DE-42 (MTS) Abrar Siddiqui, Bassam Khan

Automated Bimanual Mixology System

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PROJECT REPORT

Automated Bimanual Mixology System (ABMS)

Submitted to the Department of Mechatronics Engineering
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Sponsoring DS:
Dr Hassan Elahi
Dr Tahir Habib Nawaz

Submitted By:
Abrar Siddiqui
Bassam Khan

CERTIFICATE OF APPROVAL

It is to certify that the project “Automated Bimanual Mixology System” was done by NS Abrar Siddiqui, PC Bassam Khan under the supervision of Dr. Hassan Elahi and Dr. Tahir Habib Nawaz. This project is submitted to Department of Mechatronics Engineering, College of Electrical and Mechanical Engineering (Peshawar Road Rawalpindi), National University of Sciences and Technology, Pakistan in partial fulfillment of requirements for the degree of Bachelor of Engineering in Mechatronics Engineering.

Students:

1. **Abrar Siddiqui**
   NUST ID: 336526
   Signature:______________
2. **Bassam Khan**
   NUST ID: 359575
   Signature:______________

Approved By:

Project Supervisor: **Dr. Hassan Elahi**

Signature: ______________

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1. **Abrar Siddiqui**

   NUST ID: 336526

   Signature:______________

2. **Bassam Khan**

   NUST ID: 359575

   Signature:______________

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ABSTRACT

The Automated Bimanual Mixology System (ABMS) is an innovative project in the hospitality industry that uses automation and robotics to fully replicate beverage service. ABMS is a mechatronics engineering final year project that redesigns the concept of drink preparation and service, employing the effective creation of a wide variety of drinks like shakes and coffee. SDGs for innovation and economic progress set in place the use of rigorously selected stepper motors for the system, which reduces errors and optimizes service processes. Specialized robotic arms, combined with an intuitive mobile application, mean that the ABMS sets a new benchmark for superior service and customer interaction. This project paves the way for future advancements in the field of hospitality, much like the Automated Bimanual Mixology System paved the way with a very similar machine learning model.

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Acronyms
ABMS Automated Bimanual Mixology System
SDG Sustainable Development Goals
RL Reinforcement Learning
ML Machine Learning

Chapter 1- INTRODUCTION

The Automated Bimanual Mixology System provides a method of drink preparation and serving. Each arm of the ABMS contains cutting-edge sensor technology, such as position sensors, providing accurate motion tracking without the requirement for encoders seen in previous systems. This unique feature enables dependable functioning in a variety of situations. In addition, the ABMS arms are manufactured using 3D printing with PLA material, demonstrating a cost-effective technique. Furthermore, the system uses machine learning technologies such as computer vision and reinforcement learning to improve its performance autonomously.

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1.1. Motivation and Significance

Bimanual tasks involve forced application, object manipulation, and tool usage, among others. As the demand for more efficiency and innovation in the hospitality business grows, the idea of the Automated Bimanual Mixology System was created In hospitality environments, customers are expecting faster and more precise service and ABMS serves to cater to this need.

The ABMS would address these difficulties by receiving an automated system capable of performing complicated tasks consistently throughout drink preparation. In most service industries, notably in the hotel industry, excessive staff turnover and a skilled labor shortage can influence service quality and raise training costs. With the automation of beverage preparation services, the ABMS might be a reliable solution for reducing reliance on skilled human laborers to provide uniform service, even during peak hours. Customers nowadays expect service to be delivered faster and with more precision once they have set foot in hospitality premises, and the ABMS aims to comply with that expectation by effectively delivering an extensive range of drinks, even complex cocktails, through the fast track prepared by this technology in mixology, hence reducing wait time and errors.

Automation of the hospitality industry results in immense operational efficiencies that offer the firm better resource management and economized cost savings.". The ABMS project sets new standards in automated systems and paves the way toward serious brace strides in the industry by application cutting-edge technologies such as robotics, machine learning, and computer vision. Besides, the global impact of ABMS is directly related to most of the United Nation's Sustainable Development Goals—that is, SDG 8, Decent Work and Economic Growth, and SDG 9, Industry, Innovation, and Infrastructure. ABMS supports industry innovation by developing and implementing state-of-the-art technologies that support sustainable employment practice and economic efficiency. The design is very modular, and the system can be scaled to fit different hospitality environments very easily; therefore, flexibility in solving a wide variety of applications.

1.2. Problem Statement and Existing Solutions

Quite a few serious obstacles are facing the hotel business in many respects, which impair quality service and operational efficiency, especially in the food and beverage service sectors. The problems include such maladies as a shortage of labour, high staff turnover, uneven quality of service, and the ever-increasing needs for promptly provided personalized service. These matters are further complicated by the application of human labor to apply accuracy and consistency to tasks such as mixing and preparing drinks.

Physical limitations in the performance of humans, inconsistency in skill levels, and human error thereafter result in inefficiency and unhappy customers. The existing propositions of the market have taken various steps toward the accommodation of these problems. The early methods are the coffee makers and cocktail mixers, which are mostly automatic but quite basic in function. Such appliances generally are task-specific and lack flexibility or finesse in performance that would allow them to be properly operated by sophisticated and diversified users. Besides, they often need much human intervention in their configuration, maintenance, and operation such that it is quite impossible for them to totally address the problem of labor.

The next approach is utilizing robotic bartenders and service robots, which automate some parts of drink preparation or delivery. Those are usually expensive and complicated solutions featuring poor integration, although they provide an impression of what automation might achieve in future. Many such technologies are not designed to integrate effectively with the other elements of the service environment, such as customer interfaces and order management systems. Furthermore, the existing robotic systems often lack advanced sensing and cognitive capabilities that are critical for high standards—especially in terms of accuracy and flexibility—of high-quality beverage preparation.

All of them are effectively overcome in the Automated Bimanual Mixology System for the simple reason that it has been designed as a level of integration that combines the very latest in computer vision, machine learning, and advanced robotics research. This way, human intervention is minimized as the system mixes an extensive variety of drinks quickly and accurately. ABMS redefines automated beverage service through deep interactive sensors, powerful learning algorithms for on-the-fly modification, and an intuitive mobile application. It does so by targeting core problems in existing solutions and pushing toward new boundaries of what is practical within the hospitality sector.

1.3. Novelty and Contribution:

The Automated Bimanual Mixology System (ABMS) employs advanced absolute position sensors BNO055. This makes it a system that does not require encoders for absolute position detection, which is commonly used in traditional systems, assuring precise arm motions. Such features enable the ABMS to be both adaptable and trustworthy in the workplace. Furthermore, the arms are fabricated by 3D printing and PLA material, ensuring complete adherence to current manufacturing methods for a lower-cost and more flexible design option.

The machine learning techniques employed include computer vision and reinforcement learning, which will be deployed in such a manner that they will continually improve their performance without human intervention, while the mobile application provides insights into the management of client interaction and orders. The ABMS is scalable and adaptable beyond traditional applications, ushering in a new level of efficiency and precision in service-oriented enterprises and pushing hospitality automation even further. In this regard, it should be noted that no such exorbitantly high-tech robotic system is now accessible in the market or installed in any area of Pakistan, making the project a pioneering initiative for the country's hospitality industry.

