand,Conveyor belt,Cleaning chamber**

I. INTRODUCTION

In contemporary industries, automation and robotics have become integral components, notably transforming the landscape of the automotive and electrical sectors. Despite their ubiquity in these domains, their application in the food industry and food service sector remains limited. This restraint is primarily attributed to the inherent challenges posed by the unstructured environment characteristic of food-related tasks, exacerbated by the absence of adaptable end effectors capable of accommodating the diverse shapes, sizes, surface conditions, and physical properties of handling targets [1].

The history of dishwasher development traces back to 1886 when J. Garis Cochrane introduced the pumped-type electrical dishwasher. Remarkably, this invention, patented in 1917, marked a pioneering step in automating dishwashing processes [2,3]. Fast-forwarding to the 21st century, the relentless strides in technology have given rise to various fully automated machines and robotic arms. However, the journey towards developing a fully automated robotic dishwasher is not without its challenges, encompassing a spectrum of issues that demand innovative solutions.

Within the food services industry, including restaurants, schools, and hotels, dishwashing machines are widely employed. Despite the mechanization, human laborers still play a crucial role in the manual handling of dish plates. Notably, the insertion of plates poses a significant challenge, with numerous plates stacked in piles, often laden with water and oil residues after prewashing. Humans adeptly navigate these complexities, withdrawing and grasping plates with ease. However, for a robotic hand, accomplishing this task with the requisite speed and efficiency presents a formidable challenge. The weight of the plates, averaging around 500 grams, and the diminished friction coefficient due to water and oil further compound the difficulty [4]. Additionally, the use of suction cups as grippers for dirty plates poses a risk of damage to robotic components. In response to these multifaceted challenges, this paper introduces a novel solution in the form of a fully automatic robotic dishwasher, addressing the intricacies of plate manipulation and offering a comprehensive approach to enhance operational efficiency in the food service industry.

Our proposed robotic dishwasher system is intricately designed, comprising three fundamental components that collectively revolutionize the dishwashing process.

A. Automated Dish Retrieval and Placement

The first segment involves the identification and retrieval of dishes from a stacked arrangement, followed by the precise placement onto a conveyor belt, all performed by a robotic hand. This intricate task requires a sophisticated image processing system employing computer vision techniques. Utilizing cameras to capture images and applying advanced filtering methods, we ascertain the number of dishes in the stack and determine optimal coordinates for the robotic hand's movement. Ensuring a stable grasp of various dish types, achieved with minimal actuators, is a critical aspect of this phase. Once securely held, the dishes are strategically positioned onto the conveyor belt for further processing.

B. Efficient Washing Mechanism within the Chamber

As the dishes traverse the conveyor belt, they enter a dedicated washing chamber. Here, a carefully orchestrated washing mechanism comes into play. Water, optionally infused with detergent, is dispensed through upper surface perforations, ensuring comprehensive coverage. Rotary spray arms evenly distribute water, guaranteeing a thorough cleansing process. Following this, drainage is facilitated, and hot air circulates within the chamber to efficiently dry the dishes. This segment not only emphasizes effective cleaning but also underscores the importance of resource efficiency in the overall dish washing process.

C. Automated Dish Placement in the Rack

The final phase of our robotic dishwasher system involves the retrieval of cleaned dishes from the conveyor belt and their precise placement in a designated rack, facilitated by a second robotic hand. This auxiliary robotic hand, identical to the one used for initial dish placement, is coded differently for optimal pickup and rack placement. Once again, the success of this operation hinges on a computer vision-based image processing system. By integrating this technology, we ensure the accurate identification and placement of dishes, completing the fully automated cycle of dish washing with precision and efficiency.

This research paper introduces a comprehensive approach to the realm of robotic dishwashers, presenting several significant contributions that collectively redefine the conventional dish washing process. 1) Image Processing for Dish Identification 2) Robotic Grasping and Conveyor Placement 3) Chamber-Based Dish washing Mechanism4) Automated Cleanliness Verification 5) Robotic Arm for Dish Pickup and Rack Placement Collectively, these contributions pave the way for an innovative and efficient robotic dishwasher system, addressing critical challenges in the food service industry and setting a new standard for automated dish washing technologies.

II. LITERATURE

A. Methods for gripping plates

In 1886, a preliminary dishwashing device was designed and later presented in 1917 by Garis-Cohrane. This early innovation featured an electric motor driving a pump, facilitating dishwashing through a rotating spray nozzle [2,3]. Despite its automatic washing capabilities, this device did not address the challenges associated with the automatic loading and unloading of plates.

To tackle these issues, Kosuge et al. introduced a novel design, incorporating a hook-shaped robotic arm capable of laterally grasping multiple dishes [5]. The University of Tokyo's IRT Research Initiative further advanced this concept, developing a robotic system for domestic use [6]. This system employed image recognition techniques to identify dish types and positions, enabling a robotic hand attached to a manipulator to collect and handle dishes using various sensors.

Cambridge Consultants proposed the "Turbo Clean" system, which harnessed deep learning, machine vision, machine learning, and manipulation technologies. This advanced system could recognize objects on dishes, such as leftover food and cutlery, placing them on a conveyor belt for the subsequent dishwashing process [7, 8].

Connected Robotics presented a dishwashing system utilizing a suction cup to grasp similar dishes stacked inside out. The system soaked, washed, and properly arranged the dishes in a tableware basket. Discraft Robotics introduced a specialized dishwashing system with an iron plate attached to the plates. While innovative, this system could only accommodate specifically designed plates [9, 10].

To address the issue of dirt clogging within suction cups, a hook-shaped hand design by the Tokyo IRT Research Initiative at Tohoku University sandwiched dishes between robotic hands, ensuring a secure grip. However, this approach required substantial hardware, contributing to increased costs.

A low-hardware solution was proposed by Ayoagi et al., focusing on dish serving and table cleaning. Unfortunately, this system lacked the capability to arrange or retrieve dishes from the dishwasher [11].

B. Methods for washing dishes

In the early 20th century, electrical technologies began to spread in hand-operated and controlled applications, leading to new design perspectives and improved machine capabilities. Dishwashers, like other home appliances, have become essential due to social trends and their increased importance. Modern dishwasher design has evolved significantly since its inception.

The first systems for washing table furniture date back to 1850. Mrs. Josephine Codrane is known as the inventor of the first dishwasher. It which was a completely manually operated machine capable of washing dishes in 1886 [12]. This marked the inception of a journey towards automated dishwashing technologies.

The first electrical technology introduced was the electrical motor, which operated the pump used to circulate water. In 1917, Mrs. Codrane [13] patented an electrically powered dishwasher, introducing spraying arms and the rinse phase which began to be installed in homes in the 1920s.

In 1921, the Walker Brothers Company patented a dishwasher machine with an electrically operated impeller [14]. The dishwasher's diffusion was limited to restaurants and hotels due to high production costs and unstable social and economic contexts.

In 1949, Apex Electrical Manufacturing Co. introduced the DISH-A-MATIC model [15], which introduced electromechanical automation and a knob for controlling the washing cycle. In the 1950s, automation began to appear in dishwashers, leading to a rapid increase in production volumes. In 1954, Apex introduced another model with an impeller rotated by an electrical motor, controlling the entire cleaning cycle [16].

From the 1980s to the present, dishwashers have evolved with ergonomic loading systems, dula racks, more rotating sryer arms, and the introduction of detergents and rinse aids with advancements in energy efficiency, water conservation and smart technology integration. Electronic control systems have also been introduced, allowing for more effective control of the washing cycle and the storage of pre-defined programs. Manufacturers have also explored new features and cleaning and drying technologies to meet user needs.

