A PROJECT REPORT ON

FOOD HANDLING ROBOTIC ARM

ANAND TUGASHETTI

2025-2026

ABSTRACT

Automation tends to become a key enabler in modern food industries, enhancing hygiene, efficiency, and accuracy while reducing dependence on manpower. Challenges faced in conventional food handling practices include contamination risks, inconsistent handling quality, slower processing speed, and higher labour costs. The main goal of this project is thus to design and develop a Food Handling Robotic Arm, an automated system that would safely and efficiently handle packed food items with minimal human involvement.

The fundamental idea of the project is to design an automated mechanism which can pick, place, and sort packed food items arriving from a kitchen and deliver them to the correct customer or the respective section. The robotic arm-based system with a conveyor belt, camera-based identification, sensors, servo motors, and a microcontroller-based control unit provides a complete automated solution. A food package traveling on the conveyor may have a QR code or barcode printed on the package or order bill, which is detected and scanned by a camera. The scanned data is processed through a microcontroller that decides to which destination it should go based on the information regarding customers or delivery. Based on this decision, the robotic arm executes a pick-and-place operation with high precision.

It works on the principle of continuity and repetition. Once a package is detected, the robotic arm is guided to the pickup point, where a soft, food-grade gripper gently grips the package to avoid damage. The arm then transfers and places the item accurately at the assigned location. This operation will be looped so that the system can handle multiple orders of food efficiently with high speed and reliability.

The advantages of the Food Handling Robotic Arm include better hygiene with less human contact, consistent accuracy of handling, and speedier ways of processing orders. Its design is modular and adaptable, fitting into small kitchens and large-scale food industries. This system shall be very useful in QSRs like Domino's, Burger King, McDonald's, and KFC since these need quicker service due to high order volumes. Overall, the project showcases a highly feasible automation solution aimed at enhancing operational efficiency, hygiene, and customer satisfaction, while also opening up future possibilities of IoT and Industry 4.0 integration.

TABLE OF CONTENTS

LIST OF TABLE

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

With kitchens getting smarter and food moving quicker, the quiet revolution shaping their future is not culinary, but robotic. The rapid growth of automation during the 21st century has evidently restructured industries across the world and considerably influenced how products are created, processed, packed, and delivered. Of all sectors undergoing transformation, the food industry stands out as one of the most demanding, complex, and sensitive domains to integrate technology. Food is not just another commodity-it is essential for life and hence requires handling with high standards of hygiene, precision, safety, and efficiency.

1.1 Introduction to Robotic Automation in Modern Food Handling

In recent years, the rise of quick-service restaurants, cloud kitchens, large commercial food outlets, and online delivery platforms worldwide has amplified the challenge of managing huge volumes of food items with speed and accuracy. Given this backdrop, robotic automation is emerging as a promise that can handle not only operational inefficiency but also hygiene-related issues. The development of a food-handling robotic arm addresses these growing industrial needs and thus presents a pathway to enhancing efficiency, improving safety, and raising the overall standard for performing food handling.

The modern food consumer expects speedy delivery, accuracy, and safety. When ordering through an online platform or dining in-store, delays, mistakes, or unsafe handling will badly affect customer confidence. Traditional food-handling environments rely heavily on human labor. While humans are endowed with dexterity, adaptability, and decision-making ability, they are also susceptible to fatigue, inconsistency, errors, and limitations during peak demand periods. In a busy kitchen or zone of food dispatch, workers tend to perform repetitive tasks like sorting packaged meals, checking order labels, routing trays to different sections, and organizing prepared plates for serving or dispatch. These simple-appearing tasks require uninterrupted concentration and physical stamina. Over some time, the monotony of such tasks leads to degraded accuracy, slower performance, and bottlenecks in operation. Further, direct human contact in handling food increases the chances of contamination, highlighted throughout the COVID-19 pandemic.

Automation presents an alternative to this system because it guarantees precision, consistency, and operation without interruption. A food-handling robotic arm designed for executing repetitive tasks at very high speeds with high accuracy can operate around the clock and drastically minimize the chances of cross-contamination. Equipping it further with an intelligent system such as barcode or QR-code scanning allows the direct identification, sorting, and routing of packaged items automatically without human oversight. So instead of reading labels, workers could take advantage of the robot's interpretation of data instantly and move items to their allocated places. This combination of robotics and machine perception transforms the work from labor- to data-driven with exceptional efficiency.

1.2 Challenges, Technological Enhancements, and Industrial Relevance

The idea of using robotic arms in industry is not new; the so-called robotic manipulators have been in use in manufacturing, automotive assembly, pharmaceuticals, and production of electronics. However, the food industry presents some unique challenges that significantly differ from the requirements of traditional industrial automation. Foodstuffs differ in shape, texture, and fragility, along with several different packaging styles. While a metal component on an assembly line may not be affected when handled with firm gripping or fast-moving motions, a packaged food item or a soft edible product might deform, create spills, or otherwise be damaged if subjected to excessive force or an incorrectly designed gripping mechanism. This, however, has fueled the development of food-safe gripping technologies, including soft robotic grippers, vacuum-based grippers, and an adaptive mechanism capable of modifying grip pressure depending on the character of an object. Such advances now make it possible for robotic arms to handle delicate or irregularly-shaped food items with high-quality manipulation close to that of human hands.

Apart from gripping technology, the integration of machine vision is what allows robotic arms to intelligently interact with the environment in which they exist. QR codes and barcodes are now universal ways of embedding information regarding order numbers, customer IDs, packing timestamps, temperature, and routing information. This information, through camera-based scanning systems, can be decoded in real-time as a robotic arm views it and carries out decisions on placement and sorting. This removes dependency on manual verification and reduces logistical errors. When integrated into conveyor systems or modular food dispatch environments, such robotics technology creates a seamless flow where each food item moves through a digital pipeline from preparation to dispatch.

The need for such automation has been further intensified due to the changing structure of food distribution systems. Cloud kitchens—places specifically dedicated to preparing online food orders without dine-in facilities—are enjoying increasing popularity, meaning the number of orders daily could be very high. Cloud kitchens rely heavily on optimized workflows to maintain profitability. A single delay in sorting or routing food containers can create order bottlenecks, extend delivery times, and reduce efficiency. As multiple brands operate under one kitchen roof, simultaneous orders become all the more complex to handle. Robotic arms are capable of performing such tasks in large volumes with consistency and accuracy, thus providing a standardized solution to these challenges. They can manage everything, from picking boxed meals from a conveyor and scanning their QR labels to depositing them into assigned racks for delivery partners, without fatigue or error.

Beyond efficiency and hygiene, robotic automation supports broader industrial goals in line with the principles of Industry 4.0. This new wave of industrial transformation emphasizes interconnected systems, data-driven decision-making, real-time monitoring, and intelligent automation. A food-handling robotic arm can be easily integrated with IoT devices, kitchen management software, cloud-based analytics, and automated dispatch systems. Every food packet handled by the robot can be digitally logged, making traceability transparent and accurate. Processing times can be monitored, the busiest hours can be identified, workflow bottlenecks can be predicted, and staffing can be optimized based on data insights. Because the robotic system records every movement, it provides unprecedented visibility into the food-handling pipeline, offering opportunities for continuous improvement.

Furthermore, advances in technology have made robotic systems more available and affordable. While previously robotic automation was made possible only in large factories with big budgets, today it has become accessible to even small- and medium-scale food businesses due to modular actuators, low-cost microcontrollers, 3D-printed parts, and opensource robotic frameworks. Today, a multi-degree-of-freedom robotic arm can be realized at a fraction of its earlier cost while maintaining high reliability. The integration of opensource libraries for QR-code recognition, microcontroller-based control systems, and low-cost camera modules will make the technology practical and scalable. As robotics becomes more affordable, its potential to revolutionize the food industry expands further.

In view of these considerations, the development of a food-handling robotic arm is not an academic exercise; it is to find a solution for practical industrial problems. This project tries to fill the gap between practical kitchen operations and future automatic food handling. Hence, it handles some major challenges like sorting errors, hygiene risks, labor shortcomings, and inefficiency in operations. Combining robotic manipulation with computer vision, the system shows how technology can improve quality and speed in food handling.

CHAPTER 2

LITERATURE SURVEY

The literature survey reviews the existing research on robotic automation in food handling, including discussions related to pick-and-place systems, vision-based identification, conveyor-integrated robots, and food-safe gripper designs. Previous work underlines the role of robotic arms in enhancing hygiene, accuracy, and efficiency in food processing applications. The survey also identifies the need for integrated, cost-effective solutions combining sensing, control, and automation specifically for modern food handling applications.

2.1 Robotic Manipulation of Food Products

Author: P.Y. Chua, T. Ilschner, D.G. Caldwell

This paper provides in-depth discussion on the advances, challenges, and opportunities of applying robotic systems to food handling and processing. Although the food industry is among the largest manufacturing sectors in the world, its automation is lagging behind the automotive and electronic industries. This is mostly because food products are variable, soft, and easily deformed, hence difficult to handle by conventional robotic manipulators. The authors stressed that automation in this sector is very important for enhancing hygiene, efficiency, and profitability without compromising on strict food safety regulations.

The paper identifies the core problems of robotic food manipulation in terms of product size and texture variations, which are easily deformed or contaminated, and which require a truly cleanable robot. Three of the major strategies for gripping are discussed in more detail. Mechanical grippers achieve their hold through friction or clamping and can be used on products like meat or fish. Fragile produce is at risk with this type of gripper. Intrusive grippers pierce through a material and cannot be considered due to hygiene implications. Surface attraction grippers, which involve suction, adhesives, or electrostatic forces, offer greater adaptability but tend to get clogged or contaminated easily. New approaches involve ideas like freezing grippers by using rapid ice adhesion and airflow-based noncontact grippers.

The authors illustrate several practical robotic applications, including food processing and manufacture. Washable manipulators execute cutting and dressing operations in meat processing with high accuracies and hygiene standards. The grippers of poultry-handling robots use pneumatic muscles to avoid damages on their fragile tissues. SCARA robots automatically de-head fish on the "RoboFish" project, while sensors and pneumatics enable the robotic milking systems to milk cows accurately and independently. Agricultural robots execute selective harvesting on asparagus, fruits, and mushrooms where vision systems and soft grippers are integrated into the robotic apparatus. Automation of packaging, examples include ABB's FlexPicker and Intelligent Integrated Belt Manipulator, presents the most successful area of food robotics due to standardized material and shape inputs.

2.2 Kinematic Modelling & Maneuvering of 5-Axes Articulated Robot Arm

Author : T.C. Manjunath

This paper presents the complete design, mathematical modeling, simulation, and real-world implementation of a 5-DOF articulated robotic arm developed totally from indigenous components. The paper focuses on the derivation of an accurate direct kinematic model for the manipulator using the D–H convention and further validates the model through simulation and actual pick-and-place experiments. The robot has five rotary joints (base, shoulder, elbow, pitch, and roll), and is designed as an educational platform for teaching robotic manipulation.

It is powered by DC servomotors through gear–chain transmission systems and incremental encoders with a resolution of 0.624° per count at the load shaft. The manipulator is therefore able to execute high-precision joint motions. The D–H based modeling process involves the assignment of six coordinate frames, the derivation of 20 kinematic parameters, and the computation of the sequence of homogeneous transformation matrices from the base to the tool-tip. These matrices are partitioned at the wrist to simplify computation, thereby allowing the computation of end-effector position and orientation relative to the base. One complete composite transformation matrix T_5^0 is formulated and validated by substituting the soft-home joint angles of the robot.

The author then develops a detailed link coordinate diagram or LCD, computes joint variables, link lengths, offsets, and twist angles, and constructs a full kinematic parameter table. The correctness of the derived matrices is verified by evaluating the transformation matrices at the home position and cross-checking with the LCD.

A C++-based GUI is developed to realize real-time simulation and control of the robot. MATLAB simulations performed show consistency with the experimental results in pursuing accurate trajectory tracking and successful autonomous pick-and-place manipulation.

Concluding, the paper develops a comprehensive kinematic approach and its practical implementation for a 5-axis robotic arm, with a particular emphasis on its application as an affordable platform for teaching robot kinematics and manipulation in educational and research settings.

2.3 Low-Cost Compliant 7-DOF Robotic Manipulator

Author : Morgan Quigley, Alan Asbeck, and Andrew Y. Ng

The paper presents the design and implementation of an affordable, human-safe robotic arm that is intended for manipulation research. Unlike the commercial manipulators that often exceed $100,000, this system achieves backlash-free actuation, sub-3 mm repeatability, 1.5 m/s speed, and a 2 kg payload at the low parts cost of $4135. The motivation behind this project was to accelerate robotics research by making high-performance arms financially accessible, enabling their wider adoption in labs, classrooms, and small-scale industries.

The key innovation of the arm is its hybrid actuation mechanism. The proximal four joints utilize stepper motors with timing belts and cable drives, providing features like high torque, zero backlash, and intrinsic mechanical compliance. This series-elastic design increases human safety because external forces applied to the arm cause it to safely deflect. The distal three joints employ Dynamixel RX-64 servos that enable higher bandwidth motion while allowing overall flexibility.

Low-cost manufacturing is achieved with laser-cut plywood and off-the-shelf components, with no expensive machining. The compliance mechanism makes use of polyurethane tubes deforming under force; thus, accurate force sensing is achieved through encoder measurements. Equipped with the full sensing stack—optical encoders, motor step tracking, and ROS-based software integration—the arm features closed-loop control, inverse kinematics, and Cartesian motion planning.

Performance tests demonstrate excellent repeatability and payload handling, whereas demonstration tasks such as teleoperated chess-playing and pancake-making highlight the arm's capability for fine manipulation and safe human interaction.

The authors conclude that this low-cost, compliant 7-DOF arm represents an important step toward affordable, safe manipulation systems. Future work will involve simplifying fabrication, improving force sensing, and moving toward more durable metal structures to make compliant robots practical for widespread deployment.

2.4 Unified Closed Form Inverse Kinematics for the KUKA YouBot

Author : Shashank Sharma, Gerhard K. Kraetzschmar, Christian Scheurer, and Rainer Bischoff

This paper proposes a new analytical inverse kinematics solution for the KUKA youBot mobile manipulator by considering it as a unified 8-DOF serial kinematic chain, where the base and 5-DOF arm are included. The authors fill a key gap in the literature on mobile manipulation:

although mobile platforms introduce redundancy that should enhance reachability and flexibility, most systems operate the base independently of the arm and rely on heuristic-based planning. In this paper, the authors propose a unified closed-form IK solver able to systematically exploit redundancy, thus enabling more efficient and deterministic manipulation in complex environments.