Chapter 2- LITERATURE REVIEW

2.1. Historical Context and Evolution of Robotic Systems in Hospitality:

Leonardo Da Vinci envisioned the first humanoid robot in 1495, and with the use of pneumatic or hydraulic systems, incredible mechanical devices were produced over time. Due to their limited processing power, these early devices were manually controlled and mostly employed punch cards for data entry. A huge advancement in technology was brought about with the introduction of electronic computers, such the Colossus. The first generation of robots, called manipulators, were developed to automate repetitive activities with numerically controlled (NC) machinery to increase industrial efficiency, especially in the American car sector. Robots of the second generation began to integrate sensors, a significant step towards increased autonomy. Shakey, the first mobile robot with sensors developed by Stanford Research, and the invention of the Programmable Logic Controller (PLC) for industrial automation were two noteworthy innovations. Important developments such as the T3 robot by C. Milacron and the 6-degree-of-freedom robot Famulus by KUKA highlighted the advancement of robotic capabilities. The industrial robot era began in the 1980s, characterized by substantial global investments that drove a significant increase in modern robot sales. These robots automated a variety of tasks, including painting and assembly, facilitated by advancements such as the internet, Ethernet, and Linux-based systems. The fourth generation saw the rise of intelligent robots equipped with digital computers capable of learning and reasoning, supported by platforms like Raspberry Pi ROS , and Gazebo . The current fifth generation focuses on collaborative and personal robots, enhancing human abilities and integrating advanced AI technologies. [1]

In the hotel business, robots are becoming more and more commonplace. They can be seen doing anything from cleaning and stocking shelves to offering individualized client services. In that way, cleaning robots are more efficient and cost-effective than human cleaners. As a result, their use has grown. Similarly, robots is being used in supermarkets and other locations to move things onto shelves. This is done at a rapid pace, resulting in a significant rise in workload. Robotics boosts efficiency and accuracy in a manner comparable to the growing automation trend in many industries. Robotic food service has also grown more popular. It helps businesses to save money and, with the aid of robots, make their menus more adaptable in order to appeal to a broader customer base.

2.2. Existing Automated Solutions in the Food and Beverage Industry:

To ensure increased production, quality, and competitiveness, the food and beverage industry has undergone a fundamental transition with the use of automation technology. System Logistics is a global leader in intralogistics, devoted to optimizing supply chains and industrial processes via the implementation of cutting-edge automated storage and picking systems. These technologies have also benefited the food and beverage industries by simplifying processes and decreasing manual labour. Precision farming, sometimes known as digital agriculture, is another key area undergoing change. This agricultural production approach, also known as precision farming, is essentially a strategy that controls the use of IoT to offer correct data management and analysis, hence increasing productivity and product quality in the agro-food business. Precision farming allows for more accurate crop monitoring and management, which improves resource use efficiency and hence increases yields [2].

Furthermore, smart creation, which combines several technologies such as big data, IoT, 3D printing, and simulation tools, serves as the foundation of Industry 4.0. With the help of the technologies, a company may virtually run the whole production process before to real start-up, which aids in problem detection and process efficiency. Logistic 4.0's introduction into the supply chain has revolutionized the issue of supply chain optimization since it is completely integrated with Industrial 4.0 technologies and methodologies. It improves traceability and visibility, resulting in enhanced performance and consumer satisfaction throughout food and beverage supply chains. In this way, automation experiments in the food and beverage sector demonstrate how Industry 4.0 technologies may have a significant influence on competitiveness, efficiency, and quality.

2.3. Technological Innovations and their Impacts

The introduction of advanced automation and robotics have brought in new efficiencies, an improved customer experience, and redefined service delivery standards. The large gamut of these technological advancements boils down to two things that are most discernible: the implementation of automation and robotics in the domain of hospitality and dual-armed robotic systems. The innovations do more than streamline operations: they open a whole fresh genre of possibilities by looking at ways in which services could be more personalized and operated with pinpoint accuracy, going even further toward the use of technology in an integrated fashion.

2.3.1. Automation and Robotics in Hospitality:

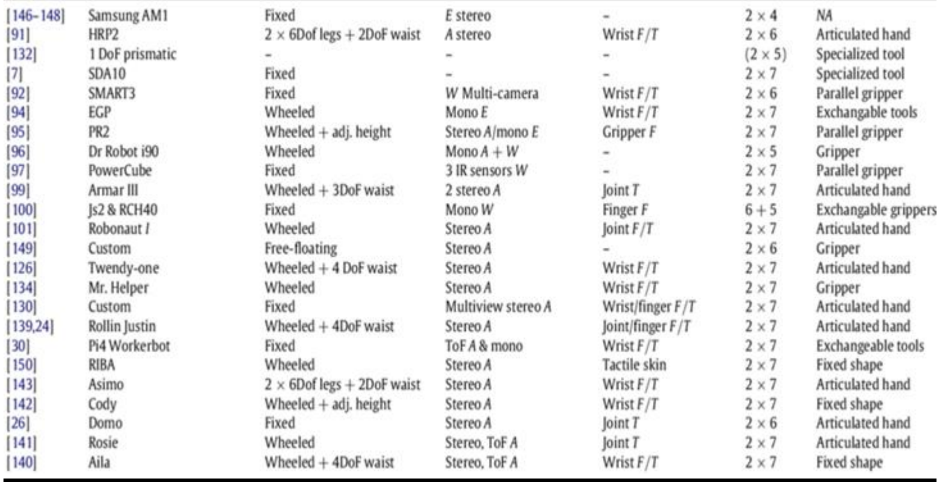
Automation and robots have changed the hotel business, making it better for the customer and with less human effort in the functioning. Hotels are using system-based autonomous interfaces or service robots, which the number has increased. By engaging, speaking, and delivering services to customers, these robots reduce the risk of disease transmission via human-to-human contact. Consequently, guests are now checking into hotels with robot employees. The service robot market for the hospitality and healthcare industries is projected to grow by 942 million USD the period from 2020 to 2024. Service robots in hotels are equipped with four different types of artificial intelligence. These are mechanical, analytical, intuitive, and emotional intelligence. Analytical intelligence derives logical decisions based on a cognitive style and structured learning from vast amounts of data, while mechanical intelligence is needed for well-defined tasks where learning is minimal. Robots that possess empathetic qualities to respond correctly to human emotions are said to have intuitive intelligence, and those who need complete information to provide services have intuitive intelligence.

The application of such advanced technologies changes the game in the entire workforce within that sector by positively altering consumer experiences and presenting effective tools for making decisions. Now, as travel reaches pre-pandemic levels, automation in the service facilities is increasingly a necessity. Robots could be made to perform labour-intensive jobs like maintenance, cleaning, and security so as to reduce pressures on human resources and therefore make sure that customers are served consistently in an optimum manner. Robots and artificial intelligence used in the context of hotels will customize operations in line with the changing customer expectations, streamline operations, and gain competitive advantage in a changing technology environment.

2.3.2. Dual Armed Robotic Systems:

Dual-arm robots are well-developed in robotics technology, with highly structured solutions that cover a variety of platforms and applications. Such systems can do more difficult and complex jobs as they mimic human coordination and dexterity. Thus, hardware platforms developed for this purpose gave rise to a new type of adaptive solution suitable for a wide variety of applications, from industrial mobilisation to human situations. As a result, robotic instruments built for industrial applications have concentrated on developing strong manipulation skills that offer both precision and speed in tasks such as material handling and assembly.

In contrast, tools developed within the context of the human-centric approach emphasize mobility and adaptability to allow robots to function and move in environments designed with humans in mind. Humanoid robots are designed in a manner just like humans in terms of appearance and structure. Examples of such robots include the CSA's Dextre and NASA's Robonaut [3]. Robots are interpreted to undertake tasks that conventionally had been done by humans. They make the best use of their human-like forms in an endeavour to enable the natural interaction with environments and tools designed by humans.