III. SOLUTIONS

A. Use of image processing

Image processing plays a crucial role in robotic dishwashing systems by enabling the robot to ”see” and make decisions based on visual information. This task involves locating and classifying objects within an image captured by the camera. In this context, object detection is crucial for the system to identify and understand the presence and the location of the dishes within its visual field.

Here is an explanation of key concepts related to image processing:

1.Image Capture

Within the framework of a robotic dishwashing system, the process of capturing images assumes a pivotal role. The strategic selection and placement of cameras, whether they be 2D or 3D, are fundamental considerations in ensuring optimal system performance.

The primary objective of these cameras is to capture images of the dishes and their immediate surroundings. This visual information is crucial for the robot, helping it figure out where the dishes are and how they’re positioned. This significantly boosts the effectiveness of the dishwashing process. In real-time, the robot utilizes this visual information to make prompt decisions, enhancing its responsiveness during the dishwashing operation. Additionally, the images serve a quality control function, enabling the robot to inspect the cleanliness of the dishes and identify any residual substances.

The robot comes equipped with a camera or cameras to take pictures of the plates. In this setup, it’s important for the cameras to have enough resolution to capture clear images. They might also come with extra features like frame rate, depth sensing, adjustable focus, zoom, and lighting control. The choice of cameras is vital and depends on the specific requirements of the dish washing system.

IDS UEye-XS is an example of a 2D camera that can be used for observing the robot’s workspace. It’s perfect for tasks like spotting objects and figuring out how dishes are placed. ZED-Mini 3D Cameras can be employed for find out depth information along color images, which can be beneficial for tasks such as robot navigation and 3D mapping. [18]

Fig. 1. IDS UEye-XS camera

Fig. 2. ZED-Mini 3D camera

2. Object Recognition

In the process of capturing images within a prewashed area, the subsequent task involves recognizing items and estimating their three-dimensional location relative to the robot base. Object recognition is a critical component of computer vision, empowering machines to identify and categorize objects in images. This MATLAB implementation employs the pre-trained AlexNet neural network model [19], renowned for its depth and efficacy in image classification.

Having been pre-trained on extensive datasets, AlexNet proves proficient in recognizing a diverse array of objects. The code outlines a comprehensive workflow for object recognition, showcasing the integration of advanced machine learning techniques with the well-established architecture of neural networks, exemplified by AlexNet. Operating on principles of deep learning rather than traditional theorems, the code highlights the practical application of deep learning in real-world visual recognition tasks. By leveraging the knowledge embedded in the pre-trained AlexNet model, the code effectively performs image classification, capitalizing on the automatic learning and extraction of relevant features during the training process inherent in deep neural networks.

By utilizing the pre-trained AlexNet model in MATLAB, the code enables the recognition of plates in images and the estimation of their three-dimensional positions relative to the robot base. In the context of capturing images within a prewashed area, this application of computer vision showcases the proficiency of AlexNet in image classification.

Fig. 3. object

Fig. 4. recognized object

3.Image Processing Algorithm

Following the successful recognition of objects as plates, the subsequent phase involves the application of diverse image processing algorithms to extract valuable information encompassing the number of plates, individual plate sizes, and their spatial locations. In the pre-washed process, plates can be arranged in two main configurations: either stacked together or placed individually on a flat surface. These arrangements offer distinct approaches to handling the pre-washing stage.

When plates are arranged in a stack, the application of edge detection methods becomes valuable for determining the number of plates. These methods capitalize on the distinct boundaries between individual plates within the stack. The process initiates with prepossessing steps, such as converting the image to gray scale and reducing noise. Subsequently, an edge detection algorithm, such as Canny, Sobel, or Prewitt, is applied to highlight regions with significant changes in intensity, indicative of plate edges. Contour detection is then employed to identify continuous curves along the boundaries of potential plates. The count of detected contours corresponds to the number of plates in the stack, with careful consideration given to filtering out small or noise-induced contours. Visualization of the detected contours on the original image aids in verification, ensuring accurate plate counting. The presented approach, illustrated through a MATLAB example, offers a systematic way to leverage edge detection for counting plates in a stack, with the flexibility to adjust parameters based on the specific characteristics of the images.

Fig. 5. edge detection of stack

When plates are arranged in the surface, the application of image processing techniques for dish segmentation within a given image becomes effective. The process begins with the conversion of the original image to a binary black and white representation. This conversion simplifies the image, making it easier to identify distinct regions corresponding to individual plates. Subsequently, holes in the binary image are filled, enhancing the continuity of plate representations. Connected component labeling is then employed to identify and label each individual plate in the image. By associating a label with each connected component, the code is able to iterate through the identified plates, extract their regions, and display them separately. The computation of bounding boxes for each connected component facilitates the extraction of individual dishes, offering a visual representation of the segmented plates. This method, rooted in image processing principles, allows for the automated identification and isolation of plates within a given image, demonstrating the practical application of these techniques in dish segmentation tasks.

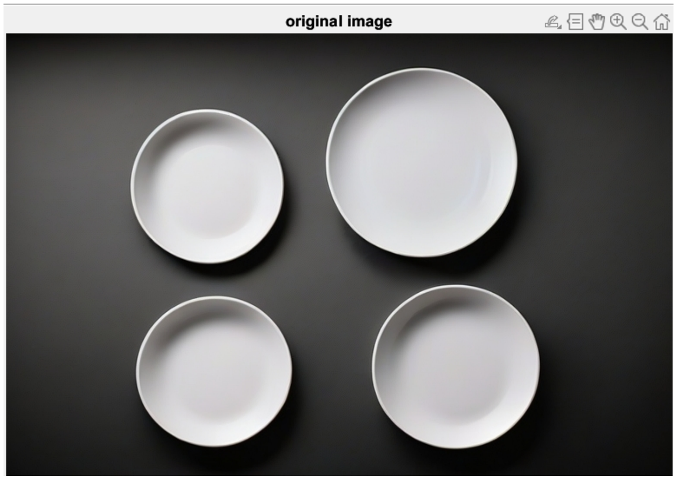

Fig. 6. dishes

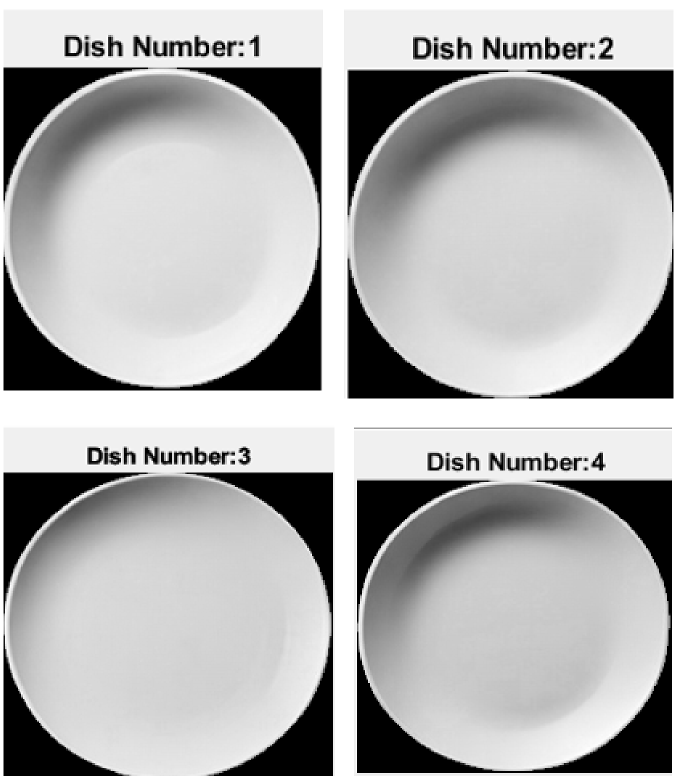

Fig. 7. segmented dishes

4.Quantitative Image Analysis

When the dish segmentation is done, we can use techniques to analyze dish images and calculate dimensions and distances to offer specific and measurable information about the detected dish. Initiated by converting the image to gray scale, the approach utilizes the Canny edge detection operator to pinpoint significant changes in intensity, effectively identifying dish edges and boundaries.