The paper initiates by explaining the difficulties of mobile manipulation, especially the coordination of base motion and arm articulation for accomplishing 6D end-effector goals. Since the youBot's arm has only 5 degrees of freedom, the missing DOF must be compensated by platform movement. The authors introduce three redundancy parameters ($\rho1$, $\rho2$, $\rho3$): $\rho1$ resolves rotational redundancy between base and first joint, $\rho2$ adjusts linear redundancy linked to arm reach, and $\rho3$ determines elbow configuration (up or down).

A systematic, analytical IK framework is developed. The solver first extracts orientation parameters β and θ from the Cartesian goal pose and then computes the arm joint angles ($\theta2$, $\theta3$, $\theta4$), based on geometrical and trigonometric relationships. In order to satisfy the overall 6D goal pose, the position (x, y) of the mobile base and the orientation will be derived, while $\theta5$ is computed from the rotational alignment between the current and desired end-effector frames. The valid range of redundancy for the solver is also defined based on mechanical constraints.

Simulation and experimental results demonstrate smooth joint trajectories for redundancy parameter updates confirming independence and allowing true nullspace motion. The unified solver enables efficient manipulation planning using IKBiRRT without heuristic base sampling.

They conclude that this unified closed-form IK solution significantly advances mobile manipulation since it allows the youBot to fully exploit its redundancy and perform more robustly and efficiently in complex tasks.

2.5 An Evaluation System of Robotic End-Effectors for Food Handling

Author: Zhe Qiu, Hannibal Paul, Zhongkui Wang, Shinichi Hirai, Sadao Kawamura.

The paper presents a holistic framework for the assessment of robotic end-effectors in performing manipulation tasks related to food handling. The motivation has come from growing demands on automation within Japan's food industries, which have been driven by labor shortages and the complexity of handling a wide variety of food stuffs. Most of the already-developed robotic end-effectors are designed for specific types of food; hence, their generalization is limited. In this work, an attempt has been made to propose an evaluation system that can quantitatively and graphically visualize the performances of various end-effectors in manipulating different food materials, with the objective of aiding in the selection or new design of end-effectors.

The authors classify the food items and the robotic end-effectors according to their physical and functional characteristics. Food products are categorized according to such body properties as shape, size, weight, elasticity, and fragility, while surface properties include friction, stickiness, humidity, and temperature. These parameters directly affect the grasping success and product safety. On the other hand, robotic end-effectors are classified according to their contact position during handling in top, side, and bottom configurations-in other words, T-type, S-type, B-type, or hybrid configurations, like TS, BS, and TBS types. Such a classification enables structured performance comparisons among several device designs. The evaluation framework consists of a robotic system based on the ROS 2 platform, equipped with a Denso robotic arm, pneumatic controllers, and an Intel RealSense 3D camera for visual recognition. The methodology included standardized pick-and-place experiments on 14 different food items using seven soft robotic end-effectors. Each end-effector's adaptability is rated across seven properties: shape, size, weight, friction, elasticity, stickiness, and fragility. Performance scores are visualized using radar charts, which provide an intuitive representation of overall efficiency and capability.

Experimental results indicated that no single end-effector operates optimally for all types of food. For example, suction-based grippers operate well on smooth surfaces but failed when the item was sticky or had a coarse surface. Pneumatic and soft-finger grippers displayed greater adaptability, especially when it came to fragile or oddly-shaped foods. Radar-based visualization of scoring offered insight into design limitations and provided direction for end-effector optimization.

2.6 Vision Assisted Pick and Place Robotic Arm

Author : Nisha, Dinesh Kumar, Sekar, and Indira

The paper describes the design and implementation of a 2-DOF robotic arm integrated with a machine vision system that is capable of fully automated pick-and-place operations. This system differs from traditional manually guided robotic arms in such a way that it utilizes a USB camera as a vision sensor and incorporates LabVIEW Machine Vision (NI-IMAQ) for capturing live images and processing. The primary objective remains to identify an object autonomously, measure its dimensions, and precisely guide the robot to pick and relocate it without human interference.

The robotic arm is fabricated from lightweight acrylic sheets and actuated by three servo motors: one each for the base, wrist, and gripper. The base rotates the entire arm, the wrist provides vertical motion, and the gripper, through a servo-driven wheel mechanism, is able to grasp widths from 1.0 to 9.3 cm. It has a total mass of 500 g and is 19 cm tall, and therefore is cost-effective, portable, and suitable for small-scale automation.

The vision system captures object images and performs image processing based on RGB-to-grayscale conversion, pattern matching, and edge detection algorithms. Pattern matching finds template similarity and extracts pixel coordinates while edge detection, with the Prewitt operator, computes the dimensions of objects. Pixel values are converted to real-world units using a calibration constant 1 pixel = 0.026458 cm. These measurements are then sent to the servo motors via RS-232 communication using an LPC2129 ARM7 microcontroller programmed to produce the appropriate PWM signal that drives the servos.

Experimental tests demonstrate the system reliably detects object dimensions, while slight discrepancies exist due to camera resolution and other illumination factors. The authors identify that the integration of vision significantly improves the automation capability, but full-scale industrial applications will involve increasing DOF up to at least seven and employing higher-resolution 3D cameras in order to achieve more accurate sensing.

2.7 Design and Implementation of Pick and Place Robotic Arm

Author : Ravikumar Mourya, Amit Shelke, Sourabh Satpute, Sushant Kakade, Manoj Botre

The paper describes the complete mechanical, control, and analytical development of a 4-DOF articulated pick-and-place robotic arm for cylindrical objects weighing up to 150 grams. The objective of the study was to replace human intervention in repetitive material-handling tasks and to present a lightweight, low-cost, and efficient robotic solution for industrial environments.

The authors first present the necessity for robotic manipulators and emphasize their role in hazardous, repetitive, or precision-demanding tasks. The robotic arm described here uses a model based on the human upper limb, having four revolute joints with each joint actuated by a servo motor. This, in turn, provides four degrees of freedom: shoulder rotation, elbow rotation, wrist rotation, and gripper rotation. Control is achieved through an ATmega16 microcontroller and a serial servo controller, enabling smooth motion and coordinated axis operation.

The selection of material was one of the important design considerations. Lightweight aluminum and rectangular sheet sections will provide rigidity and stability by reducing load on the base and shoulder. This gripper is designed to securely grasp a cylindrical object up to a volume of 150 ml and weighing up to 150 g. A CAD model for the arm on Creo should be created, including a complete 3D assembly of the base, shoulder, elbow, wrist, and two-fingered gripper.

A detailed inverse kinematics analysis, using RoboAnalyzer, calculates joint angles for a number of target positions that confirm the reachable workspace and the allowable trajectories. Joint value, velocity, acceleration, and torque graphs confirm smooth dynamic behavior.

The authors perform FEA on major components like the shoulder base, elbow, and fingers using ANSYS to ensure that structural integrity is maintained. Stress and deformation plots also show all parts operate well within safe limits under expected loads.

The paper concludes by successfully demonstrating the design, simulation, and analysis of a functional 4-DOF robotic arm that can perform pick-and-place operations reliably. According to the authors, the system provides a practical and cost-effective solution for industrial automation, and its performances can be further improved with better control algorithms and sensor integration.

2.8 Design and Construction of a Robotic Arm

Author: Md. Tasnim Rana & Anupom Roy

The paper outlines the design of an affordable, efficient robotic arm for industrial applications. The authors designed a programmable mechanical arm that emulates the structure and movement of the human arm for performing precise, repetitive, and hazardous tasks in industry. The aim was to develop a low-cost autonomous robotic system that can execute fundamental operations like object detection, gripping, and placement using basic electronic and mechanical elements. The authors highlight how robot arms are already applied in assembly lines for tasks such as welding, material transfer, and packaging, and how similar designs can be adapted for rescue or hazardous operations like bomb disposal and firefighting.

The proposed system has two major subsystems: the mechanical assembly and the signal processing unit. The mechanical system consists of a servo and stepper motor that emulates human arm joints, which are capable of both rotational and translational motion. The signal processing part is based on an Arduino Uno R3 microcontroller. Sensors like an ultrasonic sonar (HC-SR04) are integrated which detect the position of objects, thus enabling the arm to scan its surroundings and identify different objects and compute their coordinates. A mechanical gripper or claw serves as the end-effector, capable of securely holding objects up to 55mm in width. The power supply of the arm is a 9V DC with the option for solar recharging, enhancing its sustainability. This methodology involves a step-by-step motion control sequence: scanning, object detection, grasping, transport, and reset. For joint actuation, this prototype uses four servos and one stepper motor to achieve base rotation for a 360° workspace. MATLAB visualization software helps in simulating the trajectory taken by the arm and its workspace in three dimensions.

Experimentally, the robotic arm is able to illustrate fine motion control and object manipulation based on minimum power consumption. It offers four degrees of freedom and adopt modular structural elements, balancing functionality and affordability. The limited travel range of the servos diminishes the comparison with more expensive industrial robots; however, due to the simplicity and reliability, the educational, small-scale industrial, and laboratory employment of the manipulator is very suitable.

2.9 A Review of Robotics and Autonomous Systems in the Food Industry.

Author: Linh N.K. Duong, Mohammed Al-Fadhli, Sandeep Jagtap.

The authors conducted a systematic literature review of 54 research papers using a structured nine-step procedure. They found five major themes that define the impact of RAS in food supply chains, namely food quality, food safety, food waste management, supply chain efficiency, and supply chain analysis. Each theme underlines the potential of robotics and automation in adding value to different dimensions of the agri-food ecosystem.

They also note that food quality is increasingly monitored along the supply chain for freshness, color, texture, and temperature using computer vision, multispectral imaging, and IoT-based systems. These ensure real-time quality control with minimal human inspection. Applications related to food safety make use of traceability systems like RFID, blockchain, and wireless sensor networks to monitor handling conditions and prevent contamination. Walmart enhances food traceability by using RFID in China, from farm to consumer, enabling enhanced transparency and accountability.

The paper further illustrates that RAS allows for real-time tracking of waste and predictive analytics to reduce overproduction and spoilage. Systems integrated with IoT at the processing plants can monitor inefficiencies, and AI-based forecasting tools at restaurants help optimize production and minimize waste. Automation in logistics, inventory control, and agricultural operations by making use of drones, autonomous vehicles, and intelligent warehousing systems improves efficiency in the supply chain. This lowers energy usage and dependence on labor while assuring consistent operations. Supply chain analytics with the power of big data and machine learning enables decision-making and sustainability assessments across global networks.

2.10 Robot Arm Control with Arduino

Author : Aimn Mohamed Ahmed Ghiet and Dr. Abdellatif Baba

The following report describes in detail the design, development, and implementation of a 4-axis robotic arm. Control of this robotic arm is by an Arduino Nano using a Bluetooth-based Android application. The work integrates mechanical design, microcontroller programming, servo motor actuation, and wireless communication to realize an affordable, functional robotic arm capable of user-defined movements like lifting, carrying, mixing, and repeating stored motion sequences.

The project starts by explaining the theoretical basics, above all the role of servo motors, which are chosen because of their accuracy, high torque, and easy control via PWM signals. Five TowerPro SG90 mini servo motors actuate the four axes plus gripper, allowing to perform different movements like rotation, lifting, bending of the elbow, wrist action, and gripping. The authors also provide a description of the Arduino Nano microcontroller, chosen for simplicity, open-source support, and its rich library ecosystem, which makes it fit both for beginners and advanced users.

It features a Bluetooth HC-06 module for wireless communication between the robot arm and an Android app designed with MIT App Inventor. The user can manually adjust each axis using "+" and "–" buttons, send commands, save positions into EEPROM, and replay recorded sequences for the robot to perform repetitive tasks autonomously.

The arm is designed mechanically using SolidWorks, while the components are fabricated using lightweight materials, including 3D-printed parts. A detailed explanation of the kinematics of the robot arm, which covers Denavit–Hartenberg parameters, forward and inverse kinematics, and transformation matrices, provides a mathematical basis for understanding robot motion. Experimental results confirm smooth and precise motion along all axes. The system performs pick-and-place tasks reliably, and a number of real advantages of integrating mechanical engineering with electronics and embedded programming have been illustrated. The authors conclude that Arduino-based robotic arms are scalable, low-cost, and suitable for educational, medical, and industrial automation applications.

2.11 Design of 6-Axis Robotic Arm

Author : Abhishek Bhambere

The paper presents the complete mechanical design, selection of materials, torque analysis, and simulation-based validation of a stationary 6-axis robotic arm meant for pick-and-place applications. The focus of the work is to develop a cost-efficient yet structurally robust manipulator that can achieve human-arm-like motion through pitching, rolling, and yawing degrees of freedom. The main design constraints in this work include a nominal payload of 0.5 kg, horizontal reach of 0.6 m, and accuracy of 3 mm to ensure practical use in manufacturing, handling of electronics, and assembly lines when human intervention is restricted.

The selection of structural materials starts the study. Plain carbon steel 45C8 is selected for brackets, shafts, and plates since it offers a very good strength-to-cost ratio, is machinable, and weldable. For flexible components, like flanges, Aluminium 6082-T6 is used. Belt drives will be done using PET rubber and plastic pulleys. A detailed CAD model has been developed on SolidWorks and imported in V-REP to simulate the torque requirement and feasibility of the motions. Inverse kinematics and joint force modules of V-REP enabled the accurate calculation of the required torques in all the six axes, which are in the tune of 16.55 N-m (Axis-1) to 0.049 N-m (Axis-6). After simulation, manual torque calculations are made using classical formulae, $T = F \times r$, whereby each joint's load comprises the mass of motors, belts, pulleys, links, and the gripper. The paper also features lengthy pulley-belt selection tables, determining gear-reduction ratios necessary to minimize motor cost while providing adequate output torque. Shaft diameters are calculated from equations involving bending and torsional stress, using safety factors that ensure structural reliability. Bearings are selected by making use of SKF dynamic load ratings depending on expected revolutions and load factors.

The final results confirm that the design meets all the payload and accuracy requirements with a factor of safety of 1.5, allowing the arm to lift up to 0.7 kg without modification.

2.12 Challenges for Industrial Robot Applications in Food Manufacturing

Author : Farah Bader and Shahin Rahimifard

This paper looks at the gradual but steadily growing application of IRs within the food processing industry and compares it with the rapid automation attained so far in the automobile and electronics industries. Also, in spite of the long-recognized advantages of efficiency, precision, and flexibility of industrial robots, the food industry still depends mostly on manual labor because of the fragile, variable, and perishable nature of food products, along with high hygiene and safety requirements. The paper therefore gives a broad overview of the rationale, applications, challenges, and future outlook of robotics in manufacturing foodstuffs and positions automation as quite vital for meeting the global increase in demand.