Reference	Robot	Base	Vision system	Force/torque sensing	DoF	End effector
[146–148]	Samsung AM1	Fixed	*E* stereo	–	2 × 4	*NA*
[91]	HRP2	2 × 6Dof legs + 2DoF waist	*A* stereo	Wrist *F*/*T*	2 × 6	Articulated hand
[132]	1 DoF prismatic	–	–	–	(2 × 5)	Specialized tool
[7]	SDA10	Fixed	–	–	2 × 7	Specialized tool
[92]	SMART3	Fixed	*W* Multi-camera	Wrist *F*/*T*	2 × 6	Parallel gripper
[94]	EGP	Wheeled	Mono *E*	Wrist *F*/*T*	2 × 7	Exchangable tools
[95]	PR2	Wheeled + adj. height	Stereo *A*/mono *E*	Gripper *F*	2 × 7	Parallel gripper
[96]	Dr Robot i90	Wheeled	Mono *A* + *W*	–	2 × 5	Gripper
[97]	PowerCube	Fixed	3 IR sensors *W*	–	2 × 7	Parallel gripper
[99]	Armar III	Wheeled + 3DoF waist	2 stereo *A*	Joint *T*	2 × 7	Articulated hand
[100]	Js2 & RCH40	Fixed	Mono *W*	Finger *F*	6 + 5	Exchangable grippers
[101]	Robonaut *I*	Wheeled	Stereo *A*	Joint *F*/*T*	2 × 7	Articulated hand
[149]	Custom	Free-floating	Stereo *A*	–	2 × 6	Gripper
[126]	Twendy-one	Wheeled + 4 DoF waist	Stereo *A*	Wrist *F*/*T*	2 × 7	Articulated hand
[134]	Mr. Helper	Wheeled	Stereo *A*	Wrist *F*/*T*	2 × 7	Gripper
[130]	Custom	Fixed	Multiview stereo *A*	Wrist/finger *F*/*T*	2 × 7	Articulated hand
[139,24]	Rollin Justin	Wheeled + 4DoF waist	Stereo *A*	Joint/finger *F*/*T*	2 × 7	Articulated hand
[30]	Pi4 Workerbot	Fixed	ToF *A* & mono	Wrist *F*/*T*	2 × 7	Exchangeable tools
[150]	RIBA	Wheeled	Stereo *A*	Tactile skin	2 × 7	Fixed shape
[143]	Asimo	2 × 6Dof legs + 2DoF waist	Stereo *A*	Wrist *F*/*T*	2 × 7	Articulated hand
[142]	Cody	Wheeled + adj. height	Stereo *A*	Wrist *F*/*T*	2 × 7	Fixed shape
[26]	Domo	Fixed	Stereo *A*	Joint *T*	2 × 6	Articulated hand
[141]	Rosie	Wheeled	Stereo, ToF *A*	Joint *T*	2 × 7	Articulated hand
[140]	Aila	Wheeled + 4DoF waist	Stereo, ToF *A*	Wrist *F*/*T*	2 × 7	Fixed shape

Figure 1: Characteristics of some Robotic Arms

Another interesting subclass demonstrates teleoperation robots, which are designed very similarly to an in-place human operator's workplace. They are formed to replicate the one single action and workspace of the operator; although they might not necessarily be biomimetic, they allow remote operations such that when it is not physically safe or possible for humans to appear. Taken together, two-arm robotic systems are expanding the envelope of the capabilities of robots and bringing tremendous benefits to both industrial and human-centered applications. With their high accuracy in performing complex, coordinated tasks, two-arm robotic systems cannot be substituted in increasing productivity and maximizing operational efficiency for several industries.

2.4. SDGs Alignment

In the context of our project Autonomous Bin Management System (ABMS), SDGS are be important in the sense that technological innovation does comply and contribute to broad social and environmental objectives. The ABMS project, which is being carried out using dual-armed robotic systems with advanced automation, conforms most importantly to SDG 8—Decent Work and Economic Growth—and SDG 9—Industry, Innovation, and Infrastructure. This aspect is of paramount importance, and we are therefore sending a strong message about our commitment to support sustainable economic development through the innovation of waste management solutions, creation of decent job opportunities in the technology-driven waste management sector, and improvement of resilient and advanced infrastructures for the processing of waste.

2.4.1. SDG 8: Decent Work and Economic Growth

SDG 8 emphasizes the significance of fostering full and productive employment, decent work for everyone, and sustained, inclusive, and sustainable economic growth. Our ABMS project strongly corresponds with this goal. Our initiative develops new employment prospects in waste management, robotics, and automation through the implementation of automated bin management systems, hence promoting workforce skill and capacity growth. Through efficient waste management procedures and increased output, our approach guarantees fair distribution of advantages and fosters social integration in areas impacted by waste management issues, all of which support economic expansion, competitiveness, and inclusiveness.

2.4.2. SDG 9: Industry, Innovation, and Infrastructure

In addition, our ABMS aligns with SDG 9, dedicated to fostering inclusive and sustainable industrial development, innovation building, and infrastructural resilience. Our project offers automated bin management solutions in support of further industrial automation and technical innovation development in the waste management space. Our project will therefore focus on advances in developing and utilizing smart robotic solutions as a foundation for integration and implementation of advanced technologies toward improvements in operational efficiency and waste management procedures, with all this aimed at providing resources more frugally, encouraging industrial practices that are more sustainable, and making infrastructures "more" resilient through automation and robotics. In addition, our initiative engages technology suppliers, governments, and industry players in collaboration to enforce that innovation.

2.5. Sensors and Actuators in Robotic Systems:

Sensors and actuators are two important constituents of robotic systems, providing sensory organs and physical effectors to contact the environment in job execution. Sensors and actuators play important roles in realizing environmental data acquisition, information processing, and command-to-action conversion. Robotics realized with such devices can come to realize their environments and make real decisions derived from such information, so that they may rightly move. This makes robotic systems applicable and work efficiently in a huge number of environments and areas.

2.5.1. Overview of NEMA Motors

Stepper motors are hence crucial components—which are present in applications constituting consumer goods and industrial uses such as NEMA 23. Electric motors, particularly the stepper type, have a distinct capability in that they can rotate their rotation shaft by a clearly defined fixed-step angle rather than smooth motion, as performed by conventional electric motors. The arrangement in the motor's internal structure permits it to influence the turning shaft in such a manner, making well-defined practice in controlling the angle of rotation. This means, there are stepper motors that consist of a rotating part like rotor and another stationary member like stator. The iron core of the rotor is an example of a variable reluctance while the permanent magnet is another example in which the stator has teeth with coils wound on them. The rotor aligns itself to the magnetic field created when certain phases of the stator coils are on. This characteristic makes it possible to precisely position the desired angular position by sequentially energizing several phases, which allows an exact rotor rotation at the right moment. Stepper motors have always been rated as perfect in automation systems, robotics, CNC machines, and 3D printers that require accurate movement with appropriate position control because of their very natural features. In fact, the high torque and precision in regulating it gives rank NEMA 23 stepper motors at a good value for money in the field of robotics.

This allows for accurate and consistent movement control in various robotic applications, such as robotic grippers, arms, and autonomous cars. The NEMA 23 motors find much utilization in CNC machines due to precision and repeatability; consequently, pushing the machine axes to cut, mill, or engrave exactness is possible. These NEMA 23 motors deliver full control of print head and printer bed motion in such a manner that assurance is made to the quality of the final output by the proper alignment of parts. Their versatility, for example, in design, has made them easy to incorporate into many arrays. [2]

2.5.2. Absolute Position Sensor (BNO-055)

Absolute position sensors for robotics require precise orientation and motion tracking. There are many methods of sensor fusion, and the achievement of precise 3D space orientation from the raw accelerometer, gyroscope, and magnetometer data is always something a bit difficult. But Bosch revolutionized this industry by creating high-speed ARM Cortex-M0 CPUs that combine magnetometers, gyroscopes, and MEMS accelerometers in one chip. Real-time sensor fusion is made possible, avoiding the tedium of processing data while providing consistent three-axis orientation output across a variety of different forms comprising vectors, Euler angles, and quaternions.

BNO055 outputs a broad array of sensor data: absolute orientation, angular velocity, acceleration, magnetic field strength, linear acceleration, gravity, and temperature. These sensors allow the provision of the key information needed for a robotic application, enabling it to implement its motion control, navigation, and environmental sensing with precision. That makes it ideal for applications in augmented and virtual realities, robotics, and the Internet of Things with its integration, dynamic calibration, and intelligent power management function for effective motion tracking and activity categorization.

2.6. 3D Printing in Robotic Arm Fabrication:

Robotics have been revolutionized with the invention of 3D printing technology, which led to the creation of manufacturing processes. Normally, in the robotics domain, the usage of 3D printing technology in producing robotic arms is what is termed as core to the manufacturing process since it assures cost-effectiveness and flexibility in fabricating custom robotic arms from scratch and all through the production processes. Support projects, when in need, can be attained using additive manufacturing techniques for developing highly accurate and swiftly prototyped parts for robotic arms. The implementation of 3D printing technology in an innovative project that develops advanced robotic systems, especially for complex robotic arm assemblies, could be adapted to our own needs. All this falls under the general note on 3D printing in robotics arm production. This paper presents the key findings for improving design and manufacturing processes in relation to performance and effectiveness.