Following edge detection, the technique incorporates morphological operations, specifically closing using a disk-shaped structuring element. This operation plays a crucial role in refining the initially detected edges. By closing gaps and smoothing irregularities, the technique ensures a more polished and cohesive representation of the dish. This refinement is instrumental in preparing the image for subsequent analyses, contributing to the accuracy and reliability of the overall results. This technique's adaptability allows users to replace input images and customize parameters, enhancing its versatility for analyzing different dish images in real-world applications.

Connected component analysis is then utilized to identify separate regions in the binary edge-detected image, assuming the dish corresponds to the largest connected component. Region properties extraction, facilitated by the 'regionprops' function, provides quantitative insights into the characteristics of the dish, including area, bounding box dimensions, and centroid. The technique includes a visualization step, annotating the original image with a red bounding box, a red circle marking the dish's centroid, and a green circle denoting the assumed origin. Quantitative information about the dish, such as its dimensions and distance from the origin, is calculated based on the extracted region properties. Notably, the technique is designed for adaptability, allowing users to customize parameters and apply it to different dish images, enhancing its versatility in various contexts.

Quantitative analysis is another strength of the technique. By calculating dimensions such as length and width of the bounding box, area, and distance from the assumed origin, the code provides specific and measurable information about the detected dish. These metrics offer valuable data for further assessments or automation in dish-related applications.