According to the authors, major drivers accelerating automation include: changing consumer expectations for customized and sustainable products, strict government regulations on traceability and hygiene, a shortage of labor due to geopolitical changes like Brexit, and an increased need of manufacturers for efficiency and competitiveness. Such pressures push the sector toward flexible, reconfigurable production systems. Industrial robots are automatically controlled, reprogrammable, multi-purpose manipulators. According to ISO, they have the advantage of speed, precision, repeatability, and adaptability. Examples include ABB's IRB 360 FlexPicker achieving up to 200 picks per minute and KUKA robots functioning effectively in sub-zero conditions.

Despite these advantages, the study identifies four key barriers to wide-scale diffusion: difficult handling of fragile and variable food items; stringent hygiene and wash-down requirements; economic and social issues including high perceived costs and job displacement fears; and skill shortages due to limited cross-disciplinary expertise. This paper concludes by stating that industrial robots would lie at the heart of future food systems that conform to Industry 4.0. Advanced soft robotics, sensor integration, and AI-based controls are bound to drive the global food robotics market past £2.7 billion in a shift toward intelligent, hygienic, and fully automated ecosystems in food manufacturing.

2.13 Pose Estimation and Bin Picking for Deformable Products

Author : Benjamin Joffe, Tevon Walker, Remi Gourdon, Konrad Ahlin

This paper presents a deep learning-based robotic system for handling deformable food products, such as poultry, through pose estimation and automated bin picking. The authors introduce an integrated robotic system able to detect, pick, and reorient unordered bins of deformable poultry products into a consistent "canonical pose" that enables further automation in downstream tasks.

Advanced computer vision is combined with machine learning in the system. A UR-5 robotic arm fitted with a suction cup gripper and an Intel RealSense D435 RGB-D camera is employed. A Faster R-CNN neural network uses a ResNet-101 feature extractor to perceive and locate objects against cluttered bins. These object centroids are then transformed into 3D coordinates and fed into the robotic controller for planning grasping points. The gripper is designed to achieve a vacuum seal on relatively flat surfaces, ensuring the soft and slippery chicken surfaces are handled without causing any deformation or damage.

The authors develop and compare two methods for pose estimation: a direct quaternion regression model and an augmented auto encoder architecture. Both estimate the 6D pose of the poultry in terms of three translational and three rotational parameters. A regression model directly outputs the quaternion-based rotations, whereas the augmented auto encoder implicitly reconstructs the object orientations from synthetic image data. The auto encoder model showed better generalization with more robust performance under variable lighting and shape conditions. Synthetic training datasets with random augmentations (such as scaling, color jittering, and background noise) increased robustness against environmental variability.

Experimental results showed a 92% success rate for bin picking and an 81% success rate for canonical pose placement with the augmented autoencoder model, whereas the best performing regression method achieved a success rate of only 32%. The experimental results also indicated that temperature changes affected skin stiffness, thus impacting suction efficiency. Failures occurred mostly when the gripper encountered irregular surfaces or obstructed ones, like chicken wings.

2.14 Design and Development of Pick and Place Arm Robot

Author : Design and Development of Pick and Place Arm Robot

The paper presents the complete design, fabrication, and evaluation of a low-cost, electro-pneumatically actuated pick-and-place robotic arm for industrial material handling. This study seeks to enhance productivity of processes like machining, sheet-metal operations, and assembly where manual handling is time-consuming and repetitive. This robot is specially designed to transfer lightweight objects between two stations, such as glass blanks, plastic caps, or small sheet-metal parts, each weighing approximately 100 grams.

The design methodology undertaken by the authors is structured, starting with conceptual layout sketches, followed by CAD modeling, and finally the development of the assembly. The robotic system consists of a base frame, lead screw, rack-and-pinion rotation mechanism, pneumatic cylinders, and vacuum suction grippers. The rotation of the arm is provided by means of a rack actuated through a pneumatic cylinder, which allows for 180° clockwise and counterclockwise motion in order to transfer objects between stations. Vacuum grippers are preferred since they are suitable for flat and smooth surfaces and are very inexpensive.

The control architecture combines electrical and electro-pneumatic circuits, which are developed and simulated using Festo Fluidsim to ensure coordinated actuation of the three double-acting pneumatic cylinders responsible for gripping, releasing, and rotating. The robot can operate in either manual or automatic modes, allowing flexibility during setup and testing. Material selection and beam deflection calculations are performed so that the arm has sufficient stiffness to limit its deformation under load within safe limits.

Experimental testing has demonstrated significant gains in performance. One full pick-and-place cycle takes the system about 8 seconds, which translates into 900 objects per hour transferred-nearly twice the throughput compared with manual handling. Automated operation decreases human fatigue, minimizes errors, and reduces material-handling costs.

The authors conclude that the electro-pneumatic approach is a simple, reliable, and economic solution for small-scale industrial automation. Future enhancements will include full automation by the addition of sensors and advanced control for increased precision and versatility.

2.15 A Review of Robotics and Autonomous Systems in the Food Industry: From the Supply Chain Perspective

Author: Linh N.K. Duong, Mohammed Al-Fadhli, and Sandeep Jagtap

The paper by presents an extensive review of the role of RAS in improving productivity, efficiency, and sustainability throughout the whole food supply chain. Unlike most earlier works that focused primarily on the technological aspects of robotics, this paper adopts a holistic supply chain perspective to explore how RAS affects every stage of the food system, from farming and processing through distribution and logistics to waste management.

The authors performed a systematic review of 54 research papers from the period between the years 2000 and 2020, adhering to a structured nine-step approach. Their thematic analysis identified five main areas of foci, in which RAS contributes to transformative impacts: food quality, food safety, waste reduction, efficiency of supply chains, and supply chain analyses. Each of these themes illustrates how automation and digitalization can enhance control, traceability, and sustainability within global food networks.

RAS, in its turn, allows improved monitoring and control of freshness and appearance of food with the help of machine vision, sensors, and image processing. Multispectral imaging, IoT-enabled monitoring, and cyber-physical systems provide real-time assessment capabilities for parameters such as color, ripeness, and texture. Robotics improve food safety through traceability systems like RFID and blockchain integrations, recording product origin, temperature, and handling information for compliance with safety standards such as HACCP.

The paper throws light on IoT-based systems that track waste generation in real time, thus helping manufacturers to identify inefficiencies in their production lines. For instance, autonomous vehicles and drones can support crop inspection, delivery, and warehousing operations, while intelligent algorithms optimize inventory and routes of transport. The study identifies several key challenges to RAS adoption: data availability, cybersecurity risks, high investment costs, and skill shortages in handling advanced technologies. It further emphasizes that while robotics can significantly improve productivity and resilience, such wide-scale implementation requires collaboration from industry, government, and academia.

2.16 Pick and Place Robotic Arm: A Review Paper

Author : Sharath Surati, Shaunak Hedaoo, Tushar Rotti, Vaibhav Ahuja, and Nishigandha Patel

The paper provides a comprehensive overview of design principles, operational mechanisms, and technological advances in industrial pick-and-place robotic arms. By consolidating findings from multiple research studies, it traces the evolution of robotic manipulators and discusses how improvements in mechanical design, control strategies, and sensing technologies strengthened their roles in modern automation. Robotic arms substantially enhance precision, efficiency, and safety within an industrial environment and are especially very helpful around hazardous areas like high-temperature zones, metal fabrication workshops, and assembly lines.

The paper defines a robotic arm as a programmable mechanical manipulator consisting of linked joints that simulate the motion of the human arm. Different architectures of robots are described: Cartesian, cylindrical, spherical, SCARA, articulated, parallel, and anthropomorphic. Configuration and industrial suitability are discussed for each type. Cartesian manipulators are suitable for applications requiring precision in pick-and-place operations; SCARA robots operate well in high-speed assembly; while articulated robotic arms have multiple rotary joints and find extensive applications in welding, painting, handling, and general automation tasks due to their flexibility and wide workspace coverage.

Controllers and sensors have a major emphasis in making the motion of the robot accurate, adaptive, and intelligent. Microcontrollers like Arduino and single-board computers like Raspberry Pi are also used to provide closed-loop control to execute trajectories smoothly and adjust grip in real-time. Object detection systems based on computer vision are also reviewed, with particular emphasis on the use of YOLOv3 for fast and accurate recognition and localization of items to improve the reliability of automation. Other examples using color-sorting robotic arms with photodiodes, wireless gesture-controlled arms with flex and gyro sensors, and more advanced systems utilizing fuzzy logic or genetic algorithms to optimize motion planning and reduce settling time.

2.17 A Methodology for the Design of 6D Robotic Arm

Author : Y Mona Younis, Eman Nasser, Amal Nasser

The present paper deals with the design, modeling, and validation of a 6-DOF robotic arm manipulator using analytical inverse kinematics based on the Denavit–Hartenberg convention. The objective is to enable the robotic arm to quickly achieve any desired position in space with precision in its orientation, maintaining mechanical feasibility, structural strength, and precision in motion control.

This methodology follows a well-structured three-stage process: design objectives, preliminary mechanical design, and kinematic modeling with validation. The design objectives include the development of a functional arm that can pick up and place objects, PID-based control for positioning accuracy, and MATLAB-based GUI for intuitive user interaction. The robot's mechanical parts are fabricated using aluminium 6061 because of its lightweight, formability, and durability. CAD modeling is done in SolidWorks, and components are laser-cut and 3D-printed before assembly.

The final design includes six joints, a maximum reach of 700 mm, and a payload capacity of 1 kg. Belt-and-pulley transmissions increase the torque of joints while reducing the motor speed. Firstly, the kinematic analysis is done in a standard DH framework that defines link offsets, twists, lengths, and joint angles to derive the forward and inverse kinematic equations. A complete DH parameter table and the transformation matrices are constructed to calculate the position and orientation of the end-effector (Rxyz). The authors then derived the complete analytical inverse kinematic solution for all six joints by equating the elements of transformation matrices to ensure that the robot could reach any valid point inside the workspace.

Validation is performed in the MATLAB Robotics Toolbox, where the correctness of the derived joint values is checked by forward kinematic reconstruction and visual plot simulations. The system is extended with a MATLAB GUI that allows for manual joint control, Cartesian command mode, creation of trajectories, and replay of tasks.

The authors conclude that the proposed methodology successfully delivers a precise, efficient 6-DOF robotic arm capable of reliable pick-and-place operations, with accurate inverse kinematics and user-friendly control architecture suitable for industrial and research applications.

2.18 Safety-Critical Manipulation for Collision-Free Food Preparation

Author : Andrew Singletary, William Guffey, Tamas G. Molnar, Ryan Sinnet, Aaron D.

In this paper, a novel framework is introduced to ensure safety and efficiency for robotic motion in performing food preparation tasks within dynamic environments. The work focuses on one of the most pressing issues in robot cooking: how to guarantee collision-free manipulation when robotic arms interact with various moving and deformable objects in real-time. With the employment of Control Barrier Functions, the method dynamically updates existing motion trajectories; robots can adapt to environmental changes without needing full re-planning. This significantly improves the computational load while maintaining formal safety guarantees.

The paper begins by emphasizing that robotics integration is being increasingly implemented in food service industries, including automated frying, dispensing, and kitchen operations. These tasks require periodic reassessment of trajectories due to unstructured and usually unpredictable variations, such as utensil shifts, object deformation, and worker interference. Classic trajectory planners, such as CHOMP, TrajOpt, and OMPL, are computationally cumbersome and often infeasible for real-time updates. The authors introduce a CBF-based safety filtering framework that efficiently updates precomputed trajectories to ensure safety in changing environments. It builds on providing formal, mathematical proof for safety by extending guarantees from kinematic control to full dynamic behavior of robotic manipulators.

When environmental conditions change, the algorithm computes the safe velocity commands through QP, minimally updating desired inputs to satisfy safety constraints.

The study has also embedded realistic signed distance functions to calculate the separation of the robot and obstacles, with accurate computation of geometry-sensitive collision avoidance. This methodology has been integrated into a full-scale food-handling manipulator in collaboration with Miso Robotics, the creators of the "Flippy2" robotic cooking platform. Experiments done under natural kitchen conditions showed that computation time and safety performance significantly improved compared with other conventional re-planning systems. Results proved the ability of the robot to dynamically cope with cooking environments that change, such as the shifting of fry baskets or moving human operators, without negatively affecting efficiency and safety.

2.19 Challenges and Opportunities in Robotic Food Handling

Author : Wang, Hirai, and Kawamura

The paper gives an in-depth review of the current challenges, research advances, and future directions on food manipulation automation. Key issues have been framed within three realms: robotic end-effector design, food recognition, and fundamental information about food properties, and further advances in each realm have been explored along with the identification of opportunities for future research. This review begins by explaining how automation at food factories is now crucial for productivity, hygiene, and safety in the post-pandemic era. While traditional robots are already used for repetitive operations such as packaging and palletizing, many food-handling tasks—such as picking moist, deformable, or irregularly shaped items—remain challenging. It has been pointed out that the key bottleneck to achieving full automation is the lack of versatile, hygienic, and low-cost end-effectors.

For robotic end-effectors, the authors classify gripping methods based on the contact position: top, side, bottom, or combinations thereof. The most common are suction-based grippers, which are simple and fast but limited to dry, smooth surfaces. Alternatives such as Bernoulli, Coanda, adhesive, freezing, and soft grippers have been developed to handle different food textures. The paper notes that soft robotic technologies have made significant progress, with commercial examples like Soft Robotics Inc.'s mGrip and Festo's Fin Ray gripper effectively handling fragile fruits and vegetables. However, these solutions still face issues of cost, cleaning, and adaptability. In food recognition, the authors differentiate between 2D recognition for objects on conveyors and 3D recognition for random bin-picking (RBP) scenarios. While traditional 2D pattern matching is mature, RBP remains difficult due to overlapping and deformable objects. Advances in deep learning-based methods, such as Faster R-CNN and YOLOv3, have improved recognition accuracy and pose estimation in unstructured environments. These techniques are now being applied to non-rigid objects like meat, vegetables, and cooked foods. The paper also stresses the lack of quantitative data on food properties such as elasticity, viscosity, friction, and geometry, which are crucial for developing accurate robotic models and grasping strategies. The authors advocate creating a comprehensive food property database similar to the Yale-CMU-Berkeley dataset used in general robotics, to standardize research and improve end-effector design.

2.20 An Automated Robotic Arm: A Machine Learning Approach

Author : Krishnaraj Rao N S,Avinash N J ,Ram Moorthy H

The paper presents the design and implementation of a machine learning-based, computer-vision-guided automated robotic arm for performing pick-and-place operations. The main goal of this study has been the integration of object detection, recognition, and motion control into one system that could work autonomously with minimal human interference. Employing machine learning, the robotic arm is allowed to identify objects by means of visual input, make decisions on its movements according to the data learned, and manipulate the objects physically in a highly efficient way.