2.6.1 PLA Material Properties and Applications

Polylactic acid or PLA has quite a few qualities that make it an adaptable material to a range of uses. First, because of its special chemical structure—arising from lactic acid molecules in plants—it may biodegrade under certain circumstances and hence will be a sustainable option. Incredibly, PLA is very strong and durable; however, it is not as strong as the other petroleum-based polymers and can easily break under stress loads. Also, since PLA is nontoxic, it also is judged to be safe for human contact and hence finds wide use in food packaging and even medical applications. Applications-wise, PLA is used in a wide range of sectors.

It is preferred for bottles, films, containers, and cups because to its moisture resistance, safety, and clarity in packaging. Furthermore, the breathability, comfort, and moisture-wicking qualities of PLA fibers are used in textiles to improve the quality of nonwoven fabrics, carpets, and apparel. The biocompatibility of PLA is particularly advantageous to the medical industry, which uses it in tissue engineering, medication delivery systems, implants, and sutures. But one of PLA's most well-known uses is probably additive manufacturing, namely 3D printing, where its thermal, mechanical, physical, and structural qualities make it ideal for producing complex, customized parts [3]. Despite its many benefits, it's important to remember that PLA needs certain composting conditions to biodegrade. Additionally, PLA may be customized throughout the polymerization process to fulfil specific requirements, demonstrating its adaptability and versatility across a range of sectors.

2.6.2. Advantages of 3D Printed Components

There are enormous benefits of 3D printing components, spreading across a wide number of applications and sectors. They revolutionize traditional manufacturing in quite a lot of ways. For a start, fast prototyping will be enabled by the additive processes involved in 3D printing. Therefore, one will be able to prototype and iterate quickly, and therefore, one can develop a product cheaply. Within this shortened design cycle, businesses in fiercely competitive industries can always remain at the forefront through innovation and experimentation. Furthermore, extraordinary creative flexibility is offered by 3D printing, making it possible to realize complex structures with intricate geometries that just could not be made using conventional manufacturing. This design flexibility opens the doors to other means of product optimization, lightweighting, and customization for further enhancement in functionality and performance. Tremendous benefits in 3D printed components accrue and cover a wide application and sector domain.

They redefine traditional manufacturing processes in several ways: fast prototyping, achievable through additive manufacturing or 3D printing, making it possible to fabricate prototypes and important iterations of any feature of the product quickly and cheaply into any given geometry. This shortened design cycle speeds the time to market and allows business to maintain a competitive advantage in high-velocity industries by driving innovation and experimentation. In addition, the amazing creative flexibility that 3D printing offers allows for the creation of complex structures and intricate geometries that become problematic, or even impossible, to produce using regular production processing. This design flexibility enhances product optimization, light weighting, and customization, which all increase functionality, better performance, and better service life.

2.7. Machine Learning and Computer Vision in Robotics

To advance robotics and improve its capabilities, autonomy, and flexibility in a variety of activities and settings, machine learning and computer vision are essential. Furthermore, computer vision techniques allow robots to see and comprehend their environment, which makes tasks like tracking, object identification, and recognition easier. We will now look at those techniques in detail below:

2.7.1. Reinforcement Learning for Robotic Control

Robotic manipulation tasks have experienced a great advance in the use of reinforcement learning from very classic methods to learn policies with imitation learning, to more modern ways of using neural networks to learn policies from scratch. Deep reinforcement learning marked a big jump because it combined good perceptual representations with control rules that are both effective and learnable. The theoretical side of reinforcement learning is closely related to insights in neuropsychology and cognitive science about animal behaviours and decisions, which emphasize the relevance of RL to dynamic robotic systems. Current robotics makes reliability in learning more important as non-linear function approximators like neural networks become more prevalent. The underlying key concepts important for understanding how robotic control involves reinforcement learning are Markov decision processes (MDPs). Both function approximation and policy search are two components that show how to address high-dimensional control problems quite important for robotics. The discrete and continuous action space algorithms are explained wherein the DRL algorithms handle action spaces and policy representations.

Robotics grasping problems typically operate in continuous action spaces, and therefore bear a unique set of challenges for which these algorithms are specifically designed to overcome. Another division is by the categories in which the two types come under:

stochastic and deterministic forms. For DRL techniques such as this one, it is hard to have a realistic implementation in terms of physical real-world robots or simulation. Therefore, a time- and sample-efficient solution for problems involving continuous state and action spaces is highly desired. [4]

2.7.2. Q-Learning for Robotic Control

Q-learning is a favored learning technique in the space of machine learning in relation to reinforcement learning, which allows models to in turn learn and improve iteratively over time. The main idea behind this method being—deeds are praised, misdeeds are discouraged. Unlike some other reinforcement learning techniques, Q-learning takes a model-free approach and therefore ditches the need for a model of the environment that is explicit. With that feature included, the AI component or agent will be capable of inferring learning by itself concerning its surroundings. Besides this, Q-learning is off-policy; it makes the best move in a current state rather than following a fixed policy. This use of Q-learning for robotics certainly takes the robotic control to more dimensions toward their applications. Traditional Q-learning algorithms based on discretization often have problems dealing with continuous variables, such as position or speed. This discretization undermines smooth control and underuses sensory data. Currently, the latest research projects under way are in the development of non-discretization-based algorithms for managing continuous state and action variables. Examples of such systems include active head gaze control and vision-based mobile robot control. These demonstrate flexibility both in the meeting of real-time constraints and in compensating for sensor and actuation delays. Moreover, the fact that Q-learning can learn passively by observing forms is very important help for speeding the trials in learning robotics, which reduces the time of experimentation and increases the speed at which this area advances. Q-learning applied in robots comes with some complications and challenges, especially within the same convergence of learning algorithms.

The continuous state case is of course approximate, and consequently loses the guarantees of convergence that come from a perfect representation of the value function in cases where both states and actions are discrete. Therefore, convergence gets quite challenging, and the need for function approximation grows. Simulation test results show just how tough the Q-learning algorithms are squeezed to converge. Nevertheless, even by these algorithms, sometimes an effective policy is introduced. It is shown by statistical investigations that careful tuning of the design parameters of the algorithm does diminish these difficulties. These modifications lead to better convergence or improvement of some intrinsic shortcomings, among which is the "rising Q problem," meaning that the current algorithm is setting-sensitive, and solving this needs a lot of optimization sophistication.[5]

2.7.3. Computer Vision for Position Detection

A wide range of sophisticated approaches and procedures are used in computer vision for position detection to accurately identify and track objects in pictures or video frames. Among the popular methods in this field is object tracking, which is a basic job that entails first identifying objects in a scene and then giving each item a unique identifier so that the objects may be tracked continuously as they move between frames in a video stream.

Using complex algorithms, many of which have their roots in deep learning frameworks, object tracking systems can reliably and accurately analyse object trajectories.

These techniques enable a wide range of applications in surveillance, autonomous navigation, human-computer interaction, and beyond by combining feature extraction, motion estimation, and predictive modelling to smoothly track objects' motions across time. There are many factors to be considered when implementing an object tracking system, including the type of input video, the complexity of the scene, and the level of precision required. For example, if high-prompted or responsive powers for real-time processing are required, then such features will have to be accommodated to effect object tracking presented in either prerecorded video or live video feeds. This would include the use of an object tracking algorithm to perform the tasks of frame filtration, object-of-interest localization, and updating object position, all in quasi-real time.

In general, these tasks encapsulate parallel procedures of processing with frame-skipping strategies and designed data structures to optimally cut down computational overhead, which will ensure an efficient seamless operation in resource-scarce environments. Background distracters in crowded scenes, or backdrops expected to change frequently due to occlusion, are hence likely to result in noise and interference, thereby providing a hurdle for these location detection systems in efforts towards effectiveness and efficiency. Similarly, size-based, scale-based, and aspect ratio-based variations of objects make a monumental task for any system that works on a dynamic environment where objects can be found at any distance or from any orientation.