Fig. 8. original image with the bounding box and colored dish area

```
Length of the dish: 177.00 pixels
Width of the dish: 176.00 pixels
Area of the dish: 3383.00 pixels
Distance from the origin: 255.87 pixels
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Fig. 9. dimensions

The calculated dimension information serves as a crucial input for robotic systems, enabling precise object localization within their environment. With this information, robots can plan and execute optimal grasping and manipulation strategies, considering the size and spatial coordinates of the dish. Additionally, the distance from the assumed origin aids in path planning, allowing robots to navigate towards the dish with accuracy. The quantitative insights further contribute to collision avoidance strategies, as the robot can assess clearances and adapt its behavior accordingly. Ultimately, these quantitative metrics facilitate automated task execution, empowering robots to autonomously interact with and handle dishes based on the analyzed information.

5. Dishwashing Quality Assessment

In the post-washed area, the identification of washed or unwashed plates is facilitated through the application of an edge detection method in image processing. Clean plates typically exhibit well-defined and sharp edges, with smooth surfaces and clear transitions between the plate and its background. To leverage these features, edge detection algorithms such as Prewitt, Roberts, or Sobel operators are applied to the image of plates. These algorithms highlight regions with significant changes in intensity, which often correspond to the edges of objects. The resulting edge-detected images are then subject to analysis, focusing on the characteristics of the detected edges. Clean plates are expected to produce clear and continuous edges, which can be quantitatively measured by assessing factors like edge density or intensity. In contrast, unwashed plates may exhibit less pronounced or irregular edges, reflecting a lack of clarity and continuity. The edge-detected images, resulting from these algorithms, become crucial in the subsequent analysis. The features extracted from the detected edges provide insights into both the cleanliness and lack thereof. Quantitative measures, including edge density or intensity, help distinguish between clean and unclean plates, with unclean plates anticipated to show less distinct and fragmented edge patterns.

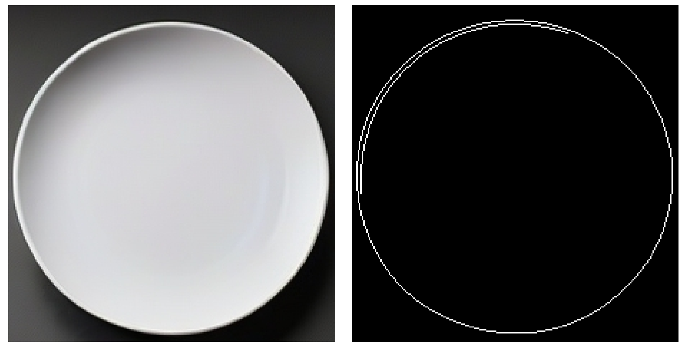

Fig. 10. washed plate

Fig. 11. unwashed plate

Upon successful identification by the robot that the dish has been thoroughly cleaned, the second robot takes charge of placing the cleaned dishes in the designated rack. A seamless transition occurs as the second robot assumes responsibility for the organized placement of the cleaned dishes in the designated rack.

B. Articulated Robotic Arm

1. Design Overview

The articulated robotic arm is a 3-degree-of-freedom (DOF) system, providing flexibility in reaching different positions and orientations. The system has been enhanced with sophisticated features, incorporating image processing techniques for dish identification. This advanced capability enables the robotic arm to intelligently interact with its environment.

The robotic arm, consisting of three joints, demonstrates a significant capability to handle dishes within a 1.5 m radius range. This extended reach is particularly advantageous for accommodating a diverse set of dish placements within the dishwasher.

Additionally, the system features an underactuated robotic hand that is seamlessly integrated into the end-effector of the robotic arm. The underactuated design, combined with the articulated arm's three joints, provides the full robot with a total of 4 degrees of freedom. This design ensures adaptability and efficiency in dish grasping tasks.

The joints of the robotic arm are actuated by electric motors, which contribute to the overall precision and control of the system. The motors enable smooth and controlled movements, allowing the robot to carry out loading and unloading tasks with optimal efficiency.[20]

2. Actuators and Motors

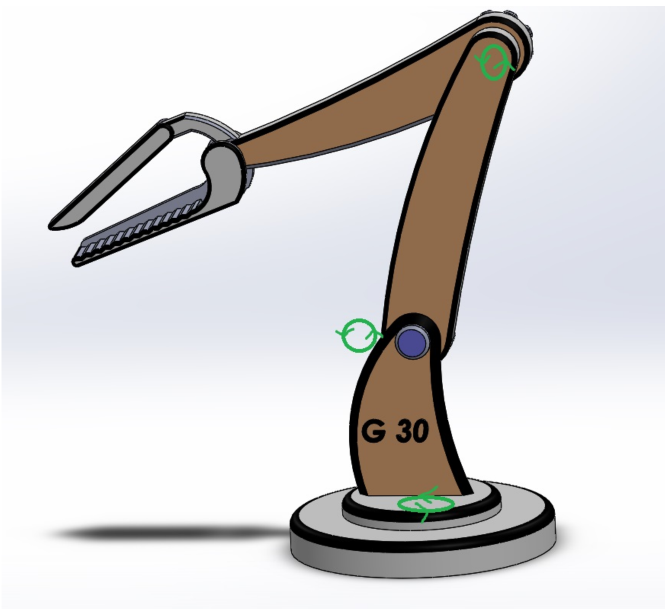

Fig. 12. Robot Arm

The robotic arm employs high-torque electric motors for joint actuation. The specifications of the motors are as follows:

- Joint1:, MG996R-Torque 9.4 Kgf.cm (4.8V)-base
- Joint2: MG996R -Torque 11 Kgf.cm (6V)-shoulder
- Joint3: SG90-Torque 1.2 Kgf.cm (4.8V)-elbow
- Joint4: SG90-Torque 1.6 Kgf.cm (6V)-gripper

These motors provide the necessary torque to carry out the loading and unloading tasks with precision.[20]

2.1 Hardware Design: The hardware design of the robotic arm encompasses both mechanical and electronic components. The mechanical system features a three-degree-of-freedom configuration with articulated joints, consisting of three revolute joints and an end-effector. The physical structure of the robotic arm plays a pivotal role, significantly influencing its overall performance and functionality during operations. The choice of materials is noteworthy, with the robotic arm being constructed using 3D printing technology and PLA (Polylactic Acid) filament derived from corn starch essence. The selected material boasts a 5% Infill Density, indicating a relatively lower fill thickness compared to 100% Infill Density, resulting in a lighter structure. This strategic use of lower infill aims to optimize the motion system of the servo motor actuators, ensuring that joint movements are nimble and efficient. The weight differential among the link components is a critical consideration, directly impacting the servo motor's motion performance.[20]

The SolidWorks 3D modeling software was employed to craft the comprehensive three-dimensional model of the robotic arm, illustrating its intricate joint and link structures, namely the base, waist, elbow, and gripper. Each joint's movement is meticulously controlled by dedicated servo motors. The electronic circuitry further enhances the system, incorporating essential components such as a 9 V power supply dedicated to the servo motors, a 5 V voltage regulator catering to the microcontroller, and strategically placed LEDs serving as indicators. This intricate integration of mechanical and electronic elements ensures the seamless operation of the 3-degree-of-freedom robotic arm, marking a harmonious synergy between hardware design and functional efficiency.[20]

3. Computational Programming

- Arduino Megaa 2560 ,ATMega 2560 operating voltage 5v
- 54 digital I/O pins
- 16 analog input pin
- Clock speed 16 MHz

The computational programming for the robotic arm is a critical component that orchestrates its movements based on the information obtained from the image processing module. The process involves multiple stages to ensure accurate dish handling:

3.1 Distance Calculation and Plate Dimension Identification: Following image processing, the system determines the distance from the robotic arm to the identified plate and extracts information about the dimensions of the plate. This information is crucial for the subsequent motion planning.[18]

3.2 Motion Planning Algorithm: The control algorithm incorporates an inverse kinematics solver, a fundamental aspect of the motion planning process. Inverse kinematics calculates the required joint angles to position the end-effector precisely at the desired location. The distances obtained from the image processing step are used to define the target position.[18]

3.3 Trajectory Planning Algorithm: Once the joint angles are computed, the trajectory planning algorithm comes into play. This algorithm determines the path that the robotic arm will follow to reach the target position smoothly and without collisions. It considers the dynamics of the robotic arm, optimizing for speed and accuracy.[18]

3.4 Signal Actuation: The calculated joint angles and trajectory information are converted into control signals that actuate the robotic arm's motors. The signals are sent to the motor controllers, specifying the required torque and speed for each joint. These signals initiate the movement of the robotic arm.[18]

3.5 Grasping Mechanism: As the robotic arm approaches the plate, the underactuated robotic hand comes into action.

The control system triggers the hand's actuators to adapt the fingers and securely grasp the dish. The compliance of the fingers ensures a reliable grip, accommodating variations in plate sizes and shapes.[21]