The proposed system is implemented on a Raspberry Pi controller integrated with five servo motors and a Raspberry Pi Camera Module (Raspicam). The arm is 3D printed using PLA material, with joints actuated by MG996, MG995, and MG90S motors for five degrees of freedom. A Python-based control program, running on the Raspbian OS, manages motor actuation through GPIO pins and processes camera input for object detection with TensorFlow and OpenCV libraries. The camera detects objects within its field of view, classifies them, and sends the positional data to the controller. From the data provided, the Raspberry Pi calculates the required rotations of the motors through inverse kinematics to reach, grasp, and move the object. The software stack consists of TensorFlow for the machine learning-based object detection part, OpenCV for image processing, and PuTTY along with VNC Viewer for remote system access and visualization. The robotic arm is designed with an ultrasonic sensor to calculate object distance by using the HC-SR04 and a barometric pressure sensor to verify if it has successfully gripped the object using the BMP-180. It assures accurate pick-up operations. The end effector-gripper-is designed to handle small and lightweight objects, while control precision is achieved by calculating PWM duty cycle. Experimental results showed that the arm could identify, pick, and place objects autonomously with high accuracy. The incorporation of computer vision and machine learning enhances adaptability immensely in unstructured environments. Such a system, the authors conclude, has immense potential for industrial and domestic automation, reducing human involvement while increasing reliability and efficiency.

2.21 Intelligent Soft Robotic Grippers for Agricultural and Food Product Handling: A Brief Review with a Focus on Design and Control

Author: Yuxuan Liu, Jixin Hou, Changying Li, and Xianqiao Wang

The paper offers an in-depth review of the design principles, material selection, and control strategies that define modern soft robotic grippers developed for agricultural and food-handling applications. It emphasizes the fact that traditional rigid robotic systems—while highly effective in industrial manufacturing—are inherently unsuitable for fragile, irregular, and deformable food products. Soft robotics, constructed from compliant materials like silicone, elastomers, and hydrogels, is recognized as a transformative solution that can deliver gentle, adaptive, and intelligent manipulation to meet the delicate requirements of agricultural produce and processed foods. A key theme of the paper is the bio-inspired nature of soft grippers, mimicking structures such as octopus tentacles, elephant trunks, and human hands. These systems have shown outstanding flexibility and adaptability; for this reason, soft grippers are able to distribute forces uniformly on the contact surfaces. This reduces problems of bruising, tearing, and wastage associated with rigid grippers. Their inherent compliance makes them ideal for grasping fruits and vegetables and other food items of different geometries, textures, and stiffness, with improved efficiency in harvesting and higher product quality.

The authors classify soft actuators, the effective "muscles" of soft grippers, as fluidic, mechanical, jamming-based, and hybrid. Pneumatic actuators, such as PneuNets, are the most common due to their simplicity and low cost, demonstrating high adaptability and achieving bending and grasping motions through the inflation of internal air chambers. Vacuum-based actuators provide stronger, more uniform grasping, while fiber-reinforced soft actuators increase load capacity by constraining unwanted deformation. Jamming-based actuators stiffen granular or layered materials under vacuum, thus allowing tunable rigidity and universal gripping. Tendon-driven systems achieve high precision by using the tension of cables and are therefore suitable for delicate fruit-picking tasks. While substantial progress has been achieved, the paper points out remaining challenges with durability, control complexity, material scalability, and environmental sensitivity.

2.22 Robotics and Machine Vision for Primary Food Manipulation and Packaging

Author : Saigopal Vasudevan, Mohamed Lamine Mekhalfi, Carlos Blanes, Michela Lecca, Fabio Poiesi, Paul Ian Chippendale, Pablo Malvido Fresnillo, Wael M. Mohammed, and Jose L. Martinez Lastra

The paper gives a critical technical review of robotics and machine vision technologies for the automation of primary food processing, which involves all essential operations immediately after harvest, including sorting, cleaning, grading, and packaging. The growing need for automation is underlined by labor shortages, strict hygiene requirements, and increasing production demands, especially in Europe, where 99% of the food industry consists of SMEs that increasingly favor flexible, reconfigurable robotics over expensive, specialized machinery.

Automation of primary food handling is uniquely challenging because many food products have high variability in shape, texture, and moisture content, and fragile items require very careful grasping, cutting, or sorting action to avoid bruising or other damage. No single robotic solution can handle these tasks, and each application requires customized end-effectors and vision systems for different products. This review groups automation systems into two broad components: sensing technologies (machine vision) and actuation systems (robotic manipulators and end-effectors).

The paper reviews RGB imaging, multispectral, and hyperspectral sensing, and 3D imaging as representative non-destructive and high-speed techniques for quality assessment in machine vision. Such systems are capable of detecting bruises, estimating ripeness, assessing the quality of meat, and finding contaminants. Artificial intelligence integrated with deep learning greatly improves the accuracy in real time by allowing object recognition, detection of defects, and classification of diseases. However, some of the areas that still remain challenging are illumination control, reflective surfaces, and handling large datasets.

On the manipulation side, the authors review different robot configurations, such as SCARA, delta, articulated, Cartesian, and collaborative robots. SCARA and delta are best suited for fast pick-and-place operations, while the articulated and cobot systems have greater dexterity for fragile or irregularly shaped products. It also highlights hygienic, food-grade design with easy cleaning and resistance to environmental conditions.

2.23 Prospects of Robotics in Food Processing

Author : Y. B. Wakchaure, B. K. Patle, and Sachin Pawar

The paper reviews the evolution, applications, and future prospects of robotics in food processing, showing how automation has transformed manufacturing, packaging, and distribution to meet global challenges such as population growth, labor shortages, hygiene concerns, and rising consumer expectations. Historically, the food sector has been slower to adopt automation compared with other manufacturing sectors, but today it is identified as one of the top four domains that can be most automated.

Drivers include a growing need for food safety, high-quality food, and mass production, coupled with increased productivity and reduced human error. According to the paper, about 94% of packaging operations in the food industry are already roboticized, especially in areas like palletizing, sorting, material transfer, and high-speed pick-and-place.

The review covers segments of the food industry like grains, sugar, dairy, beverages, meat, seafood, bakery, fruits and vegetables, spices, frozen food, etc., showing how robotics has been integrated at different stages of processing. This was appropriately represented with examples such as RGB and NIR sensor optical sorting machines for grain defect detection, automated vacuum systems for consistent sugar juice extraction, HPP in beverage preservation, and AMS in dairy operations. Robots are increasingly performing delicate, specialized tasks such as meat deboning, cake decoration, and cheese cutting with much higher precision and hygiene than manual labor.

All these developments are situated within the broad frameworks of Industry 4.0 and Industry 5.0, with cyber-physical systems, IoT, AI, cloud computing, and machine learning playing the central role. Such technologies enable better traceability, real-time monitoring, predictive maintenance, and autonomous decision-making, while transforming workforce roles by shifting workers away from repetitive labor to supervisory and technical ones.

The authors conclude by emphasizing that robotics has become indispensable in modern food manufacturing. It improves hygiene, safety, efficiency, and product quality in all stages: from raw material handling to end-stage packaging. The authors look ahead and envision a future dominated by intelligent robots, AI-driven inspection, and adaptive soft grippers, which altogether will drive fully automated, sustainable, and consumer-responsive food processing environments.

2.24 Robotics Revolution: Transforming the Food Industry Through Automation and Innovation

Author : Dr. G. Nedumaran and M. Madhuritha

The paper explores how robotics, artificial intelligence, and automation technologies are redefining the food industry worldwide, from farm to fork. While the food sector has been slower than others to embrace automation, pressures such as a lack of labor, high levels of hygiene required, and a growing demand for safe and high-quality food have led in recent years to a faster pace in the use of intelligent robotic systems. All these pressures were further increased by the COVID-19 pandemic, which showed weaknesses in food production and staffing, and the rapid integration of robotics into manufacturing, packaging, and delivery of foodstuffs is the result.

The authors identify five major domains where robotics is already making a big difference: agriculture, manufacturing, packaging, cooking, and delivery. In agriculture, autonomous robots and drones monitor crops, allow for selectivity in harvests, and supervise livestock, hence enhancing precision and reducing the need for seasonal labor. For instance, fruit-harvesting robots from T&G Global improve picking efficiency while reducing product damage. Food manufacturing involves the use of robots for performing repetitive tasks that are hazardous to human life, such as sorting, cutting, and meat processing. Companies like Tyson Foods employ robotic systems to separate meat and package it, improving hygiene and increasing throughput.

In the process of packaging, robotic equipment repeatedly assembles, labels, and seals products while supporting eco-sustainability through optimized material use and integrating biodegradable packaging. Culinary robotics is another area worth mentioning, as systems like "Flippy", developed by CaliBurger, are able to cook foods like fries and hamburgers with great precision and consistency, using considerably less labor. Further advancing last-mile logistics come autonomous delivery robots and drones employed by companies like Kroger and Starship Technologies, enabling safe, contactless delivery.

The authors conclude that robotics will dominate the future of food processing, packaging, and distribution. The food industry is moving toward safer, faster, and more sustainable automated ecosystems through combinations of AI, smart sensing, and collaborative human–robot systems.

2.25 Robotic Handling of Compliant Food Objects by Robust Learning from Demonstration

Author : Ekrem Misimi, Alexander Olofsson, Aleksander Eilertsen, Elling Ruud Oye, John Reidar Mathiassen

The paper proposes a robust LfD framework that enables teaching robots to handle fragile and deformable food materials like fish, meat, and vegetables-materials inherently exhibiting variable size, shape, and mechanical texture. Traditional robot grasping systems are not satisfactory for such manipulations, as they rely mainly on rigid-body assumptions and pure vision-based approaches. This paper presents a multi-modal LfD approach that fuses RGB-D visual data with tactile feedback in order to estimate optimal grasp pose, finger configuration, and gripping force, while automatically filtering inconsistent human demonstrations.

In this paper, we use a 6-DOF Denso VS087 robot arm, a ReFlex TakkTile multi-fingered gripper, and a Kinect v2 RGB-D camera. During teleoperation, a human teacher demonstrates grasping motions using Sixense STEM controllers, recording data about gripper position and orientation, as well as tactile pressure and RGB-D images. These demonstrations are used as training examples for the robot. We collected a dataset of 525 demonstrations using lettuce because of its high compliance and variability, and data augmentation was performed to improve generalization.

A key contribution of this work involves the automatic rejection of inconsistent demonstrations. Rather than manually discarding poor data, the authors use a one-class Support Vector Machine to discover outliers in the state-action space and retain only those demonstrations which are consistent with the intended policy. Subsequent ε-insensitive Support Vector Regression learns a mapping between visual-tactile features and grasping actions. This combination yields a robust policy which generalizes well even under demonstration variability.

Experimental validation reveals that 497 of 525 demonstrations were consistent, and after filtering, the robot reached an average grasp success rate of 75% on unseen lettuce samples. The system demonstrated stable grasping by adjusting its finger pressure dynamically according to tactile feedback, although occasional failures were caused by incorrect gripper orientation or uneven object surfaces.

2.26 Robotic Grippers in Food Industry

Author: Hamid Abdullayev and Elnur Huseynzade

It provides an overview of technological advances and their limitations, as well as new emerging trends concerning robotic gripping systems in the food industry. The authors have outlined the challenges in manipulating soft, weak, and unstructured materials like fruits, vegetables, and raw meat using conventional industrial grippers, which cannot accommodate delicate textures, irregular geometries, or moisture-rich surfaces. Considering that food products are so easily damaged by excessive force, slipping, or inappropriate contact, the authors support the need for novel, hygienic, and adaptable gripping technologies capable of preserving the integrity and safety of such products. Food processing presents unique difficulties not encountered in standard manufacturing, including softness, irregular shapes and surfaces, contamination risks, and complex grip physics.

These challenges are grouped by the authors into five essential domains: soft material requiring gentle force control, uneven surfaces decreasing suction stability, irregular forms complicating grasp planning, hygiene demands compelling food-grade materials, and the constraints of physics imposed on force distribution during gripping.

The paper reviews various gripping mechanisms: pinch, penetration, suction, and freezing-based "surface effect" grippers. Pinch grippers use friction but may crush fragile objects; penetrating grippers insert pins that interlock with the surface and cannot be used with edible products; suction grippers require a smooth, dry surface yet do not perform well on wet foods; and freezing-based systems use a thin layer of ice to attach to high-moisture objects like meat. The authors review two-finger, multi-finger, and servo-driven mechanisms that apply force dynamically, as well as anthropomorphic designs modeled on human hands, though these are generally expensive and mechanically complex.

This review concludes that while development has indeed been significant, soft, hygienic, and sensor-integrated grippers remain an area of active development. Future advancements of the technology will depend on soft robotics, advanced sensing, and machine-learning-based control to realize gentle, reliable, and contamination-free food automation.

2.27 Automation and Optimization of Food Process Using CNN and Six-Axis Robotic Arm

Author : Youngjin Kim and Sangoh Kim

This paper proposes the FPRIS, which is a totally automated AI-driven framework incorporating robotics, computer vision, and smart sensing for coffee roasting process optimization. By enhancing the precision, consistency, and safety of operations, FPRIS embodies a specially designed 3D-printed six-axis robotic arm, multisensory feedback, and CNN monitoring and controlling real-time roasting.

As the primary actuator in the system, the six-axis robotic arm is fabricated through 3D printing. This will dynamically observe changes in the roasting chamber and make parameter adjustments as required. The system is integrated with RGB cameras, thermocouples, and MQ-3/MQ-7 gas sensors to continue gathering data on the color of the beans, temperature, and generated gases throughout the operation. These multimodal inputs are processed by the BeanFinder CNN (BFCNN), a custom deep-learning model that was trained to classify coffee beans and estimate their Degree of Roasting (DoR) from over 11,000 images. The CNN segregates beans from empty and noisy backgrounds and achieved a high accuracy of classification of about 97.59%, allowing reliable identification of roast levels from light to dark.

FPRIS independently controls roasting conditions such as gas intensity and roasting time using the predictions from CNN and through robotic actuation. To investigate the validity of the system, the authors conducted tests on PCS and VCS, considering color (L*, a*, b*), gas index, weight loss, and pixel brightness. Experimental results demonstrated a good agreement between PCS and VCS, validating that with an increase in the darkness degree of roast, gas emissions and weight losses were significantly higher, while decreases were observed in the grayscale and color metrics as expected from the roasting behavior.

The study concludes that FPRIS achieves roasting precision comparable to expert human operators while improving safety by monitoring CO levels. Beyond coffee, the authors propose extending the system to other thermal food processes—such as baking, drying, and frying—positioning FPRIS as a scalable AI-robotics platform for next-generation Food Processing 4.0.