2.7.4. Color Marking Techniques

Color-based marking techniques find wide applications in computer vision for tasks like object detection, indexing, and location. Techniques of color indexing are very strong in creating indexes of multi-colored objects through histograms of colors in them and have been used for efficient indexing of large databases of models. The approach of color indexing has shown robustness, appropriateness, and efficiency for the applications of quick retrieval and recognition of items. On the same note, histogram intersection algorithms have been developed for matching model and image histograms, through which correct detection of objects is accomplished without actual object segmentation. On the other side, histogram back-projection methods use color distributions for the rapid localization of cluttered scenes with known objects to offer useful information in terms of object localization in complex environments. Therefore, color histograms are a reliable representation for content-based retrieval, especially in situations where there is occlusion or a shift in perspective. The Histogram Intersection approach enriches its power of identifying more since it allows good matching of the histograms in the model and the picture—a fact that is more useful in those cases where a correct object segmentation might not be detected.

In robotic vision systems, color can be one important indexing feature used because it enables one to interact decently with different things i.e. being perceptive of them. Although colour has been historically neglected in favour of geometric algorithms, it has emerged as a fundamental indication for object identity, highlighting its relevance in enabling efficient and intuitive robot perception in some settings. Issues like colour constancy, ensuring stable colour perception even with changing lighting conditions, go to suggest that there are challenges that call for very sophisticated algorithms, still expected to work well in diverse environments.[7]

2.8. Mobile Applications for Order Management

Mobile order management solutions are an important part of current corporate operations since they allow for seamless coordination and efficiency in order processing. The following content elaborates in detail the background of such systems which serve to provide smooth interaction and data sharing between mobile devices and robotic platforms.

2.8.1. Integration with Robotic Systems

However, one of the most important integrations in mobile order management is with robotic systems, which mainly rely on accuracy and automation provided by robotic technology, coupled with the functionalities of mobile applications. It will enable businesses to cut down on human error, operate with efficiency, and optimize the process of order fulfilment. Providing communication channels between robotic systems and mobile order management applications with the use of API is a major consideration in this respect. With the availability of these APIs, mobile order management applications can thus be able to send work assignments, order information, and status updates in real time, exchanging the performance metrics and feedback. This could also be part of the integration effort that includes the creation of unique software interfaces and middleware layers which can tie together the robotic control systems and the mobile order management app. These interfaces abstract the complexities of hardware control and sensor data processing, which put mobile apps in communication with robotic actuators, sensors, and decision-making algorithms. Besides that, the integration process could also apply sensor fusion techniques, where it allows the robot to make use of information from sources such as GPS modules, LiDAR sensors, and on-board cameras to better its situational awareness with respect to navigational skills.

2.8.2. Connectivity and Communication Protocols

Strong communication protocols and connectivity are required for mobile application level of order management integrated with robotic systems to ensure effective information exchange and control. Common Industrial Protocol (CIP) offers a very general way to coordinate the services of control, communication, and routing between the Ethernet networks and the Internet. It represents a particular protocol family, of which the CIP is part. It is designed for specific layers of the communication stack with respect to the network and data link layers, and also the physical connection. This modular strategy guarantees scalability and interoperability while enabling flexible deployment across a range of industrial applications. Ethernet/IP, one of the protocols under the CIP umbrella, is a well-known solution that makes use of Ethernet physical layer technology with ordinary TCP/IP. EtherNet/IP enables high-speed communication by making use of already-existing network infrastructure. Transmission speeds can increase from 10 Mbps to 1 Gbps or more. Its adaptability is further enhanced by its compatibility with TCP and UDP ports (44818 and 22222), which allow for smooth interaction with business networks and remote-control capabilities. [8]

When it comes to networked appliances, all systems consist of three basic hardware parts: the manipulator, which is usually a robotic one; an embedded microprocessor, which can be part of the manipulator itself or act as an independent interface to link the object to a computer or network; and the operator, which is usually a PC acting as a client on the network. These parts are interconnected, which makes it easier to manage and communicate with the robotic system. Using a server, several robotic manipulators may be controlled simultaneously. Commands can be sent by parallel or serial interfaces. For more basic robots, a dedicated process or thread understands and carries out orders; for autonomous robots, the server orchestrates commands directly. Although it could be explored for future implementations, remote code changes for onboard embedded devices or processes that interface with them is not yet accessible. This means that server restarts after updates will need a temporary cessation of connection. Robotic systems' control architecture and connection are governed by several methodologies. One method is to use an embedded system to link the robot to a computer so that it may function independently if the computer connection is lost. On the other hand, a single computer may manage several parts, each of which has its own embedded system, allowing parts to communicate with one another even when there is no computer connection. This approach increases complexity and expense by requiring each embedded system to implement network protocols. Using current connections or custom networks, a single embedded system may manage several appliances in another method. Robot manipulators are implemented with great care, considering important aspects like autonomous recharging capabilities, low-latency multimedia feedback, collision avoidance systems, and real-time control. The result is a comprehensive system that includes multimedia transmitters, control servers, client-side interfaces, and built-in robot controllers.

Chapter 3- METHODOLOGY

The ABMS project integrates a dual-armed robotic system aimed at the automation of beverage preparation and service. It would be nice to integrate an adequate actuation system, sensors, and control mechanism to implement a robust mechanical framework for any robotic system. Each one of these integral elements will necessarily be required to contribute to the project goals.

The first stage includes the design and development of the mechanical structure, which includes conceptualization and subsequent drafting of the full-fledged CAD model. Surveying of the materials involved and structurally analyzing the construction would be done in this stage, followed by making and constructing the structure. The robotic arms are made from PLA material, 3D printed for precision and durability, as is the specially constructed cart. High-precision servo motors are used to move robotic arms. The motor drivers regulate the current and pulses needed for these motors to move precisely. The actuating system makes sure the robotic arms can accurately and dependably carry out the required functions of gripping, shaking, and dispensing beverages.

The ABMS relies heavily on sensors to provide vital data for precise functioning. While current sensors keep an eye on the load and offer input for servo control, absolute position sensors—like the BNO055—are utilized to track the location of the robotic arms. For the robotic arms to track and move precisely, they need to deliver correct data, which is why the sensors are calibrated meticulously. The functioning of the system may be continuously monitored thanks to the introduction of additional sensors for data collection.

The entire mechanism is coded to be controlled by the microcontroller, ESP32. To guarantee that the robotic arms are positioned precisely, it interprets the data from the sensors and adjusts the motors accordingly.

3.1. Mechanical Structure

The physical mechanical structure of the proposed Automated Bimanual Mixology System is an important part that allows for the physical realization of our dual-armed robotic system. The robotic arm should be physically stable, accurate, and long-lasting in its structure to have the grasping, shaking, and liquor-pouring-type operations performed. Although this on-line founding design of the robotic hand is old, since it has been slightly modified and updated again according to unique requirements. Importantly, some of the major stages in the development of this mechanical structure are CAD design, choice of materials, manufacture, and assembly of parts, the process of troubleshooting, and some changes last minute.

3.1.1. CAD Design

The CAD design is intended to expose the detailed modeling and simulation efforts that were made in coming up with major features of the Automated Bimanual Mixology System (ABMS). In the following section development of accurate CAD models for the auger mechanism, robotic arm, and cart system are illustrated in relation to the final function and performance of the ABMS. SolidWorks was used for item design to the point of maximum performance, manufacturability, and assembly simplicity. The auger model was focused on effective material handling, while the robotic arm model pertained to both precision and range of motion, followed by the final cart system model based in stability and mobility, all together making the core base hardware capabilities for appropriate ABMS operation.

A. Augur: The solid dispensing auger system was designed and fabricated in-house using CAD software by us. Dual mounting plates were placed in the final layout to avail flexibility regarding actuation—an option to use either a servo or stepper motor according to appropriateness with the demands of the application in respect to considerations on torque, control over speed, and other pertinent criteria.