3.6 Plate Placement on Conveyor Belt: Once the plate is securely grasped, the robotic arm follows another computed trajectory to place the dish on the conveyor belt. The trajectory ensures a controlled descent, minimizing the risk of collisions or abrupt movements that could potentially damage the dish.

3.7 Feedback Mechanism: Throughout these processes, a feedback mechanism continuously monitors the actual positions of the robotic arm and the grasping force applied by the robotic hand. This feedback loop ensures that the robot can dynamically adjust its movements based on real-time conditions, enhancing precision and reliability.

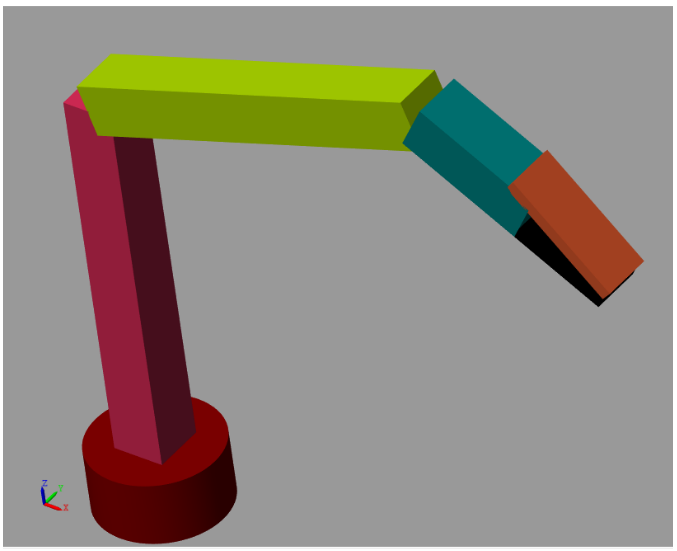

Fig. 13. Robot Arm(Matlab Simulink)

The program is written in MATLAB and Simulink, providing a comprehensive simulation and control environment. The integration of the image processing module facilitates real-time dish detection, enabling the robotic arm to adapt to the number and dimensions of the dishes.

4. Power system

4.1 Power Supply: The electrical system is powered by a dedicated power supply unit, providing stable and reliable power to the motors and control electronics. The power supply is rated at 24 V DC to meet the operational requirements of the robotic arm.

4.2 Control Electronics: The control electronics include microcontrollers and motor drivers responsible for interpreting control signals and driving the motors. A feedback loop is established to ensure accurate and responsive control of the robotic arm's position.

5. Concept of robotic hand

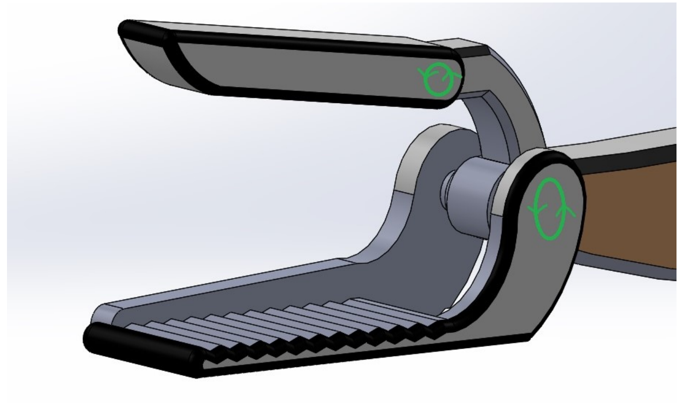

Fig. 14. Underactuated Robot Hand

- **Versatile Grasping Capability:** The robotic hand is designed to handle a wide variety of tableware, including both cups and dishes. For cups, which are often cylindrical, a standard gripper is employed to grasp the sides effectively. For dishes, the robotic hand features multi joint fingers that can adapt to the shape of different dish types, allowing stable grasping of dishes with various shapes and sizes.[21]

- **Efficient Manipulation of Stacked Dishes:** The robotic hand addresses the challenge of manipulating stacked dishes, especially when extracting them from a dishwasher or placing them in a dish basket. A plate-shaped part, referred to as a claw, is attached to the robotic hand to facilitate the grasping of stacked dishes. This enables the robot to pick up the topmost dish from a stack and place it in the desired location. The system is optimized for efficient dish organization, considering limited workspace constraints.[21]

- **Cost-Effective Design with Under actuated Drive Mechanism:** To minimize costs and streamline the design, the robotic hand employs an under actuated drive mechanism. This mechanism allows the robotic hand to open and close two multi joint fingers using a single motor and a ball screw. By adopting this approach, the number of required actuators is reduced, contributing to a more economical and practical robotic hand for dishwashing applications. Additionally, the design eliminates the need for contact sensors, simplifying the control system.[21]

5.1 Grasping Stacked dishes

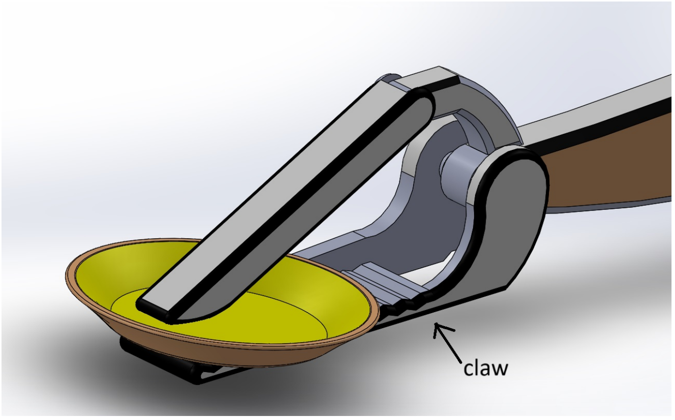

Fig. 15. Grasping a Dish

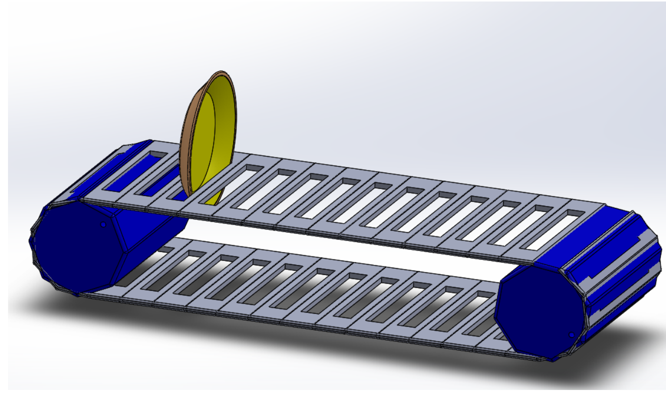

Fig. 16. Plate mounted on the conveyor belt

The robotic dishwashing system incorporates an underactuated robotic hand designed for efficiently grasping stacked dishes. The hand features a claw positioned opposite the fingers to facilitate the grasping of dishes at their edges. The system takes advantage of the gap between the edges of stacked dishes, allowing the insertion of a plate-shaped object, such as the provided claw. The grasping procedure involves inserting the claw into the gap, closing the fingers, and lifting the hand to grasp the top dishes one by one from the stack. This design proves effective for various dish types, providing a versatile solution for both loading dishes into the dishwasher and unloading them onto a worktop.[21]

C. Cleaning mechanism of the washing chamber

In the dishwashing system, an automated loading mechanism facilitates the seamless introduction of dishes into the cleaning chamber. A conveyor belt, featuring specially designed strips with molded dish-holding structures, transports the dishes towards the cleaning chamber. The conveyor belt is equipped with sensors that detect the appropriate length of the load inside the chamber. As the designated length is reached, the conveyor belt intelligently halts its movement, ensuring precise alignment of the dishes within the cleaning zone. This automated stopping mechanism not only streamlines the loading process but also optimizes the spatial arrangement of the dishes for efficient and thorough cleaning. Once halted, the washing process commences, leveraging this strategic pause to enhance the precision and effectiveness of the dishwashing operation.

In the dishwashing system, a well-orchestrated water management mechanism plays a pivotal role in achieving effective cleaning. The process begins with the controlled release of water through an inlet valve, directing it into a tray strategically positioned at the bottom of the cleaning chamber. The water is maintained at a shallow yet sufficient level within the chamber, providing an ideal environment for the cleaning process. This tray serves as a central hub, receiving not only water but also inputs from various detergents and softeners through dedicated inlets. Ensuring a comprehensive cleaning approach, a pump unit, equipped with an inlet filter, is seamlessly integrated into the tray, facilitating the circulation of water and cleaning agents. Additionally, a water heater is intricately connected to the system, allowing for precise temperature control to optimize cleaning efficiency. To complete the cycle, a drain pipe, featuring a water drain valve strategically positioned at the lowest point of the tray, efficiently evacuates the used and soiled water from the system. This integrated water management system ensures a dynamic and controlled cleaning environment, where water, detergents, and temperature harmoniously collaborate to achieve superior cleaning outcomes.

The heart of the dishwashing operation lies in a sophisticated spray system where precision meets efficiency. The pump, a key component, strategically channels water to both upper and lower rotors, seamlessly linking the cleaning process. The spray rotors, pivotal in achieving thorough cleaning, are equipped with a remarkable three degrees of freedom. This design allows dynamic movement along the x and y axes, ensuring coverage across the entire surface of the dishes, while the additional rotation around the z-axis adds a layer of adaptability. As the pump initiates, the spray rotors, facilitated by specially crafted nozzles, commence their intricate dance, effectively dispensing water in a controlled and targeted manner. This dynamic spray system, with its multi-dimensional capabilities and precision-engineered nozzles, guarantees optimal water distribution for a comprehensive and efficient cleaning experience, leaving dishes spotless and ready for use.

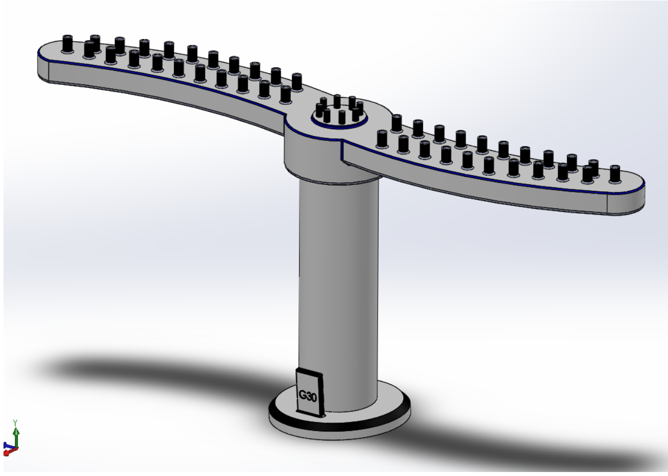

Fig. 17. rotor with spray nozzles

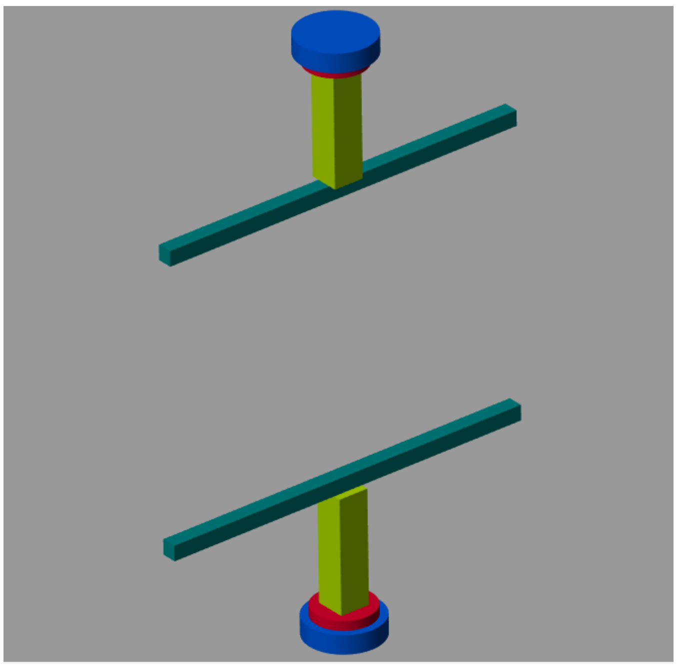

Fig. 18. matlab stimulation of rotors

Incorporating intelligence into the dishwashing experience, our system comes equipped with an intuitive control panel, acting as the user's window into the operational dynamics. The interactive screen provides real-time information on detergent and water levels, ensuring transparency in the cleaning process. Any shortages are promptly communicated through clear and concise on-screen displays, allowing users to address the situation proactively. Moreover, the system is designed to detect and alert users about potential filter blockages. When a clog is detected, the control panel displays a corresponding notification, enabling quick identification and resolution of the issue. This user-friendly interface not only enhances the overall operational awareness but also empowers users to maintain the system at peak efficiency, ensuring a seamless and trouble-free dishwashing experience.

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  DishwasherSimulation with properties:

       waterLevel: 0
   detergentLevel: 100
           dishes: 0
        isRunning: 0

>> dshwasher_data
Added 10 dishes to the dishwasher.
Added 50 liters of water to the dishwasher. Current water level: 50
Added 30 grams of detergent to the dishwasher. Current detergent level: 130
Dishwasher started. Washing 10 dishes...
Dishwasher stopped.
```