2.28 Design and Control of Soft-Rigid Grippers for Food Handling

Author : Valerio Bo, Leonardo Franco, Enrico Turco, Maria Pozzi, Monica Malvezzi, Domenico Prattichizzo, and Gionata Salvietti

The paper presents the design, control methodology, and experimental evaluation of a novel soft–rigid, tendon-driven robotic gripper—the Double-Scoop Gripper, DSG—engineered specifically for food handling in confined and cluttered environments. The gripper is intended for delicate pick-and-place operations involving fragile, easily deformed, or irregularly shaped food items stored in narrow trays and containers. The combination of structural rigidity with mechanical compliance allows the DSG to perform gentle manipulation while supporting efficient motion planning required in real-world food-handling tasks.

It has two scoop-shaped fingers that can flex to form a single plate. Each finger includes a rigid internal plate surrounded by a flexible TPU border that enables the gripper to slide underneath soft food items and lift them without applying damaging pressure. Actuation is through a tendon-driven mechanism-providing precise control along with reduced friction and lower mechanical complexity. Made of ABS-like resin and TPU (Shore 85A), the DSG is lightweight and strong, with an onboard camera supporting vision-based feedback.

One of the main contributions to this work is a data-driven approach for designing a gripper, incorporating past grasping experience into the geometry of the gripper. Through simulation and topology optimization, the scoop structure is refined for stability while minimizing material usage and adapting to the environmental constraints. The authors also developed specialized control strategies, leveraging container walls and surrounding structures for aiding grasp and release actions. Four grasping strategies and three placing strategies are defined based on object position, height variation, and container geometry.

Extensive experiments performed using a UR5 robotic arm across different food items such as meatballs, sausages, cookies, carrots, and zucchini demonstrate the grasp success rate at 88.6% and release success rate at 97%. The DSG effectively handled single and multiple items without damage, even in restricted areas.

2.29 Review of Robotic Grippers for High-Speed Handling of Fragile Foods

Author : Yang Zhang and Zhongkui Wan

It provides an in-depth survey of the recent advancements, challenges, and emerging opportunities in developing soft robotic grippers that can perform high-speed and damage-free handling of fragile foods such as tofu, oysters, and pudding. While industrial robots have shown outstanding performance in manufacturing industries, their applications in food processing are still quite limited owing to the delicate, deformable, and irregular nature of food items. The paper identifies two key issues: food fragility and high-speed inertial effects. Foods with extremely low Young's modulus values-for example, tofu at 10–13 kPa and bread at 8–18 kPa-exhibit deformed shapes under very minimal pressure. However, in industrial applications where transferring 60–74 oyster pieces per minute is needed, increased mechanical stresses associated with fast operations develop. Most robotic grippers currently lack the adaptability and fine force regulation that can ensure safe handling of those materials at such high speeds.

To address these, the authors classify state-of-the-art solutions into three domains: damage-free design, variable-property actuators, and cost-efficient optimization techniques. The strategies for damage-free design involve soft–rigid coupling structures that are bioinspired from human fingers, thus providing both stability and gentle contact. Form-closure grippers increase the contact area to decrease localized pressure, thus offering safety for fragile foods. Variable-property actuators could be in the form of jamming mechanisms, magnetorheological fluids, or liquid metal alloys, while enabling the dynamic adjustment of stiffness, thereby letting grippers change properties to cope with different food properties. However, the review remarked that the current force feedback methods are too slow for real-time, high-speed manipulation.

The paper identifies finite element analysis, topology optimization, and data-driven simulations as tools that support design refinement without extensive physical testing. As for successful industrial implementations, the commercially available soft grippers include Soft Robotics' mGrip, Piab's soft hand, and Nitta's Softmatics.

2.30 Design and Field Evaluation of an End Effector for Robotic Strawberry Harvesting

Author : Ezekyel Ochoa and Changki Mo

This paper describes the design, simulation, and field validation of a pneumatically actuated end effector integrated with a Delta X parallel robot for automated strawberry harvesting. The study addresses severe labor shortages in the U.S. strawberry industry by proposing an affordable, modular, and high-speed robotic system that is able to operate in open-field environments-an area where current commercial harvesters struggle due to variable terrain and dense foliage.

Strawberry picking is still very labor-intensive because the fruit is fragile and has to be picked gently to avoid getting bruised. Systems already in place, like Organifarms' BERRY and Dogtooth Technologies harvesters, although promising, are very expensive and generally bound to controlled greenhouse or tabletop production. The proposed solution targets open-field farms, where strawberries grow closer to the ground, are more variable in their environment, and therefore call for a more flexible robotic design.

It utilizes a commercial Delta X parallel robot due to its high precision, rigidity, fast movement, and affordability. A lightweight (0.271 kg) 3D-printed PLA end effector was designed with a pneumatic blade mechanism that can cut, pinch, and hold the strawberry stem simultaneously. At an operational pressure of 206.8 kPa (30 psi), the mechanism acts in real time with respect to any change in airflow and thus provides speed during harvesting while maintaining the payload limit of the robot at 0.5 kg. The end effector design is modularized to facilitate faster replacement and modifications, resulting in further reduced operation costs.

Workspace analysis done in MATLAB and SolidWorks showed that the motion range of the robot effectively covers standard two-plant-per-row configurations of a field. Field validation at Farias Farms showed high performance, with 94.74% success in simulations and 100% success during real harvesting, even under dense late-season foliage. The system was able to harvest strawberries at 2.8–3.8 seconds per fruit, outperforming other systems such as Rubion at 4 seconds and Dogtooth's dual-arm harvester at about 25% of human speed.

CHAPTER 3

PROBLEM STATEMENT

The modern food industry faces tremendous pressure to maintain high standards related to hygiene, speed, and accuracy in handling a large and fast-growing volume of food orders. Conventional food handling methods involve higher contamination risks due to human contact, inconsistent handling quality, and a slower speed of processing, with heavy dependence on labour. These issues become even more crucial in Quick Service Restaurants, cloud kitchens, and big food outlets where hundreds of orders must be prepared and dispatched within very short time frames. In these high-demand environments, manual systems often fail to offer uniform cleanliness, timely delivery, and order sorting accuracy.

The limitation of conventional food handling systems mainly points to the absence of automation, especially in the identification and routing of food packets. Lack of an automatic QR code or barcode reader mechanism on the food packages might result in errors, such as wrong delivery, misplaced orders, and delay. These inefficiencies weaken the dependability of the operations while growing customer dissatisfaction and adding extra workloads on staff. Further, repetitive manual handling results in fatigue, which again affects accuracy and consistency.

These challenges call for an automated solution that can safely, accurately, and continuously execute food handling tasks. A Food Handling Robotic Arm offers an effective solution where it reduces human interaction, hence promoting hygiene and reducing contamination risks. Using QR or barcode scanning, the integrated system ensures correct identification of each food item within a pack and delivery to a destination using precise robotic pick-and-place operations. Such an automated approach enhances overall efficiency, improves order accuracy, reduces dependency on labour, and supports reliable, high-speed food-handling operations suitable for modern food service environments.

CHAPTER 4

OBJECTIVES

The objectives of the Food Handling Robotic Arm include solving some of the major challenges in modern food service systems: hygiene, accuracy, and speed. Manual food handling increases the risk of contamination and operation errors, especially in high-demand settings. With the application of automation through the conveyor-based transport, order identification with the use of labels, and robotic pick-and-place operations, the system reduces human contact for accurate order delivery and provides fast, consistent, and hygienic food handling.

- To reduce human contact with food, minimizing contamination risks and improving hygiene in the food-handling process.
- To enable customers to place food orders through an application, where all required inputs are provided and a QR code is automatically generated for each order, ensuring a seamless digital ordering experience.
- To use a conveyor belt system to transport food items from the kitchen to the serving counter, enabling smooth, continuous, and reliable movement of dishes without manual intervention.
- To recognize orders using labels and QR codes generated at the ordering station and scanned using a webcam, ensuring accurate identification and delivery of dishes.
- To automate the picking, placing, and handover of food items using a robotic arm for faster and more consistent service.

CHAPTER 5

DESIGN & DEVELOPMENT

The Fig 5.1 illustrates the hardware control architecture of the food handling robotic arm system. A webcam mounted above the conveyor scans the QR code on food packets and sends the decoded data to the Arduino Uno through USB serial communication. The Arduino, powered by 5 V from the laptop USB, acts as the main control unit and processes the received data to generate appropriate control signals.

A PCA9685 16-channel PWM driver, powered by an external 5 V adapter, is interfaced with the Arduino to provide accurate and stable PWM signals for controlling multiple servo motors of the robotic arm and gripper. This offloads PWM generation from the Arduino and ensures smooth motion. The Arduino also controls the 12 V DC motor–driven conveyor system, enabling synchronized packet transport and pickup. Overall, the diagram represents a clean separation of logic power and actuation power, ensuring reliable and safe operation of the robotic food handling system.

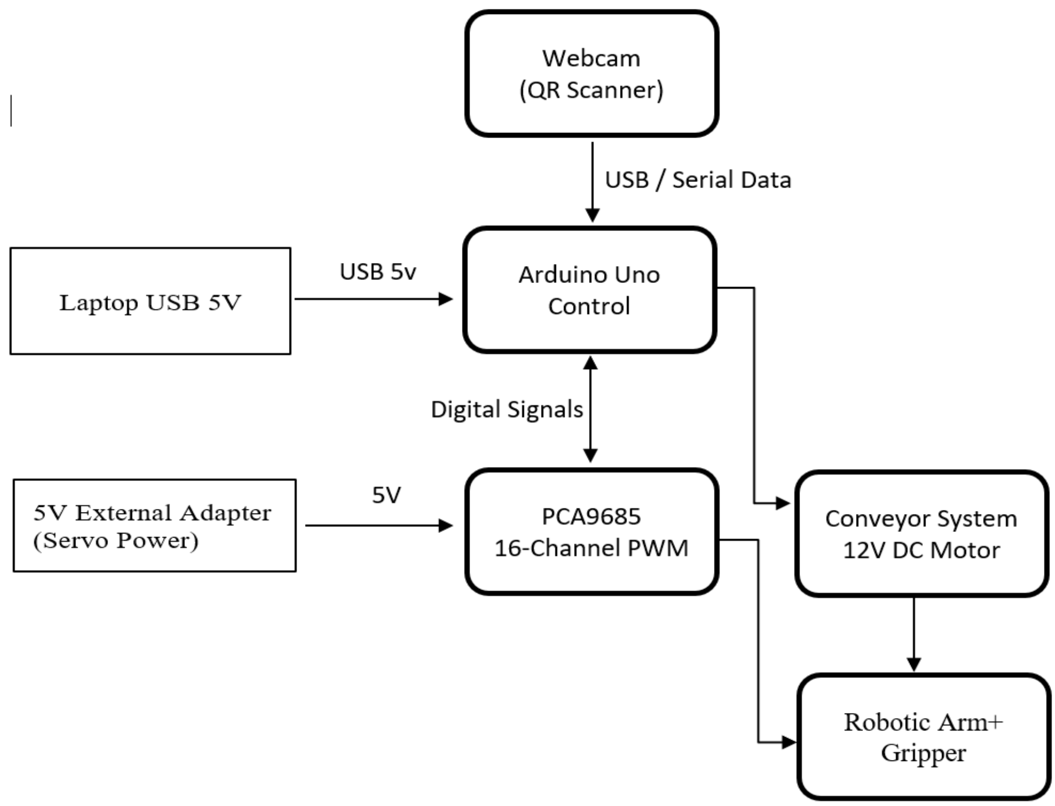


Fig 5.1 : Block Diagram of Hardware control architecture

5.1 Overview

The methodology defines a combined approach for perception, identification, motion planning, and manipulation of food automatically. The structure of the system is modular in nature, with three subsystems cooperating: perception, control, and robotic actuation, each designed to comply with the hygiene, accuracy, and speed as set by the project scope.

The perception subsystem should ideally perform real-time detection and identification of food packets that are in motion on a conveyor. Herein, an embedded camera captures frames that undergo pre-processing, QR/barcode localization, and decoding. Output parameters include customer ID, bin assignment, and pickup coordinates.

The control subsystem converts decoded data into executable motion trajectories. Inverse kinematics and state-based logic are executed on a microcontroller to create joint commands for the manipulator. The system operates through an eight-state finite-state machine: Idle, Detect, Decode, Localize, Approach, Grip, Transport, and Place. Trajectory generation leverages precomputation of keyframes to move at high speeds and invokes real-time inverse kinematics to accommodate arbitrary positions of food items. Safety constraints imposed on joint limits, collision avoidance, and gripper-force bounds accommodate packaged foods.

The actuation subsystem comprises a multi-DOF robotic arm integrated with a compliant food-safe soft gripper. CAD-based simulations support the validation of reachability, constraints on payload, and workspace coverage. The employed low-pressure, high-friction contact model within the soft gripper avoids slippage and deformation of food packets.

The total workflow thus integrates sensing, decoding, trajectory planning, gripping, transportation, and placing into one continuous automation loop. System validation entails accuracy tests, cycle time measurement, evaluation of the sorting success rate, and reliability in the case of repeated operation. In this way, the methodology ensures repeatable, hygienic, and identity-driven food handling consistent with modern automated kitchen and food distribution environments.

5.2 System Design & Mechanical Design

The system design of the food handling robotic arm integrates a web-based ordering system, QR code identification, conveyor mechanism, and robotic arm control into a single automated workflow. The control unit processes QR data from a webcam, computes pickup coordinates, and synchronizes conveyor and arm operations to ensure accurate and hygienic food handling.

5.2.1 System Design

The system was designed with a closed-loop automation cycle of detection, identification, manipulation, and placement. For modularity, reliability, and ease of maintenance, the design of the system follows a hierarchical architecture that includes:

1. Perception Unit: The Perception Unit is the front-end interface between the environment and the robotic system. The unit captures visual data through an integrated webcam positioned at the scanning station. When a food packet is placed on the conveyor, an infrared sensor detects presence, enabling selective frame capture rather than continuous processing. The captured frame undergoes QR-code detection and decoding.

The code contains a unique order number generated previously from the website used by the customer for order placement. Once decoded, the Perception Unit sends the order number and its detected spatial location in real time to the Processing and Control Unit.

2. Processing & Control Unit: The Processing and Control Unit interprets data and formulates trajectories of motion. It translates decoded information to calculate the pickup coordinates relative to the robotic workspace. A predefined calibration relationship converts image coordinates into reference positions accessible by the robotic arm. The system employs inverse kinematic computation to convert final positions of pickup and placement into corresponding actuation angles at the joint level. The decisions on movement are carried out through a finite-state logic that transitions sequentially through the standard states: Detect, Decode, Approach, Grip, Transport, Place, and Reset-to-Home. The Arduino Uno is used as the central processing controller. However, the computational overhead due to multi-joint actuations is minimized by transferring PWM generation duties to the PCA9685 servo driver.