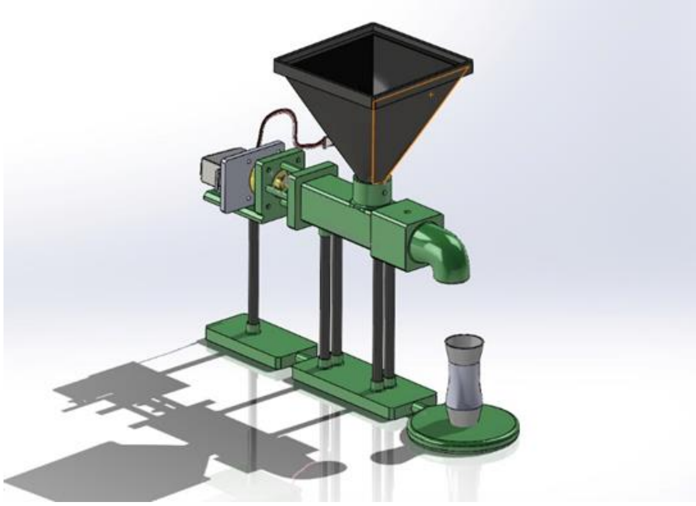


Figure 2: Augur CAD Model

The figure is an assembly drawing, in the CAD software, of the manufactured auger system. You can observe:

Auger Flight: The central helical part that directly moves the material. The thread design—the sum of all variables, pattern, and diameter—is arranged to make the material easily move down the conveyor.

Shaft: The shaft rotates the motor power to the flights of the auger. The diameter and material selection are made in a manner to emphasize strength without failing in ensuring flawless rotation.

Dual Mounting Plates: Two strategically located plates allowing secure points for attachment of either a servo or stepper motor. The design allows change across application needs and customization to be done easily and very quickly.

Motor (place holder): This model contains a place holder for where generally a motor is going to be attached. The actual model of the motor will be subject to the selection of general specifications of torque, speed requirements, etc. The

motor can be either a stepper or a servo.
B. Robotic Arm: This arm features three primary joints, each driven by robust stepper motors: a NEMA 23 motor at the base, which provides significant vertical load support up to 15 kg, and two NEMA 17 motors, one geared in the middle section and another at the end effector. The arm's base is mounted on a sturdy platform to ensure stability during operation. The robotic arm, a core component of the ABMS, was meticulously designed and modelled using SolidWorks as well.

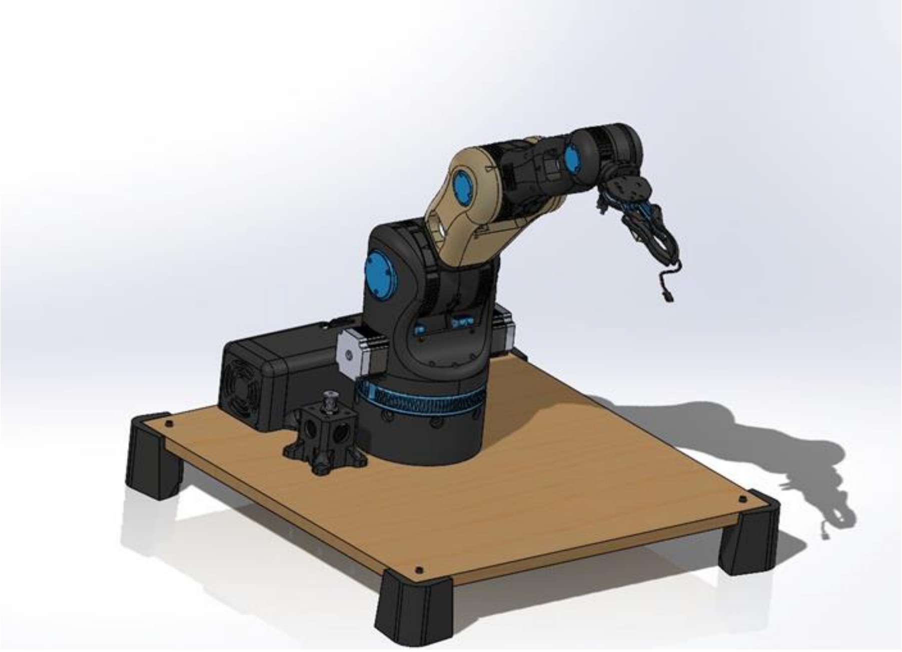


Figure 3: CAD Model of the Robotic Arm

The figure depicts a detailed CAD model of the robotic arm, showcasing its key components and their assembly. Here's a breakdown of the visible elements:

Base: The rectangular base plate provides a stable foundation for the robotic arm. It likely houses essential components like motors, gearboxes, and control systems (not shown in the CAD model).

Arm Linkages: Three primary linkages, connected by joints, form the main structure of the arm. The first linkage extends vertically from the base. The second linkage connects to the first at a right angle, creating a horizontal section. The third linkage attaches to the second at another right angle, extending the arm outwards. The lengths and materials of these linkages are crucial for ensuring structural strength, range of motion, and weight optimization.

Joints: Revolute joints, indicated by cylindrical shapes, connect the arm linkages. These joints allow for controlled rotation along specific axes, enabling the arm to maneuver through its range of motion. The design of these joints considers factors like friction, backlash, and the ability to handle the anticipated loads.

Servo Motors: Three servo motors (orange rectangular boxes) are visible in the model. One motor is mounted on the base, likely responsible for controlling the vertical movement of the first linkage. The other two motors are located at the joints between the linkages, responsible for controlling the rotational movement of the arm's second and third segments.

End Effector: The end effector (not shown in the image you provided) attaches to the final arm segment and is designed for specific tasks such as grasping or manipulating objects. The CAD model might depict a generic end effector or one customized for your application.

C. Cart:

The CAD model presents a multifunctional mobile cart with state-of-the-art robotic arms aimed at performing several application-specific operations. The cart is built with big wheels and strong construction to make it easy when maneuver and stabilize it, so this kind of setting finds its application indoors and outdoors, in settings for different purposes where portability and adaptability are required.

The cart accommodates two robotic arms mounted on the base platform individually. The auger mechanism is built into the left side of the cart, including its motor system. There is plenty of interior room in the central platform area to include various modules, control units, and required power supplies to package all these components in a well-organized set within the confines of the cart's structure. The cart is a multipurpose operational condition choice because the side panels and the roof work to protect environmental conditions on the delicate contents, including robotic arms.

Figure 4: CAD Model of Cart

Base Frame: This refers to the bottommost part of the cart that is fitted with a very strong metal frame like aluminum or steel, which offers support in terms of structure to all the other components.

Drive Wheels: The forward motion and driving of the vehicle are respectively propounded by two large drive wheels situated in the rear of a cart.
Small Caster Wheel: Found right at the front of the cart, it ensures the cart is steady and easily controlled in direction.

Caster Wheel Mount: This part is mounted on the caster wheel and it allows the caster to swivel and therefore get well-directed when under movement.

Battery Compartment: In the main frame, this is the compartment that houses the battery pack, which powers the motors and control systems for the cart (the one on the CAD model is not shown.).

Motor Controllers: This is located on top of the base frame. These are enclosures that house electronic devices controlling power distributed to drive motors, thence controlling speed and direction.

Lidar Sensor (optional): At the front part of the trolley, mounted on top of a pole, is a LiDAR, which stands for Light Detection and Ranging. The device projects laser light pulses that help create mapping around the surroundings to guide the robot in navigation and obstacle avoidance.

3.1.2. Material Selection:

Material selection should thus be done carefully to ensure performance, reliability, and cost-effectiveness in the system. Because of its flexibility and ease of use, polylactic acid (PLA) is the preferred material for both ABMS functional components and prototyping. Since it is cheap, very easy to print at low temperatures, and good at adhering to non-heated print beds, PLA has been a very good material for making preliminary development and fast prototyping. Additionally, the organic characteristics associated with stiffening, light weight, and drill-ability of PLA equated nearly perfectly to the specifications needed on behalf of ABMS, with little worry about structural integrity, and very easy installation. In many of these areas, where ABMS called for a higher quality than typical PLA can offer, PLA Plus (PLA+) was developed to enhance these features and correct for what could be potential shortcomings of typical PLA.