Fig. 19. Control panel- Displaying the details of water and detergents

Upon the completion of the cleaning process, the conveyor belt resumes its motion, marking the commencement of the subsequent cycle. This automated sequence ensures the continuous and repetitive operation of the dishwashing system, facilitating an efficient and streamlined cleaning workflow.

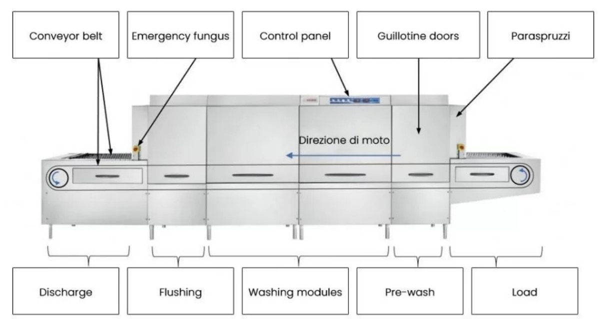

Fig. 20. Over view of the automatic dish washer

D. *The chemical approach in cleaning*

In the context of automatic dishwashers, the dishwashing fluid constitutes a crucial element, primarily composed of water supplemented with various detergents. This fluid serves as the medium for removing particles adhered to plates and utensils during the cleaning process. The choice of detergents and the temperature of the water play pivotal roles in tailoring the cleaning approach to different types of food residues.

Detergent selection

Enzymatic detergents, a cornerstone of chemical dishwashing, are formulated with specific enzymes like proteases, lipases, and amylases. These enzymes target and break down proteins, fats, and carbohydrates, respectively. For example, after cooking a protein-rich dish like steak, the detergent's proteases efficiently break down protein residues. This targeted enzymatic action ensures a thorough cleaning process, aligning with the need for precision in handling diverse food remnants in a commercial kitchen.

Temperature considerations

Temperature plays a critical role in the effectiveness of the cleaning process. Warmer water generally enhances the solubility of various substances, facilitating the dissolution of food residues. Adjusting the temperature based on the nature of the soiled items ensures optimal cleaning. For instance, protein-based residues, such as those from meats or dairy, often require higher temperatures for efficient removal, while lower temperatures may suffice for fats or carbohydrates.

It's worth noting that room temperature water, which is typically around 70°F (21°C), may not be sufficiently effective for thorough cleaning. To enhance cleaning efficiency, it is advisable to heat the water to a temperature within the range of 130°F to 140°F (54°C to 60°C). This elevated temperature range has been found to be particularly effective in breaking down and removing a wide range of food residues. The graph below illustrates the temperature variation simulated using MATLAB, demonstrating the transition from room temperature to the recommended cleaning temperature range.

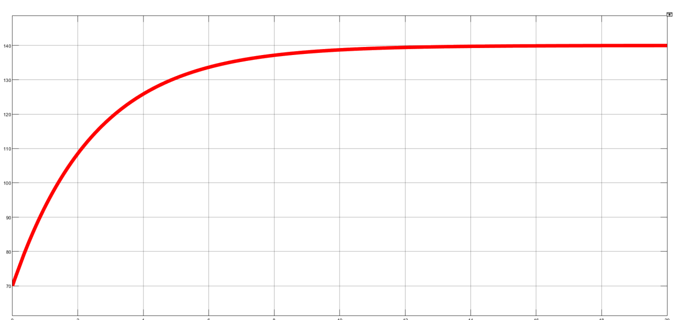

Fig. 21. temperature variation of the water

Tailoring cleaning stratergies

Catering companies handling events with diverse culinary offerings face unique challenges. The dishwashing strategy involves using tailored detergent formulations. For an event featuring a range of dishes, from creamy pasta to rich desserts, detergents with diverse enzymatic capabilities are employed. This customization ensures that residues from various foods are effectively broken down during the cleaning process. By adapting the detergent composition to the specific foods prepared, the catering service can maintain a high standard of cleanliness and operational efficiency.

The need of an inteligent system for efficient cleaning

Implementing an intelligent design system in commercial dishwashers can significantly elevate efficiency and resource utilization. Through the integration of advanced sensors, the dishwasher gains the capability to assess the types of food residues present on the dishes. These sensors can detect the molecular composition of residues, allowing the system to identify specific enzymes required for optimal cleaning. For example, if a protein-heavy dish is detected, the system can selectively introduce protease enzymes into the detergent stream.

Moreover, the system can dynamically adjust water temperature based on real-time sensor inputs. This ensures that the temperature aligns precisely with the nature of the residues, optimizing the detergent's enzymatic activity. A streamlined process is achieved by seamlessly tailoring the cleaning approach to the unique characteristics of each load. This intelligent adaptation not only enhances cleaning effectiveness but also contributes to resource conservation by avoiding unnecessary detergent usage and minimizing water and energy consumption.

In practice, this intelligent dishwasher design promotes a sustainable and cost-effective solution for commercial kitchens. It aligns with the broader trend of incorporating smart technologies in the foodservice industry to improve operational efficiency, reduce waste, and uphold stringent hygiene standards. This intelligent approach transforms the dishwashing process from a one-size-fits-all model to a precision-driven, adaptive system capable of handling the intricacies of diverse culinary residues efficiently.

Overview of the designed embedded system

Inputs: Sensory Data Acquisition - The system relies on a diverse set of sensory inputs to gather critical information about the load inside the dishwasher. These inputs include optical sensors for identifying food types, temperature sensors for monitoring water and air temperatures, and chemical sensors to analyze the composition of residues. Additionally, load weight sensors can provide insights into the volume and distribution of dishes, contributing to optimized resource allocation.

Process: Intelligent Embedded System - The sensory data is processed by a sophisticated embedded system that acts as the brain of the intelligent dishwasher. The embedded system utilizes machine learning algorithms to interpret the sensory inputs and make informed decisions. For instance, it identifies the molecular composition of residues, determines the suitable enzymes, and calculates the precise water temperature needed for effective cleaning. This adaptive decision-making process is continuously refined through machine learning, allowing the system to improve its performance over time based on feedback from each cleaning cycle.

Output: Adaptive Cleaning Parameters - The output from the embedded system comprises adaptive cleaning parameters that dictate the dishwasher's operation. This includes the formulation of detergent mixtures with specific enzymes tailored to the detected residues, adjustments to water temperature, and modulation of water flow rates. The output also extends to the operational settings of mechanical components, such as spray arm rotation speeds, based on the load characteristics. Ultimately, the adaptive cleaning parameters ensure a customized and efficient cleaning process that maximizes cleanliness while minimizing resource usage.

As this kind of an embedded system should be design in a manner which can be easily incorporated inside the dish washing chamber.

E. Efficient Post-Washing Handling in Dishwasher System

In the automated dishwashing process, dishes emerge from the cleansing phase via a conveyor belt. Positioned along this conveyor belt is a sophisticated camera system employing advanced image processing techniques. This camera diligently assesses the cleanliness of each dish, ensuring a thorough inspection. The camera acts as the guardian of cleanliness, utilizing image processing algorithms to detect any lingering residues. If the camera identifies a dish that is not yet fully clean, it triggers an alarm system to promptly notify the operators. This instantaneous alert ensures that any subpar cleaning can be swiftly addressed, maintaining high standards in dish hygiene.