3. Robotic Manipulation Unit: A 6-DOF articulated arm comprises a mechanical two-finger gripper. Each joint executes the motion profiles generated from kinematic computation. The arm picks up the packet at the conveyor exit region, lifts with programmed vertical and translational motions, and places it at the delivery area. There is no manual transfer since the execution of the motion pipeline happens without external intervention.

4. Conveyor & Delivery Unit: The Conveyor and Delivery Unit ensures steady, continued motion of packets into the scan and pick-up area. The conveyor itself establishes a reference boundary of the workspace, providing well-defined regions of packet pickup. The delivery area is fixed, providing a reliable release position that is easy for the customer to see.

5.2.2 Mechanical Design

The robotic arm was designed to be a 6-DOF articulated manipulator that has fine control in orientation and positioning. The joints were allocated torque-heavy MG995 servos at the base, shoulder, elbow, and wrist-pitch, while lightweight SG90 servos were used for wrist rotation and the gripper. This hybrid actuator strategy allowed a balancing of cost, power consumption, and weight.

The mechanical design process followed an iterative workflow that combined CAD modeling, kinematic analysis, and motion simulation. In the CAD environment, Fusion 360 provided a parametric setup where joint lengths, link shapes, and servo placements could be adjusted while maintaining overall mass distribution and balance.

Key Mechanical Design Steps:

1. Base Joint Optimization

The base joint required the highest torque due to long lever arms and full-arm rotation. MG995 was picked because of its high stall torque. The base mount was designed with a large stable footprint to minimize vibration and improve positional accuracy.

2. Shoulder & Elbow Joint Geometry

The load is concentrated on the shoulder and elbow. In order to minimize inertia without losing stiffness, a lightweight link geometry was designed with hollow profiles. Stress due to bending was analyzed by FEA simulations to ensure that the arm would be able to lift packets without any structural deformation.

3. Wrist Assembly

The wrist had two joints: pitch (MG995) and rotation (SG90). Here, compactness and low mass were prioritized to reduce the load on the upstream joints. The wrist bracket was designed to integrate cable routing for cleanliness.

4. Soft gripper development

Compliance in the gripper was essential for not tearing or deforming delicate food packaging. Therefore, a TPU/silicone-based structure of a gripper was chosen. The design simulated human-finger curvature and patterns of pinch-grasp for improved adaptability.

5.3 Development Framework for the Robotic Food Handling System

- **Requirements analysis:**

We identified the need for clean, automated food handling and pinned down the technical specifications-payload, degrees of freedom, workspace, and gripper details.

- **Concept and Design Development:**

We sketched ideas and settled on a suitable robotic arm configuration. We mapped out a conveyor-driven food flow and a QR-guided delivery process.

- **Ordering Application & QR Integration:**

We designed an application wherein the users fill in the order details. The system generates a unique QR code, which a webcam identifies and tracks the order.

- **CAD Modeling & Simulation:**

A robotic arm was designed in Fusion 360, motion limits were set, and simulations were run to confirm its range of motion, reach, and operation without collision.

- **Material Selection & Fabrication:**

ABS was chosen for fabrication, with all components 3D-printed. Post-processing was completed and component fitment was checked.

- **Mechanical & Electronic Assembly:**

We have assembled joints, motors, sensors, and the gripper, integrated the conveyor, and verified smooth multi-axis motion.

- **Programming & System Integration:**

Microcontrollers were configured, joint movements programmed, and motors were calibrated. QR scanning was woven into the robotic workflow for automated tasks of pick-and-place.

- **Testing and Calibration:**

Thorough full-system testing was conducted, QR recognition was validated, payload handling was confirmed, movement accuracy was tuned, and prototype performance was stabilized.

5.4 Workflow Diagram of Automated Food Handling System

As shown in Fig 5.1 workflow diagram depicts the entire flow of operation for the Food Handling Robotic Arm system. The processing starts with the user ordering through a web application that generates a unique QR-based Order ID. Then, it gets scanned using a webcam to recognize order details. Further, the packed food item is placed on a conveyor belt meant for transportation to the pick-up area.

It calculates the coordinates of pick-up and sends them to the Arduino controller. Based on this data, the robotic arm moves into the pick-up zone, and with the help of a two-finger gripper, it picks up the packet and accurately places it at the designated delivery area, thus completing the operation efficiently and hygienically.

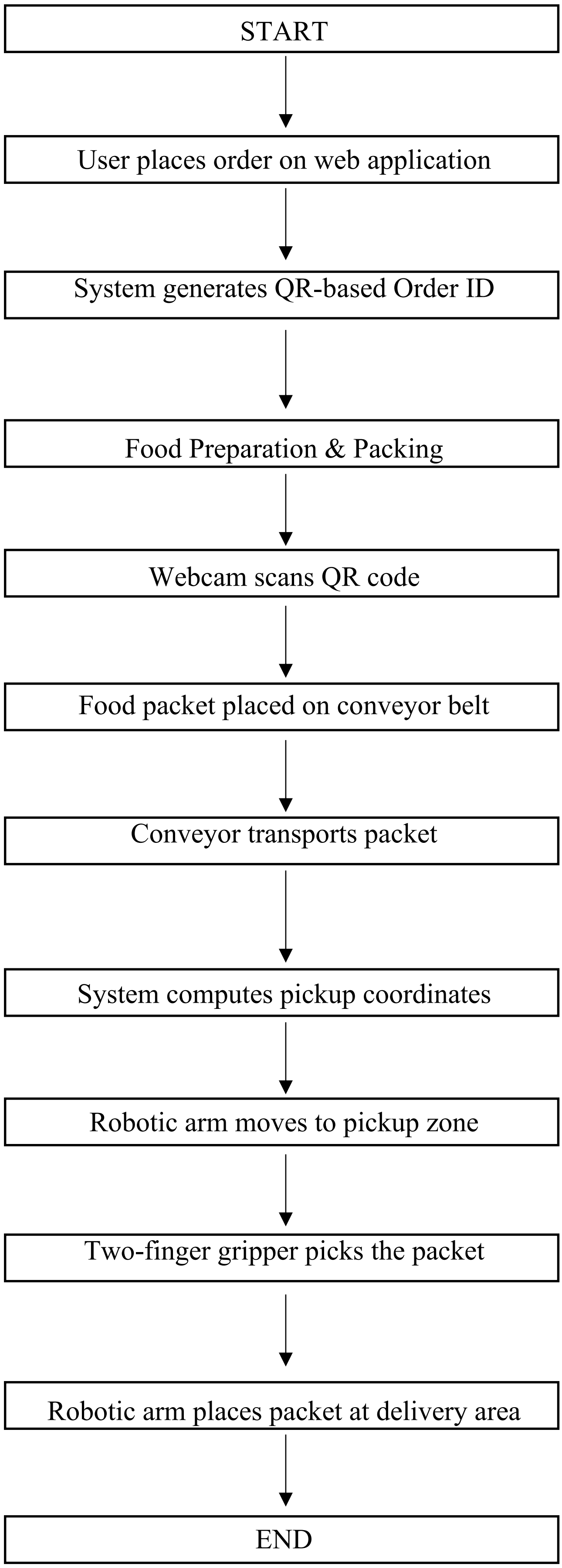


Fig 5.2 : Workflow diagram

CHAPTER 6

IMPLEMENTATION

As shown in Fig 6.1 circuit diagram for the Food Handling Robotic Arm shows the electrical connections of the control unit, actuators, and power supply. The central controller is an Arduino Uno interfaced with several servo motors driving the motion of the base, arm, wrist, and gripper. Each servo gets a control signal from the Arduino's digital pin, and it regulates a 5V power supply that keeps it running smoothly. This circuit will allow precise coordination of all joints, enabling pick-and-place actions required in automated and hygienic food handling.

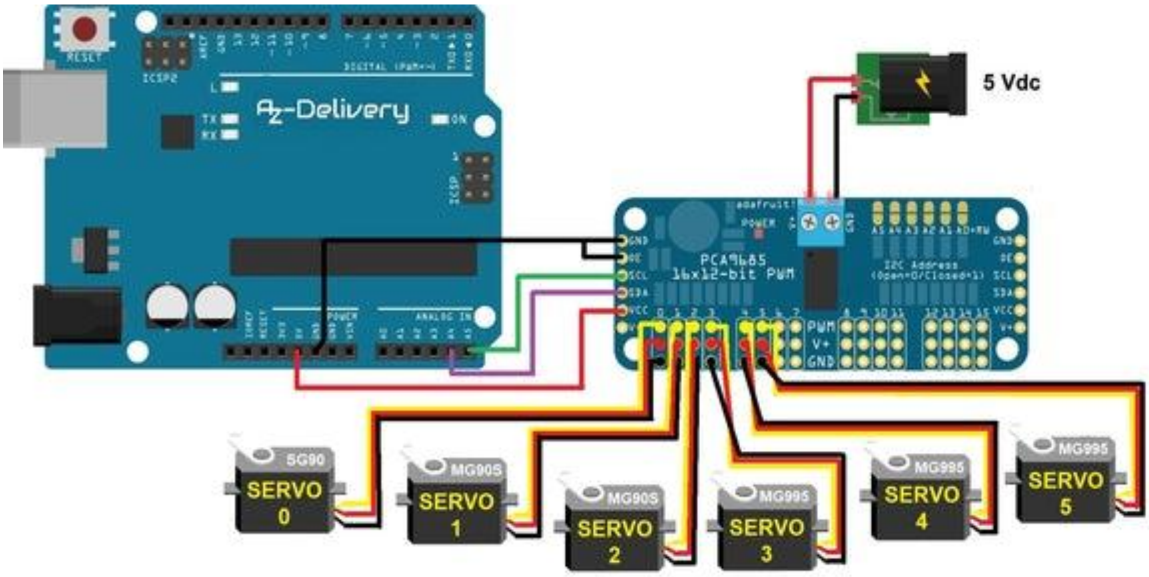


Fig 6.1: Circuit Diagram

6.1 Hardware Implementation

The hardware for the food-handling robotic arm has been designed with reliability, precision, and hygiene in mind by taking into consideration the thoughtful integration of control, actuation, sensing, and power. An Arduino Uno serves as the brain, orchestrating servo motors, sensors, and a conveyor. Main joints are driven by high-torque MG995 servos, while the wrist and gripper use micro servos of type SG90 to facilitate accurate pick-and-place action. A 12 V geared DC motor powers the conveyor to maintain packet placement consistent, wherein an infrared sensor confirms the same when items arrive. A webcam-based QR scanning setup sends in the visual input, and a dual power supply with common grounding and protection components keeps the whole system stable. In essence, all these hardware pieces put together form a robust, easily scalable robotic food-handling setup.

6.1.1 Arduino Uno Microcontroller Unit

Fig 6.2 Arduino Uno provides the computational backbone of the project and is one of the most adopted microcontroller development boards because of its open-source architecture, its powerful ecosystem, and how it easily integrates peripheral hardware. The Uno, based on the ATmega328P microcontroller, operates on a clock frequency of 16 MHz, which is quite adequate for timing-critical applications like servo synchronization, real-time I/O handling, and state-based system execution. As many as 14 digital I/O pins are integrated onto the board, six of which can provide PWM output, thereby making it inherently suitable for motor actuation, LED dimming, and modulation-based control logics. Furthermore, six analog input pins enable acquisition from sensors like IR modules, voltage dividers, or potentiometers, hence letting the board interpret real-world analog signals with precision.

Onboard hardware-level I2C and UART serial interfaces significantly enhance interfacing flexibility: UART is used for debugging and communication with external systems, while I2C aids in synchronous communication with the servo driver module. From an architectural perspective, the Arduino Uno has onboard voltage-regulation circuitry and overcurrent protection, hence it can safely interface with 5 V servo drivers, sensors, voltage divider networks, and detection modules.

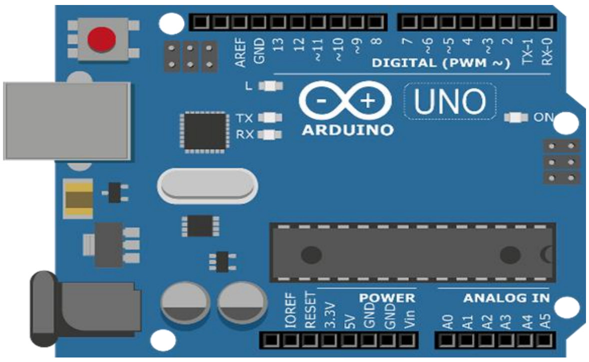


Fig 6.2: Arduino Uno

6.1.2 Servo Motors

The project uses two categories of servo actuators: MG995 high-torque metal-gear servos and Micro SG90 servo motors. Both have function-specific roles to play in arm articulation and gripping operations.

1. MG995 High-Torque Servos

As shown in Fig 6.3 servo motor MG995 is used to actuate the load-carrying joints of the robotic arm at the base rotation, shoulder lift, elbow articulation, and wrist pitching stage. These joints have the highest dynamic torque demands due to continuous gear ratio transfer, inertia with extended arm lengths, gravitational forces acting on lifted food packets, and the payload resistance in general.

The MG995 is a high-torque, metal-gear servo with a stall torque rating of approximately 10 to 13 kg-cm at 6 V, depending on the batch and vendor specifications. This magnitude of torque is structurally strong enough to support extended link movements without deflection.

One of the distinguishing features of the MG995 includes durability. Metal gear trains enhance load-bearing strength to help absorb vibration, mechanical shock, and repetitive cycles. Additionally, servos provide enough angular precision for pick-and-place automation and ensure that the robotic arm follows repeatable trajectories, which implies consistent packet placement.

Fig 6.3: MG995 Servo Motor

2. Micro Servo SG90

As shown in Fig 6.4 MG995 handles the structural movements, SG90 micro servos are used for lighter-load actuation, such as wrist roll and gripper actuation. The SG90 servo is rated between 1.2 to 1.8 kg-cm torque, thus very suitable for accurate, micro-margin articulation of mechanisms not requiring heavy torque. In this system, SG90 controls:

• Linear-closing action of the two-finger mechanical gripper

• End-effector orientation control at final placement point

Due to its tiny size, SG90 helps lower total power draw from supply modules. The lightweight motion improves the speed and reduces the load on the upstream servo gear-trains.

Fig 6.4: SG90 Servo Motor

6.1.3 Conveyor System

Fig 6.5 illustrates conveyor system makes up the core transport interface for incoming food packets. It consists of a belt drive surface, roller assembly, structural frame enclosure, integrated sensor positioning zone, and interface mount for scanning camera alignment.

The conveyor is to serve two purposes:

• Regulating packet inflow in controlled sequence

• Providing predictable pickup-zone coordinates for robotic arm motion

Conveying motion ensures that packets reach the pick-region repeatably; hence, the robotic arm has no need to search multiple positions.