PLA+—a modified version of PLA—was used in parts under high mechanical loads and assemblies because it has high tensile strength, ductility, and an improved ability to flex. In addition, PLA+ shows better resistance to elevated temperatures compared to regular PLA, which supports the usability of these products for operations in elevated temperature conditions. Incorporating PLA+ into key ABMS regions improves performance and helps produce prints of superior quality with smoother surfaces and better aesthetics.

3.1.3. Manufacturing and Assembly

Both the robotic arms and the cart body were constructed using sophisticated 3D printing and traditional machining. Most of the components were printed using Creality Slicer, Creality Print 5.0, and Bambu Labs software to maximize print precision and efficiency. During assembly, all components are properly attached with steel screws and bearings to provide smooth rotation and linear motion. Connecting the limbs of robotic arms requires a sturdy backbone, which was achieved using stainless steel rods. The pulleys must not only be sturdy, but also retain a suitable level of tension while being machined via a lathe to service the operating mechanism. The combination of 3D printing and lathe operation helps to materialize the system's intricate design features and high-strength needs.

3.1.4. Issues and Changes:

Several challenges arose throughout development that necessitated design re-iterations and final revisions to build a functional and dependable robotic arm. One big issue was that one motor in one degree of freedom overheated, melting the PLA case. In response, we opted to remove that one degree of freedom and lengthen other component lengths to fit the adjustment.

The other major problem was instability in the reinforcement learning model, which used to cause system self-destruction several times because of some wrong values. This enabled the development of more accurate angle feedback through the DD implementation of the BNO055 absolute angle IMU. There exists some drift and variable inaccuracy in an environmental factor in MPU6050 and MP9250 models, whereas from the case of BNO055, calibration data is still retained even on a reboot. Its built-in drift correction algorithms on the microchip are automatically offset so that it continuously provides reliable and consistent position data.

Furthermore, the control of the robot's operation was divided into two parts: one for the complete arm and another for the gyro. This is essential owing to power concerns that may arise if the same ESP32 controls both the gyro and the motors. Aside from that, the I2C protocol is susceptible to interference from lengthy wires running near high-power lines, which is how it is currently utilized for communication. As a result, we placed the gyro circuit at the top of the arm, along with its ESP32, to minimize interference and ensure stability throughout operation.

3.2. Actuating System

The actuating system for the manipulator includes two types of motors—NEMA 23 and NEMA 17—which are specifically chosen due to their appropriateness. The first of these is a NEMA 23 servomotor located at the base. Due to its characteristics, it can maintain 15 kg in a vertical configuration. It has a GT2 pulley system that multiplies its torque and offers extra precision. The unipolar stepper motor, which can also be made bipolar, is NEMA 23 with a step angle of 1.8° per phase; it offers long life and high precision. It has six leads of size AWG #22 lead wire, with current ratings from 1.8A to 2.5A, which makes it adaptive to different load requirements.

Figure 5: NEMA 23 Attached at Base

Seated at the center of the arm would be a NEMA 17 motor with a 100:1 gear ratio planetary gearbox, which would yield high torques and low speeds demanded proper positioning and holding of loads. Framed in the center of the arm is a NEMA 17 motor with a 0.018-degree step angle; not affected by a gearbox, it has a hold torque of 39Ncm. It is rated with a winding current of 1.68 A per phase, has a phase resistance of 1.6 Ω, and an inductance of 3.2 mH. The end actuator turns a second NEMA 17 motor, which also benefits from the reflective configuration to ensure precision and power density within a planetary gearbox. The technical requirements on the maximum permissible torque are at 15 Nm and at a moment permissible torque at 20 Nm, thus always guaranteed to be able to execute diversified manipulations.

The TB6600 motor drivers are used to manage the motors for reliability and achieve accurate motions in a current and pulse mechanism. These drivers give signals to the coils of the stepper motor for smooth and controlled stepwise movements in both directions: clockwise and anticlockwise. These drivers also enable the fine-tuning of the number of steps taken for the smooth operation of the motor and control current from 0.5A to 4A. The inclusion of the ACS current sensors for feedback further enhances the actuating system. One of the ACS sensors monitors the current draw of the arm to determine when an object has been grasped, while the second one determines the amount of current draw by each motor located before the TB6600 motor driver to grade the load being handled within the rated limits. It assures that each of the motors is effective in functioning, thus leaving precise control of the arm's movements without being overloaded.

3.3. Microcontroller Integration

Microcontrollers need to be integrated seamlessly for robotic systems to function efficiently. Installed in the robotic arm is the ESP32-S3 microcontroller, taking care of low-level computing activity within the Automated Bimanual Mixology System and the high-level computations in the back-end server with Jetson TX2 power. Using a Jetson TX2, which splits the type of work or labor seamlessly and efficiently. It drastically reduces processing time, mainly on the complex computations and algorithms entailed in a beverage-making operation. It is the robust I2C communication protocol that binds the server to an ESP32-S3 microcontroller; hence, it can allow many master and slave configurations on a single bus. That arrangement ensures the server and microcontroller will work together seamlessly for improved total systems' performance.

Apart from the robotic arm, the ABMS has an ESP32-S3 microcontroller mounted on the cart. The microcontroller is tasked with controlling the valves and other components. The microcontrollers communicate among themselves through MQTT, while the gyro and the ESP32-S3 communicate via I2C. Previously, there had been a power issue since the gyro and motors were both converged into a single arm that was powered by a single ESP32-S3. The gyroscope circuit is placed on top of the arm next to the ESP32-S3, away from interference, especially close to high-power lines. The MQTT servers manage to allow low-power, high-speed communication to be optimized, hence reducing latency, and improving performance. A HawkEye camera mounted on the cart helps in reinforcement learning; in addition, other plans are meant to place another camera in front of the cart on a tripod. It is through this integrated approach that ABMS can be accurately controlled and effectively operated, showing complex coordination between different parts.

3.4. Sensors

The Automated Bimanual Mixology System (ABMS) relies heavily on sensors to provide the data required for accurate control and operation of robotic arms. They guarantee precise movement, placement, and load management—all crucial for the system to operate well. We will now look at the sensors in detail:

3.4.1. Current Sensors (ACS)

For the ABMS to accurately measure the current flowing now in a given conductor and also to ensure the safe operation of robotic arms, the equipment uses the ACS712 current sensors, relying on the Hall effect. There are only two reasons these sensors are so important for this system. The Automated Bimanual Mixology System is quite dependent on two critical aspects of feedback: that acquired from the ACS current sensors. These sensors carry out a few primary functions critical to the design. One ACS current sensor is used in supplying feedback concerning the current draw to detect the variations or dips thereby showing that the arm has stopped after gripping an object successfully. This feedback system is also used by the ABMS to determine whether the arm has effectively picked an upward object. A second ACS712 sensor is attached to the front of the TB6600 motor driver. While measuring continuously, this sensor provides real-time data on the force applied by each arm link.

Figure 6: ACS712 Current Sensor

This information is critical to ensuring the motors run within the designated voltage and current limits, which is normally a maximum current draw of 3 amperes. The ABMS continuously monitors the current and hence it can stop a motor overload situation. The low noise in the analogue signal channel reduces unwanted noise in the measurements of the current, thereby improving the general system accuracy. The ACS712 provides the best accuracy at room temperature, 25°C, and a tolerable amount of 1.5% for total output error.

3.4.2. Absolute Position Sensor BNO-055

The BNO055 is an absolute position sensor that works in pretty much the same way as an IMU gyro. Its embedded code calculates the error, during the 60 degrees rotation of the arm. It is in this preservation of the system calibration data upon a system reboot that gives BNO055 the superiority over other sensors like MPU6050 and MP9250 in that its performance remains stalwart regardless of changes in surrounding conditions.