Once the cleanliness is verified, the clean dishes move along the conveyor belt. A 3-Degree-of-Freedom (3DOF) robot arm then takes charge, delicately retrieving each dish and precisely placing it in the designated dish rack. This intricate process not only requires mechanical precision but also leverages complex machine learning algorithms to adapt to various dish shapes and sizes.

This integrated system, harmonizing image processing, machine learning, and robotic automation, not only guarantees impeccable cleanliness but also showcases the synergy of cutting-edge technologies in modern dishwashing operations.

IV. MATLAB AND SIMULINK

```
clc;
close all;
clear all;

% Load pre-trained AlexNet
nnet = alexnet;

% Read the image
picture = imread('plate_image.jpg');

% Display the original image
figure(1);
imshow(picture);
title('Original Image');


% Resize the grayscale image to the expected input size of AlexNet (227x227)
resized_img = imresize(picture, [227, 227]);

% Classify the resized image using the pre-trained AlexNet
label = classify(nnet, resized_img);

% Display the result
figure(2);
imshow(resized_img);
title(['Classified as: ' upper(char(label))]);
```

Fig. 22. object Detection

Designed for object detection, this MATLAB code (fig 22) is tailored to operate efficiently within the online MATLAB workspace. It utilizes the AlexNet machine learning database [19]. The code has been edited by 210696A.

```
clear all;
close all;
%original image
Img = imread("stack.png");
figure(1)
imshow(Img)
title('original image')

%conversion of RGB image into gray image
gray_img = im2gray(Img);
figure(2)
imshow(gray_img)
title('gray image')

%edge detection

%edge prewitt
edges_prewitt = edge(gray_img,'prewitt');
%edge roberts
edges_roberts = edge(gray_img,'Roberts');
% edge sobel
edges_sobel = edge(gray_img,'sobel')

%visualize
figure(3);
imshow(edges_prewitt)
title('edges by prewitt method')
figure(4);
imshow(edges_roberts)
title('edges by roberts method')
figure(5);
imshow(edges_sobel)
title('edges by sobel method ')
```

Fig. 23. edge detection

Authored by 210696A,(fig 23) this MATLAB code processes input images to detect edges of dishes and determines whether the plate is clean or not.

```
clc;
close all;
clear all;

%display the original image
A=imread('plates.tif');
figure,imshow(A);
title('original image');
%covert the original image into black and white image
B=im2bw(A);
figure,imshow(B);
title('black and white image')
%fill holes in the black and white image
C=imfill(B,'holes');
figure,imshow(C);
title('image of filled holes')
%finds out independant components and labels them
label=bwlabel(C);
%display number of objects identified
max(max(label))
%display the identified first dish
im1=(label==1);
figure,imshow(im1);
title('identified first image')

%iterate over all identified components
for j=1:max(max(label))
    % Find row and column indices of pixels belonging to the j-th component
    [row,col]=find(label==j);
    % Compute the length and breadth of the bounding box for the component
    len=max(row)-min(row)+2;
    breadth=max(col)-min(col)+2;
    % Create a target image initialized with zeros
    target=uint8(zeros([len breadth]));
    % Compute the starting coordinates of the bounding box
    sy=min(col)-1;
    sx=min(row)-1;
 % Copy pixel values from the original image to the target image
 for i=1:size(row,1)
     x=row(i,1)-sx;
     y=col(i,1)-sy;
     target(x,y)=A(row(i,1),col(i,1));
 end
 % display the dishes with title indication the plate number
 mytitle=strcat('Dish Number:',num2str(j));
 figure,imshow(target);title(mytitle);
end
```

Fig. 24. labelling and segmentation

Coded by 210696A,(fig 24) This is designed to determine the number of dishes present in a given area and can identify each dish separately.

```
clc;
close all;
clear all;
% Read the input image
image = imread('machine_learning.png');

% Convert the image to grayscale
grayImage = rgb2gray(image);

% Use edge detection
edgeImage = edge(grayImage, 'Canny');

% Perform morphological operations to clean up the edges
se = strel('disk', 5);
cleanedImage = imclose(edgeImage, se);

% Find connected components in the binary image
cc = bwconncomp(cleanedImage);

% Get region properties (Assuming the dish is the largest object)
stats = regionprops(cc, 'Area', 'BoundingBox', 'Centroid');

% Find the index of the largest area
[~, idx] = max([stats.Area]);

% Extract bounding box and centroid of the largest area
boundingBox = stats(idx).BoundingBox;
centroid = stats(idx).Centroid;

% Create a binary mask of the dish
mask = zeros(size(cleanedImage));
mask(cc.PixelIdxList{idx}) = 1;

% Display the original image with the bounding box and colored dish area
figure;
imshow(image);
hold on;
% Mark the origin by a small circle
scatter(0, 0, 'g', 'filled', 'Marker', 'o');
% Label the origin with text
text(0, 0, ' Origin', 'Color', 'g', 'FontSize', 10, 'VerticalAlignment', 'bottom', 'HorizontalAlignment', 'right');
rectangle('Position', boundingBox, 'EdgeColor', 'r', 'LineWidth', 2);
scatter(centroid(1), centroid(2), 'r', 'filled');

h = imshow(repmat(mask, [1, 1, 3])); % Color the dish area
set(h, 'AlphaData', 0.5); % Adjust transparency

% Calculate dimensions of the bounding box
lengthOfDish = max(boundingBox(3:4));
widthOfDish = min(boundingBox(3:4));

% Calculate area of the dish
areaOfDish = stats(idx).Area;

% Calculate distance from the origin (assuming the origin is at the top-left corner)
distanceFromOrigin = sqrt(centroid(1)^2 + centroid(2)^2);

% Display the results
fprintf('Length of the dish: %.2f pixels\n', lengthOfDish);
fprintf('Width of the dish: %.2f pixels\n', widthOfDish);
fprintf('Area of the dish: %.2f pixels\n', areaOfDish);
fprintf('Distance from the origin: %.2f pixels\n', distanceFromOrigin);
```

Fig. 25. calculating dimensions and distance to the object

Developed by 210699K,(fig 25) This code is designed to ascertain both the distance of the dish from the origin of the robot and the dimensions of the dish.

```
% Sample MATLAB code for robot arm control based on image processing

% Define serial connection to Arduino (adjust the port as needed)
serialPort = serialport('COM3', 'BaudRate', 9600);

% Open the serial connection
fopen(serialPort);

% Image processing - Replace this section with your actual image processing code
% Assume you have the coordinates (x, y) of the dish
dish_x = 320;  % Example x-coordinate
dish_y = 240;  % Example y-coordinate

% Conversion factors (adjust based on your system)
scale_x = 1;  % Scale factor for x-axis
scale_y = 1;  % Scale factor for y-axis

% Convert image coordinates to robot arm coordinates
robot_x = scale_x * dish_x;
robot_y = scale_y * dish_y;

% Control the robot arm based on the detected position
fprintf(serialPort, 'X%.2fY%.2f\n', robot_x, robot_y);

% Close the serial connection
fclose(serialPort);
delete(serialPort);
clear serialPort;
```

Fig. 26. converting to robot co-ordinations

Coded by 210699K, this MATLAB script (fig 26) generates signals to actuate the robot based on the provided data from (fig 25).