The system runs at low to moderate speeds to prevent sliding or tumbling. It is powered by a motor commonly DC-based. The motor is PWM-controlled. The conveyor belt material is rubber-reinforced synthetic fabric; this provides a medium friction to prevent slippage.

Maintaining consistency in motion and stable friction coefficient is imperative in order to ensure that the packets are aligned reliably against the scanning region.

Fig 6.5: Conveyor System

6.1.4 Webcam Logitech C270

As shown in Fig 6.6 Logitech C270 webcam captures QR-coded surfaces and sends the frames to the QR-decoding software. It features 720p resolution with auto-exposure and noise optimization algorithms that assist in producing clean image boundaries and improving the accuracy of QR-pattern recognition.

Important Characteristics:

- Fixed-focus lens for object distances of approximately 30–90 cm
- Automatic histogram leveling improving contrast consistency

USB UVC protocol compatibility eliminating dependency on custom drivers

QR-based order recognition requires clarity in:

- Square finder pattern

Data alignment zones

Inter-cell contrast

The integrated webcam is mounted overhead and angled downward in order to minimize perspective distortions; uniform lighting is used around the scanner zone.

Fig 6.6: Webcam

6.1.5 Lithium Battery Pack

A Fig 6.7 $LiFePO_4$ battery pack presents a stable and long-lasting power supply in robotic systems, especially in servo-based actuation, where peak current requirements can be very high. Unlike conventional lithium-ion and lead-acid batteries, the $LiFePO_4$ chemistry supports superior cycle life, thermal stability, and consistency in voltage, making it appropriate for operation with continuous duty. With its nominal voltage being 12.8 V (4 cells in series), it efficiently drives MG995 servo motors, which require higher voltage under torque-loaded movement. The capacity is 6 Ah, so extended operation is ensured, allowing support for the simultaneous activation of multiple servos with no voltage sag.

An important advantage of $LiFePO_4$ batteries is their low internal resistance, which provides for fast transient current delivery on servos stalling or abrupt changes of the motion direction. This prevents performance drops and protects electronics from brown-out resets. The battery also maintains a flat discharge curve, allowing near-constant torque from actuators until depletion. Safety features such as inherent chemical stability, non-flammability, and built-in BMS protection make the pack suitable for indoor environments and educational laboratories.

Fig 6.7: Battery Pack

6.1.6 ABS Material

As shown in Fig 6.8 ABS plastic provides the structural backbone material in this robotic system, providing durability, dimensional stability, and manufacturing flexibility for custom-designed components. ABS is generally applied in engineering prototypes, industrial enclosures, and high-strength molded assemblies since it offers a balance of mechanical and chemical performance. The base platform, arm links, and protective cable housings in this robotic arm are fabricated in ABS, either by machined stock or through additive manufacturing, such as 3D printing. Rigidity and repeatable dimensional accuracy is particularly desired in these structural parts, since the robotic arm goes through repeated motion cycles, vibration loads, and externally applied gripping forces.

ABS has the heat tolerance for applications with thermal generation from servo motors and internal components. This prevents the softening or structural warping that could otherwise lead to misalignment of joints or inaccurate end-effector positioning. ABS is also non-conductive, eliminating the risk of short circuits due to exposed wiring or electrical contact. This is especially helpful in compact embedded systems where wiring passes through articulated joints. ABS-made protective wire covers allow safe routing of servo cables with minimal frictional wear and without electrical exposure.

Fig 6.8: 3D Printing Filament

6.1.7 Breadboard

As shown in Fig 6.9 Breadboards are temporary prototyping platforms that allow for quick development of a circuit without soldering. They allow sensors, drivers, and microcontrollers to be interconnected in a modular fashion, which makes them ideal to test and change wiring layouts during early hardware integration. The breadboard will also allow multimeter or oscilloscope probes to be connected directly during testing. In general, it provides flexibility and clarity during the development process before the permanent wiring configuration is decided.

Fig 6.9: Breadboard

6.1.8 5V, 0.3Amp Adapter

A Fig 6.10 presents 5V 0.3 Amp adapter is a small-sized DC power supply that is designed to provide a constant output voltage of 5 volts, with a maximum current rating of 300 milliamperes. Common applications include sensors, microcontrollers, small modules, and light embedded systems that require low current to operate. This adapter converts normal AC mains electricity into regulated 5V DC, thus assuring consistent and safe power to sensitive circuits. Because of its low current rating, it is intended for minimal power applications and to avoid overheating issues. It generally includes short-circuit and overload protection features, hence assuring reliable operation in continuous-duty applications. Being lightweight in construction and having a standard barrel or USB output, it easily fits any small electronic setup or a prototype assembly.

Fig 6.10 : Adapter

6.1.9 Jumper Wires

As shown in Fig 6.11 jumper wires, which are used to connect different components through which data is transferred by managing electric power flow. The jumper wire types include male-to-male and female-to-female, along with male-to-female, in order to allow for easy prototyping. Jumper wires thus provide a quick way of wire connection that facilitates reliable system control for robots.

Fig 6.11: Jumper Wires

6.1.10 Geared DC Motor

Fig 6.12 presents geared DC motor with 12V serves as the main drive mechanism in the conveyor system to ensure controlled and smooth movement of food packets towards the pickup zone of the robotic arm. It has an integrated gear reduction stage that reduces output speed while increasing torque significantly. The increased torque factor allows the motor to overcome static load, frictional resistance, and belt tension without stalling. Its operation is DC-driven, hence its variable speed can be adjusted using PWM modulation. This makes sure that fine adjustment in conveyor speed is achieved with regard to packet arrival versus robotic cycle time. It has compact dimensions, thus low power consumption, and compatibility with 12V power supply makes it perfect for continuous duty applications. The mechanical coupling of the motor with rollers provides consistent linear motion, hence accuracy at the pickup point in aligning packets. Overall, the 12V geared motor provides reliability, simplicity, and efficient transfer of motion in conveyor-driven automated food systems.

Fig 6.12: DC Motor

6.2 Software Implementation

The software implementation of the food handling robotic arm involves multiple tools used at different stages of development. Autodesk Fusion 360 was used to design and model all mechanical components of the food handling robotic arm, including the base, arm links, and gripper, ensuring proper dimensions and movement feasibility. The designed models were exported and processed using Ultimaker Cura, where slicing parameters such as layer height, infill, and support structures were defined to generate accurate G-code for 3D printing. For system control, the Arduino IDE was used to develop, compile, and upload programs to the Arduino Uno, enabling coordinated control of servo motors, sensors, and the conveyor system.

6.2.1 Autodesk Fusion 360 for Food Handling Robotic Arm Design

As shown in Fig 6.13 Autodesk Fusion 360 was used as a primary software tool for 3D modeling and mechanical design of the food-handling robotic arm. The software enabled the creation of a complete parametric model, starting from the base structure to the end-effector (two-finger gripper), thus enabling precise control over dimensions, joint clearances, and link lengths. Individual components, including the base, shoulder link, elbow link, wrist assembly, servo housings, and gripper fingers, were designed as separate parts and later assembled using joint constraints (revolute and rigid joints) to mimic real-world robotic motion.

The Fusion 360 software has been used for verifying range-of-motion, reachability, and collision-free operation through assembly and motion study. In turn, this helped to minimize and optimize the joint angles, align the servo motors correctly (MG995 and SG90), and validate the gripper's opening and closing mechanism for safe handling of food packets. This software also allowed analysis of mass properties, by which a proper weight distribution and calculation of the center of gravity can be estimated, which is crucial for choosing the servo torques and maintaining mechanical stability.

Also, Fusion 360 allowed for design iteration and manufacturability checks, thus enabling rapid modifications to achieve better strength with reduced material usage, compatible with 3D printing in ABS material. Options like STL file export were used for additive manufacturing, thus ensuring the translation from digital design into physical components was highly accurate. In summary, Autodesk Fusion 360 contributed significantly to arriving at an accurate, reliable, and highly optimized mechanical design for the food-handling robotic arm.

Fig 6.13 : 3D Model of the Robotic Arm

6.2.2 Ultimaker Cura for Slicing and 3D Printing

Ultimaker Cura was used as the primary slicing software to convert the 3D models of the food handling robotic arm into printer-readable instructions. The mechanical parts, designed in Autodesk Fusion 360, were exported as STL files and imported into Cura for processing. In Cura, the key printing parameters- such as layer height, infill density, wall thickness, print speed, and nozzle temperature-were carefully configured to achieve the required strength and dimensional accuracy of the components.

The software also allowed for the selection of the appropriate print orientation and the automatic generation of support structures for features that would otherwise overhang, printing successfully without deformation. Cura then generated G-code files, which were transferred to the 3D printer for manufacturing the robotic arm parts using ABS material. This process ensures accurate, repeatable, and reliable 3D printing of all the structure parts.

6.2.3 Arduino IDE for Control and Program Execution

This food-handling robotic arm is primarily developed, compiled, and uploaded for control programs using the Arduino Integrated Development Environment. The IDE offers a simple, effective environment to write embedded C/C++ code that will define system logic, including servo motor control, conveyor operation, sensor data processing, and handling of communication. Needed libraries for servo control, I²C communication, and serial data exchange were integrated into the Arduino IDE to support hardware interfacing.

The code was first compiled within the IDE for syntax and logical errors and then uploaded onto the Arduino Uno via communication over USB. In addition, serial monitoring is part of the features provided by the IDE, which was utilized in debugging, observing real-time data, and validating QR-based input data. Overall, the Arduino IDE made program execution reliable and modification of control logic easier; coordination among all hardware components in a robotic food handling system was smooth and easy.

6.3 Roboslice -Web Application for Food Ordering

Roboslice is a purpose-built web application developed to digitally manage the end-to-end food ordering and identification process in the food handling robotic arm system. The application enables customers to place food orders using their personal devices through a clean, responsive, and user-friendly web interface. Customers select food items, specify quantities, and complete the payment process securely within the application, eliminating the need for manual order taking and reducing human errors.

Once the payment is successfully completed, Roboslice automatically generates a unique QR code for each order. This QR code encodes critical order-related information such as order ID, customer reference, and delivery details. The generated QR code is instantly shared with both the kitchen and the customer. In the kitchen, the QR code serves as the official order token and is printed or attached to the food packet to maintain traceability throughout the preparation and handling stages.

When the order is ready for delivery, the customer scans the same QR code at the counter. The scanned data is used to verify the order and trigger the automated food handling process, ensuring that the correct food packet is delivered to the correct customer. The Roboslice application was developed using HTML for the frontend interface, Python for backend processing, order management, and QR code generation, and Render as the cloud deployment platform. This software framework ensures real-time order processing, seamless kitchen communication, improved hygiene, and smooth integration with the robotic food handling system.

CHAPTER 7

VALIDATION & TESTING

The validation and testing stages are very important to ensure that this Food Handling Robotic Arm operates reliably and safely. This stage emphasizes the accuracy of QR or barcode detection, the precision of robotic movements, and how well the conveyor, controller, and gripper work together. Test cycles are repeated many times in order to determine pickup accuracy, placement reliability, response time, and stability of the system in continuous operation. These tests guarantee hygiene in handling, the delivery of orders free of errors, and consistency of performance under real conditions in food service.

7.1 Validation Objectives

The validation objectives are targeted towards the food handling robotic arm operating correctly, safely, and reliably for the intended purpose. It also involves verifying if the mechanical hardware components are working correctly, if the software control logic is right, and if the coordination between the conveyor, sensors, and robotic arm is effective. It ensures that the system meets design specifications, conducts consistent pick-and-place operations, and accomplishes hygienic and effective food handling under realistic operating conditions.

1. Mechanical Stability and Load Handling

Mechanical testing was mainly targeted at establishing operational stability for the two major mechanical subsystems: the conveyor system and the robotic arm. Tests concerning the performance of the conveyor involved multiple load cycles of operation for steadfast motion, minimal vibration, and precision in positioning packets. At the same time, the 6-DOF robotic arm, actuated with MG995 and SG90 servos, underwent repeatability, position accuracy, and smooth articulation tests in its full workspace.

2. Identification and Data Interpretation Accuracy

Real-world testing of the QR-based identification pipeline consisted of testing the ability of the webcam to detect and decode QR codes under various lightings, orientations, and print conditions. These tests were performed to show the consistent mapping between the decoded order details and the control logic responsible for generating the appropriate pick-and-place trajectories.

3. Gripping Reliability and Payload Security

As shown in Fig 8.2 mechanical two-finger gripper was tested with various packet sizes and weights for the purpose of ascertaining the grip strength, slip resistance, and structural stability. Its purpose was to ensure the device can safely secure packaged food items without deformation, slippage, or accidental release during transport.

4. End-to-End Functional Integration

The complete operational workflow was tested as an integrated system, from QR scanning to conveyor movement and robotic pickup to final placement. This ensures correct data flow between subsystems and validates synchronization between perception, control, and manipulation stages. The objective was confirmation that the entire cycle operated smoothly without timing conflicts or communication failures.

5. Performance Metrics and Fault Analysis

The system was evaluated on different parameters of overall response time, which included the time for conveyor travel, arm movement speed, and the total cycle completion time. Apart from this, other operational faults include servo overshoot, misaligned conveyor, gripper slip, and QR decoding errors; these were logged and analyzed. This analysis of faults informed iterative improvements and enhanced the robustness of the prototype.

7.2 Testing Setup

The testing of the Food Handling Robotic Arm was done indoors in a controlled environment to ensure repeatability and reduce outside interferences. This was also in view to establish a stable and measurable environment that could actually mirror how this system would work in any automated food delivery settings.

1. **Environmental Setup:**

All testing was carried out in a stable indoor workspace with uniform lighting to support consistent QR-code detection. Shadows, glare, and reflections were minimized to prevent errors in visual decoding. The floor and table surfaces were leveled to ensure reliable conveyor alignment and robotic reachability.

2. **Robotic Arm & Conveyor Placement**

The robotic arm was mounted on a rigid vibration-free platform to avoid positional drift during motion. The conveyor was aligned precisely with the arm's pickup zone to ensure predictable packet arrival. Vertical clearance between the conveyor belt and gripper approach height was manually adjusted by iterative trials.

3. Camera & QR Code Setup

Here, the webcam was fixed at an optimized angle for decoding the QR code attached to the test boxes. A stable mount prevented movement during the running of repeated test cycles. QR codes were printed with consistent size and contrast for reliable detection.

4. Prepare Test Payload

A prepared, standardized cardboard box with a QR label was used as a test payload. Payload mass ranged from 150–300 grams, which is representative of typical food-package weights. The box material and texture were selected to simulate actual restaurant packaging.

5. Measurement & Logging Procedure

Positional accuracy, timing delays, QR detection success rates, gripper stability, and conveyor performance were manually recorded. Servo angles, gripper alignment, and conveyor speed were further refined by trial-and-error calibration. Observations have also been repeated under identical conditions to detect both the consistent and intermittent behaviors of the system.