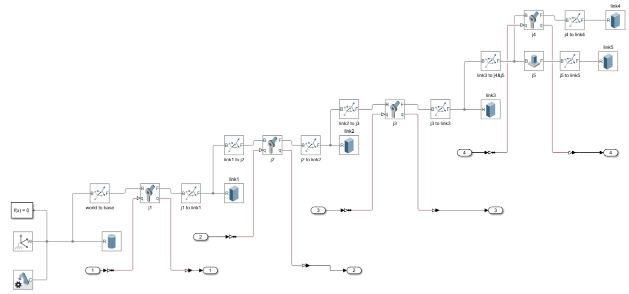

Fig. 27. Robot Arm simulation in matlab

Done by 210699K, this MATLAB Simulink diagram (fig 27) simulates a 3-DOF robot arm.

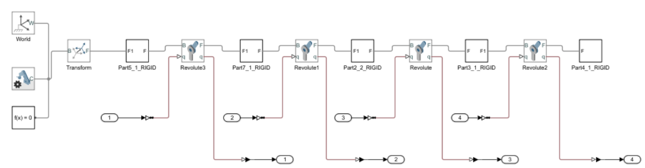

Fig. 28. Robot simulation in matlab with solidwork model

Created by 210699K, this MATLAB Simulink diagram (fig 28) simulates a 3-DOF robot arm, incorporating an imported SolidWorks file for enhanced accuracy and realism in the simulations.

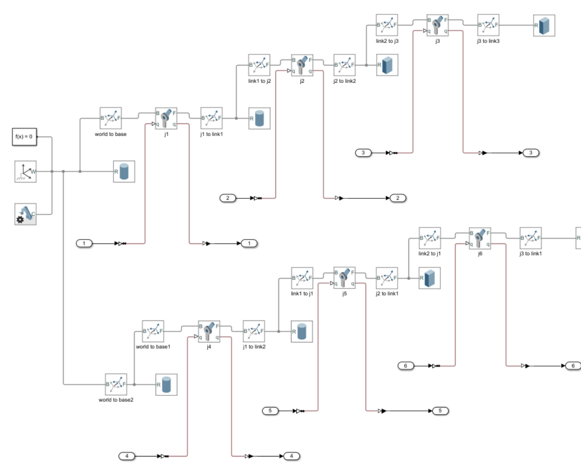

Fig. 29. Dishwasher rotor simulation in matlab

Developed by 210733L, this MATLAB Simulink diagram (fig 29) simulates the behavior of rotors in a dishwasher, providing a realistic representation of their dynamics and interactions within the system.

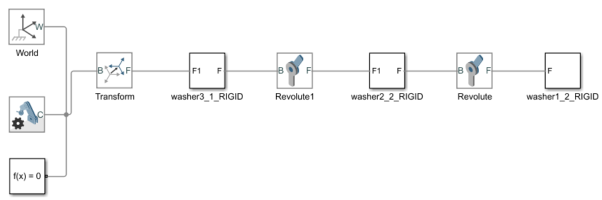

Fig. 30. Dishwasher rotor simulation in matlab with solidwork model

Created by 210696A, this MATLAB Simulink diagram (fig 30) simulates a dishwasher rotor, incorporating an imported SolidWorks file for enhanced accuracy and realism in the simulations.

```
classdef DishwasherSimulation
    properties
        waterLevel % Current water level in the dishwasher
        detergentLevel % Current detergent level in the dishwasher
        dishes % Number of dishes in the dishwasher
        isRunning % Flag indicating whether the dishwasher is running
    end

    methods
        % Constructor
        function obj = DishwasherSimulation()
            obj.waterLevel = 0;
            obj.detergentLevel = 100; % Assume full detergent at the beginning
            obj.dishes = 0;
            obj.isRunning = false;
        end

        % Function to add dishes to the dishwasher
        function obj = addDishes(obj, numDishes)
            obj.dishes = obj.dishes + numDishes;
            fprintf('Added %d dishes to the dishwasher.\n', numDishes);
        end

        % Function to add water to the dishwasher
        function obj = addWater(obj, amount)
            obj.waterLevel = obj.waterLevel + amount;
            fprintf('Added %d liters of water to the dishwasher. Current water level: %d\n', amount, obj.waterLevel);
        end

        % Function to add detergent to the dishwasher
        function obj = addDetergent(obj, amount)
            obj.detergentLevel = obj.detergentLevel + amount;
            fprintf('Added %d grams of detergent to the dishwasher. Current detergent level: %d\n', amount, obj.detergentLevel);
        end

        % Function to start the dishwasher
        function obj = startDishwasher(obj)
            if obj.dishes > 0 && obj.waterLevel >= 50 && obj.detergentLevel >= 20
                obj.isRunning = true;
                fprintf('Dishwasher started. Washing %d dishes...\n', obj.dishes);
            else
                fprintf('Insufficient dishes, water, or detergent to start the dishwasher.\n');
            end
        end

        % Function to stop the dishwasher
        function obj = stopDishwasher(obj)
            if obj.isRunning
                obj.isRunning = false;
                fprintf('Dishwasher stopped.\n');
            else
                fprintf('Dishwasher is not running.\n');
            end
        end
    end
end
```

Fig. 31. dishwasher water-detergent measuring system

Created by 210733L, this MATLAB code (fig 31) displays real-time information on the current water level, detergent level, dishes, and functions of a dishwasher.

```
% Create a dishwasher simulation object
dishwasher = DishwasherSimulation();

% Add dishes, water, and detergent
dishwasher = dishwasher.addDishes(10);
dishwasher = dishwasher.addWater(50);
dishwasher = dishwasher.addDetergent(30);

% Start the dishwasher
dishwasher = dishwasher.startDishwasher();

% Stop the dishwasher
dishwasher = dishwasher.stopDishwasher();
```

Fig. 32. dishwasher Data

Designed by 210733L, this MATLAB code (fig 32) serves as a user interface for seamlessly adding water, detergent, dishes, and controlling various functions of a dishwasher.

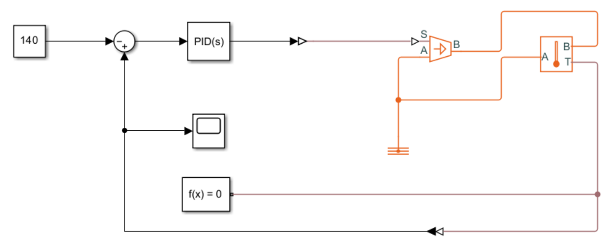

Fig. 33. Dishwasher water temperature variation

Created by 210733L, this MATLAB simulation (fig 33) illustrates the progressive increase in water temperature within the dishwasher, starting from room temperature.

V. Conclusion

In conclusion, this research has undertaken a thorough exploration to develop an innovative, fully automated dishwashing system by building upon existing solutions and advancing them to address the technical, economical, and social dimensions of conventional dishwashing processes.

The proposed smart dishwashing system incorporates image processing, machine learning, and a sophisticated three-degree robotic arm to ensure a meticulous and efficient cleaning process. The under-actuated robotic hand is strategically employed for grasping plates and dishes, showcasing a nuanced approach to handling various types of tableware. To facilitate a seamless operation, a network of conveyor belts is implemented. The use of under-actuated robotic hand delicately retrieves and places each dish from the conveyor belt, placing them precisely in a rack.

This intricate orchestration of robotic components and advanced technologies not only enhances efficiency but also significantly contributes to energy conservation, aligning seamlessly with the demands of the contemporary world. The strategic use of multiple conveyor belts ensures a continuous flow throughout the dishwashing process, maximizing the system's throughput and minimizing downtime.

By shifting the focus from studying various grasping models to creating a fully automated dishwashing system with these advanced features, this research marks a groundbreaking contribution to the evolution of dishwashing technology. It underscores the transformative potential of intelligent systems, offering a glimpse into a future where technology seamlessly integrates with everyday tasks, promoting sustainability and efficacy in domestic and industrial settings alike.

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