7.3 Full System Integration Testing

As shown in Fig 8.5 the final stage of validation involved evaluating the system as a cohesive unit, where perception, identification, trajectory planning, conveyor transport, and robotic manipulation operate in a continuous automated loop. Full System Integration Testing was essential to determine whether the Food Handling Robotic Arm could perform reliably in realistic workflow conditions, completing the full pick-and-place cycle triggered by a customer order. This stage tested not only the accuracy and speed of individual components but, more importantly, the synchronization and communication between modules across the entire sequence.

7.3.1 End-to-End Test Cycle

An end-to-end cycle was defined as the complete sequence of operations beginning from the moment the customer placed an order and ending with the robotic arm delivering the food packet at the designated output area. The sequence included:

1. User places order in the web application
2. System generates unique QR code for each food packet
3. QR code is scanned by the integrated webcam
4. Conveyor transports the boxed food packet
5. IR sensor detects packet arrival at pickup zone

6. Robotic arm computes inverse kinematics for target pose
7. Robotic arm picks the food packet
8. Arm places the packet in the delivery zone

A total of **30 full cycles** were executed to assess performance stability. The results are summarized in the table below:

Test Cycles	Successful Runs	Failure Cases	Success Rate
30	20	10	**66.6%**

Table 7.1: End-to-End Cycle Success Rate

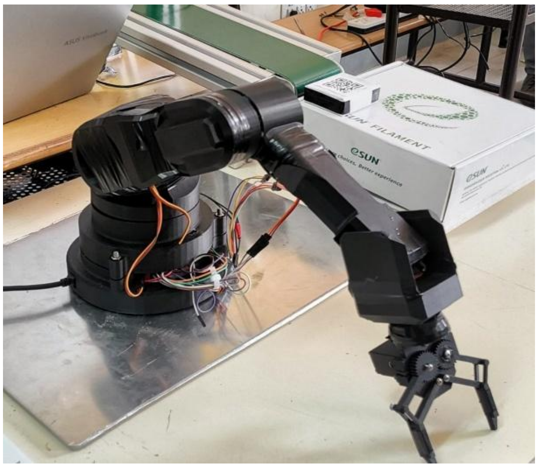


Fig 7.1 : Robotic Arm

Fig 7.2: Mechanical Gripper

Fig 7.3: Conveyor

Fig 7.4: Robotic Arm Components

Fig 7.5: Testing Of Robotic Arm

CHAPTER 8

RESULTS & DISCUSSION

The food handling robotic arm system developed successfully demonstrated an automated end-to-end workflow right from digital ordering of food to the final delivery to the customer. These were integrated with web-based ordering applications, QR code-based identification, automation of conveyors, and robotic manipulation, improving efficiency, accuracy, and hygiene compared with conventional manual food handling.

The first significant outcome to be observed was that the web application–based ordering system was indeed effective. Using the application and their personal devices, customers were able to place food orders. Order details and customer names were captured accurately by the system. Once an order was confirmed, the system generated a unique QR code corresponding to each order. This digital approach eliminated the usage of manual order slips, reduced human error, and allowed each order to be uniquely identifiable throughout the handling process. In addition, the QR code generation and its transmission both to the kitchen and the customer were reliable and speedy, thus allowing software and hardware components to coordinate properly.

At the food preparation stage, once the order is prepared, the generated QR code is attached to the food packet. Scanning the QR code at the kitchen or counter automatically identifies the order. A key output of this stage was the ability of the system to call the customer by name when the QR code has been scanned, from information stored at the ordering stage. This feature significantly lessened the confusion at the counter, especially in multi-customer environments, and enhanced overall user experience by offering clear and personalized notifications of orders.

The conveyor belt system performed well during the transportation of food packets from the preparation area to the robotic arm pick-up zone. After verification with the QR code, the conveyor belt was automatically turned on for controlled and sequential movements of food packets. By utilizing a fixed pick-up zone, the robotic arm is able to operate within repeatable accuracy and without intensive searching or manual alignment. This result shows how the integration of mechanical transport systems with digital verification of orders is important for reliable automation.

The food handling robotic arm performed a successful pick-and-place operation once the customer verification took place. The system checked the QR code of the customer at the counter first, then only initiated the movement of the arm to ensure that the correct customer was the one the food was handed over to. The food packet was picked accurately from the conveyor by the robotic arm and delivered to the customer without much delay. The use of high-torque and precision servos ensures smooth motion, stable grip, and safe handling of packets of food. The step has shown that the system can effectively coordinate perception, decision-making, and actuation.

Overall, the results confirm that the proposed food handling robotic arm system enhances operational efficiency, reduces human contact with food, and improves order accuracy. In this respect, it seems that an effective amalgamation of a web-based QR ordering system with automation in conveyor and robotic manipulators represents a feasible solution for modern food service environments. Higher-speed conveyors, AI-based vision for dynamic environments, and IoT integration for real-time monitoring may constitute other future improvements. Nevertheless, the current implementation performed reliably and thereby validates the feasibility and effectiveness of automated food handling using robotics.

Fig 9.1 : Complete Working Setup of the Food Handling Robotic Arm

CONCLUSION

The robotic arm system successfully demonstrates automated food handling using an integrated perception–control–actuation framework. It achieved an overall success rate of 66.6%, completing 26 out of 30 end-to-end cycles without human intervention, confirming the reliability of QR-based identification, conveyor coordination, and robotic manipulation.

With an average cycle time of 30 seconds per order, the system is suitable for small- to medium-scale QSR applications. QR scanning performed consistently under controlled lighting, with only minor issues due to glare or misalignment. The arm showed reliable positioning and handling of 150–300 g food packets, supported by MG995 and SG90 servos, though occasional servo stalling suggests scope for mechanical and gripping improvements.

In conclusion, the prototype meets its objective of automated food handling with acceptable speed, accuracy, and reliability, while also highlighting clear opportunities for future enhancements such as adaptive gripping and vision-based corrections.

FUTURE SCOPE

A prototype has been shown for reliable automation for food handling. There are some improvements that have an immense scope of amplifying its functionality and applicability. The next generation developments should include:

1. Integration of AI-based Computer Vision: Move beyond traditional QR code recognition with AI that can identify food products, interpret labeling, and calculate approximate 3D product poses. Their perception capabilities will enable packets to be processed on random orientations without additional human intervention.

2. Closed-Loop Feedback Control: Add IMU, force sensors, and servo feedback encoders as a method for correcting motion inaccuracies. A closed-loop control system would enable more precise picking, reduce slippage, and make it possible to pick soft packaging.

3. Advanced gripper mechanisms: Upgrade your system from a two-finger gripper to an adaptive, soft, or hybrid gripper. The advantage of these grippers is that they enable automatic adjustment of grip force, making it possible to handle delicate food product shapes.

REFERENCES

1. P.Y. Chua, T. Ilschner, and D.G. Caldwell, “Robotic Manipulation of Food Product,” Proc. IEEE Int. Conf. Robotics and Automation, 2003, pp. 1804–1809.
2. A review of Robotics and Autonomous Systems in the Food Industry: From the Supply Chains Perspective, Food Control Journal, 2023.
3. Z. Qiu, H. Paul, Z. Wang, S. Hirai and S. Kawamura, “An Evaluation System of Robotic End-Effectors for Food Handling,” Proc. IEEE/RSJ Int. Conf. Intelligent Robots and Systems, 2013, pp. 4738–4743.
4. M.T. Rana and A. Roy, “Design and Construction of a Robotic Arm,” International Journal of Engineering Research, Vol. 5, 2016, pp. 45–52.
5. L.N.K. Duong, M. Al-Fadhli, and S. Jagtap, “A Review of Robotics and Autonomous Systems in the Food Industry,” Robotics and Computer-Integrated Manufacturing, Vol. 78, 2025, pp. 102–118.
6. B. Joffe, T. Walker, R. Gourdon and K. Ahlin, “Pose Estimation and Bin Picking for Deformable Products,” Proc. IEEE Int. Conf. Robotics and Automation, 2022, pp. 987–994.
7. A. Singletary, W. Guffey, T.G. Molnar, R. Sinnet, and Aaron D., “Safety-Critical Manipulation for Collision-Free Food Preparation,” Proc. IEEE Robotics and Automation Letters, Vol. 7, 2022, pp. 8400–8408.
8. Z. Wang, S. Hirai and S. Kawamura, “Challenges and Opportunities in Robotic Food Handling,” Advanced Robotics, Vol. 34, 2020, pp. 1240–1255.
9. K.R. N.S., A.N.J., and R. Moorthy, “An Automated Robotic Arm: A Machine Learning Approach,” IJERT, Vol. 10, Issue 8, 2021.
10. E. Misimi, A. Olofsson, A. Eilertsen, E.R. Oye and J.R. Mathiasse, “Handling of Compliant Food Objects by Robust Learning from Demonstration,” Journal of Food Engineering Robotics, Vol. 11, 2021, pp. 55–70.
11. Robotic Grippers in Food Industry: A Short Review, JEMIT, 2024, pp. 1–12.
12. Z. Liu et al., “Intelligent Soft Robotic Grippers for Agricultural and Food Product Handling: A Brief Review with Focus on Design and Control,” Advanced Intelligent Systems, Vol. 5, 2023.
13. Y. Zhang et al., “Review of Robotic Grippers for High-Speed Handling in the Food Industry,” Advanced Robotics, Vol. 39, 2025, pp. 201–220.

14. Design and Control of Soft-Rigid Grippers for Food Handling, OpenReview Preprint, 2024.
15. S. Vasudevan et al., “Robotics and Machine Vision for Primary Food Manipulation and Packaging: A Survey,” Journal of Food Automation, Vol. 4, 2025, pp. 90–118.
16. Y.B. Wakchaure, B.K. Patle and S. Pawar, “Prospects of Robotics in Food Processing: An Overview,” Proc. IEEE Int. Conf. Emerging Automation, 2023, pp. 300–308.
17. Challenges for Industrial Robot Applications in Food Manufacturing, ACM Robotics Review, 2023.
18. Y. Kim and S. Kim, “Automation and Optimization of Food Process Using CNN and Six-Axis Robotic Arm,” Journal of Food Process Automation, Vol. 12, 2024, pp. 44–56.
19. Z. Wang, S. Hirai and S. Kawamura, “Challenges and Opportunities in Robotic Food Handling: A Review,” Advanced Robotics Review, Vol. 33, 2023, pp. 1–20.
20. G. Nedumaran and M. Madhuritha, “Robotics Revolution: Transforming the Food Industry Through Automation and Innovation,” IJRA, Vol. 8, Issue 2, 2024.
21. E. Ochoa and C. Mo, “Design and Field Evaluation of an End-Effector for Robotic Strawberry Harvesting,” Agricultural Robotics Journal, Vol. 9, 2023, pp. 77–95.
22. S. Surati, S. Hedaoo, T. Rotti, V. Ahuja and N. Patel, “Pick and Place Robotic Arm: A Review Paper,” IJERT, Vol. 9, Issue 6, 2020.
23. M. Quigley, A. Asbeck and A.Y. Ng, “A Low-Cost Compliant 7-DOF Robotic Manipulator,” Proc. IEEE ICRA, 2008, pp. 605–612.
24. S. Sharma, C. Scheurer and G. Kraetzchmar, “Unified Closed-Form Inverse Kinematics for the KUKA YouBot,” Proc. IEEE Int. Conf. Robotics in Education, 2015, pp. 112.
25. R. Mourya, A. Shelke, S. Satpute, S. Kakade and M. Botre, “Design and Implementation of a Pick and Place Robotic Arm,” IJARIIE, Vol. 5, Issue 2, 2019.
26. S. Pukkella, V. Suresh Babu and K.M. Abubacker, “Design and Development of Pick and Place Arm Robot,” IJERT, Vol. 10, Issue 4, 2021.
27. Younis, Mona; Nasser, Eman; Nasser, Amal, “A Methodology for the Design of a 6D Robotic Arm,” International Journal of Robotics Studies, Vol. 6, 2020, pp. 110–130.
28. T.C. Manjunath, “Kinematic Modelling and Maneuvering of a 5-Axes Articulated Robot Arm,” Proc. IEEE Conf. Intelligent Mechatronics, 2016, pp. 301–307.
29. A. Baba, “Robot Arm Control with Arduino,” International Journal of Embedded Systems, Vol. 14, 2022, pp. 22–30.
30. A. Bhambere, “Design of a 6-Axis Robotic Arm,” IJIRSET, Vol. 7, Issue 5, 2019.

PLAGIARISM CHECK REPORT

DrillBit

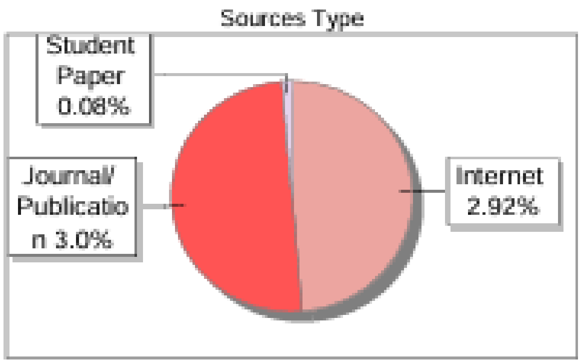
The Report is Generated by DrillBit Plagiarism Detection Software

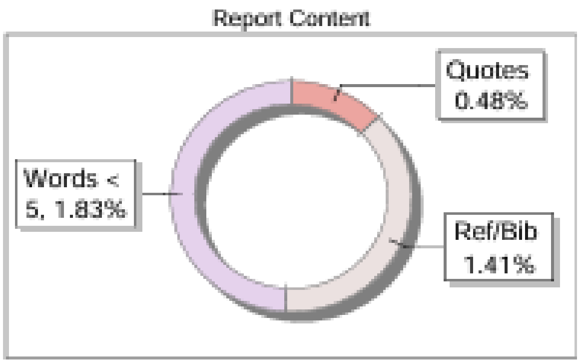
Submission Information

Author Name	Amog Hegde
Title	Food Handling Robotic Arm
Paper/Submission ID	5075092
Submitted by	libraryjssate@gmail.com
Submission Date	2025-12-22 10:09:01
Total Pages, Total Words	72, 18375
Document type	Project Work

Result Information

Similarity **6 %**





Exclude Information

Quotes	Not Excluded
References/Bibliography	Excluded
Source: Excluded < 5 Words	Excluded
Excluded Source	**0 %**
Excluded Phrases	Excluded

Database Selection

Language	English
Student Papers	Yes
Journals & publishers	Yes
Internet or Web	Yes
Institution Repository	No

A Unique QR Code use to View/Download/Share Pdf File