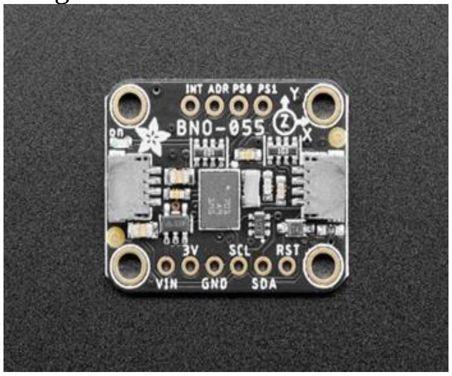


Figure 7: BNO-055 Absolute Position Sensor

In absolute position sensors, drift is essentially a stable variation or shift in the output signal of the sensor over time, without any change in the input or other alteration resulting from environmental influences. This is mainly due to reasons such as temperature variations, ageing of internal components, mechanical stress, and external influences. Drift can harm the accuracy and reliability of the sensor's measurements, possibly leading to an imperfect determination or control of the location.

Fortunately for on-chip correction algorithms, the sensor becomes robust through this automatic adjustment for drift in providing accurate and reliable location data. Moreover, the I2C protocol allows easy interfacing of BNO055 with other system components to provide full data integration and exchange. Standardized communication protocol of the BNO055 sensor with other components within the entire system guarantees synchronized operations, thus enhancing performance and reliability through orderly and coordinated operation.

3.5. Control Mechanisms

The ABMS robotic arm control mechanism includes a number of components and algorithms that allow proper movement and coordination. The main control script, main.py, initializes a Pygame interface with gyro data coming in via serial port connection. It reads the data from the gyro, processes it, and then the output is used as input in drawing the position of the robotic arm rendered in 3D space. This allows one to verify the orientation of the robotic arm for control purposes with full confidence in making assured movements well within range.

The file motor_params.py defines the parameters of a few motors in the setup: the base motor, gripper motor, gear motor, and z motor. All the parameters of each motor, like the steps to move the motor by one step, delay between steps for the next and the actual function, along with the pin configuration that each runs are defined and served under a Flask-based API. It will set parameters to be readily retrievable and editable, thus giving dynamic control over calibration.

The main core of the controller is the hand_bridge.py script, which contains the logic to control and correct the movements associated with robotic hands. It listens to MQTT and acts upon the motor movements based on the commands received. The script has functions that home the base and gear motors, set a new zero position, and correct movement from gyroscope data. The MotorManager takes care of interfacing with the motors and translating the angles necessary for them.
The control algorithm works in the following sequence:

A. Initialization: The HandBridge class initializes the MQTT client and connects it to the broker. It subscribes to topics that are needed to receive gyro data and correction commands.

B. **Data Handling:** When the gyro data is received and checks whether the motors need to be homed or new zero positions need to be set, it attempts to correct the positions of motors based on new received gyro data.

C. **Motion Contro**l: On receipt of new coordinates, the system calculates the required movement of motors and issues such commands to them. This motion is guided in that following a sine wave pattern gives smooth acceleration and deceleration—a profile in a way vital to profiling, thereby maintaining precision and stability.

D. **Error Corrections:** If the gyro data indicates a specific kind of error in its system position, then it would try to apply some corrections. Zero to four positions to correct are checked; corrections in the turns of both motors are done accordingly.

E. **Homing and zeroing:** this is done in order to have the system assign a right position of the base and gear motors or to set in new zero positions, or recalibrate the system. In summary, the control mechanism further integrates real-time data visualization with accurate motor control and enhanced error correction to result in proper and efficient operation of robotic arms.

This combination of MQTT for communication, sine-wave control for smooth movements, and detailed management of the motor parameters makes it possible for the ABMS to execute complex tasks with high reliability and precision.

3.6. Power Supply and Management

Our project is dependent on robust power supply systems with good management. There are basically two main sources of power used: one 24 V, 15 A power input for the arms and another 24 V, 9 A power input to the carts system. The power supplies meet the voltage and current requirements to run the several ABMS components. This way, power control and optimization in power distribution are realized through the application of buck converters and modules. These gadgets play a crucial role in stepping down the higher voltage supplied by the power sources to the levels that are demanded for the proper functioning of the components in the system. The Buck converters help avoid overloads, making sure no component receives more power than it requires without crossing over the limits at which individual components can effectively function.

Meanwhile, the power distributed also ensures the smooth functioning of the arms and cart systems. Each arm-specific power supply with 24V/15A capacity serves to drive the motors, sensors, and control circuits of the respective arm. The different functionality associated with the cart system, such as mobility, communication, and control, is facilitated with the help of the 24V 9A cart-specific designed power supply. Taken together, buck converters and module integration, along with efficient use of power supply, help seep in reliable and optimum power management inside the ABMS, such that the system continuously runs smoothly, which further improves overall system performance when it comes to providing drinks on its own.

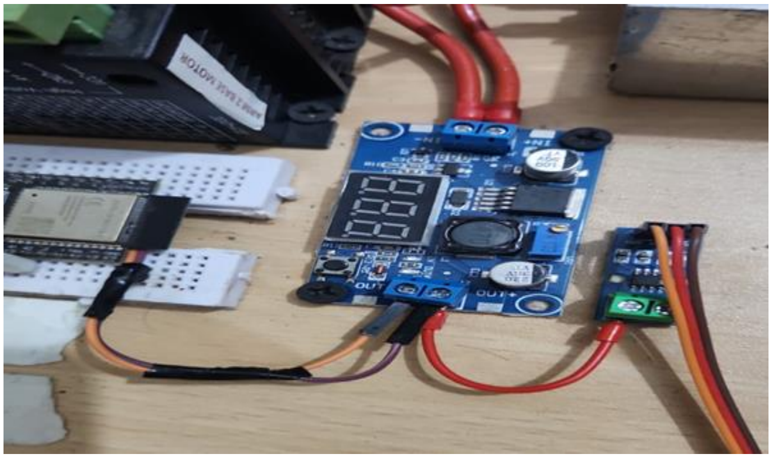


Figure 8: Buck Converter (Left), Current Sensor (Right)

3.7. Electronics and Wiring

Our plan for the robotic arm project's electronics and wiring was straightforward and safe, with a plug-and-play circuit design that eliminated the need for specialist PCBs. We powered the system using two 24V 15A supplies for each arm and a 24V 9A supply for the cart, managing voltage via buck converters. Despite the circuit's simplicity, assembly took a long owing to its power consumption and the number of connections. To avoid sparking and maintain solid connections, we used earthing, lugs, screws, threaded inserts, and other anti-spark techniques, which eliminated the need for soldering and improved the system's reliability and safety.

3.8. Software Development

The software has been developed to enable our project to have the chance to upgrade and become better in several important things. Implementation and training techniques regarding it are very much detail-oriented and also obtained according to the Reinforcement Learning Model; thus, this is how adaptability of intelligence is obtained, and operational efficiency can be enhanced. Due to the same reason and according to the Implementations in Computer Vision, we use Intel Hawkeye camera and perform color marking and position determination tasks to ensure that an object is identified and tracked correctly. Apart from this, it is the part of mobile application development that emphasizes the ease in using an interface and a strong communication to a server so that users can access control and monitoring of the system from a distance very effectively and with ease. All of these go a great way in making this an integrated and effectual software framework for the project.

3.8.1. Reinforcement Learning Model

A pre-trained Q learning algorithm has been implemented in the reinforcement learning model to introduce constant improvement of the path in our system. Q-learning is a model-free type of reinforcement learning whereby one learns the value of an action in a particular state toward maximizing cumulative reward. The model was trained on a large dataset and, as a result, taught a very strong policy to be able to make good decisions. This pre-trained model was further fine-tuned as per our environment and application necessities, i.e., it customizes the method of path optimization through interaction at every step with the environment. The Q-learning model continuously changes its Q-values to tune iteratively with the environment; hence, even better methodologies for path optimization are ensured. This is done in such a way that the system can adapt dynamically to novel situations and new obstacles, becoming even more effective and efficient over time. One important ingredient to realize autonomous navigation and operational efficiency in our project is the ability of the model to improve its path-finding capabilities by learning from experience.

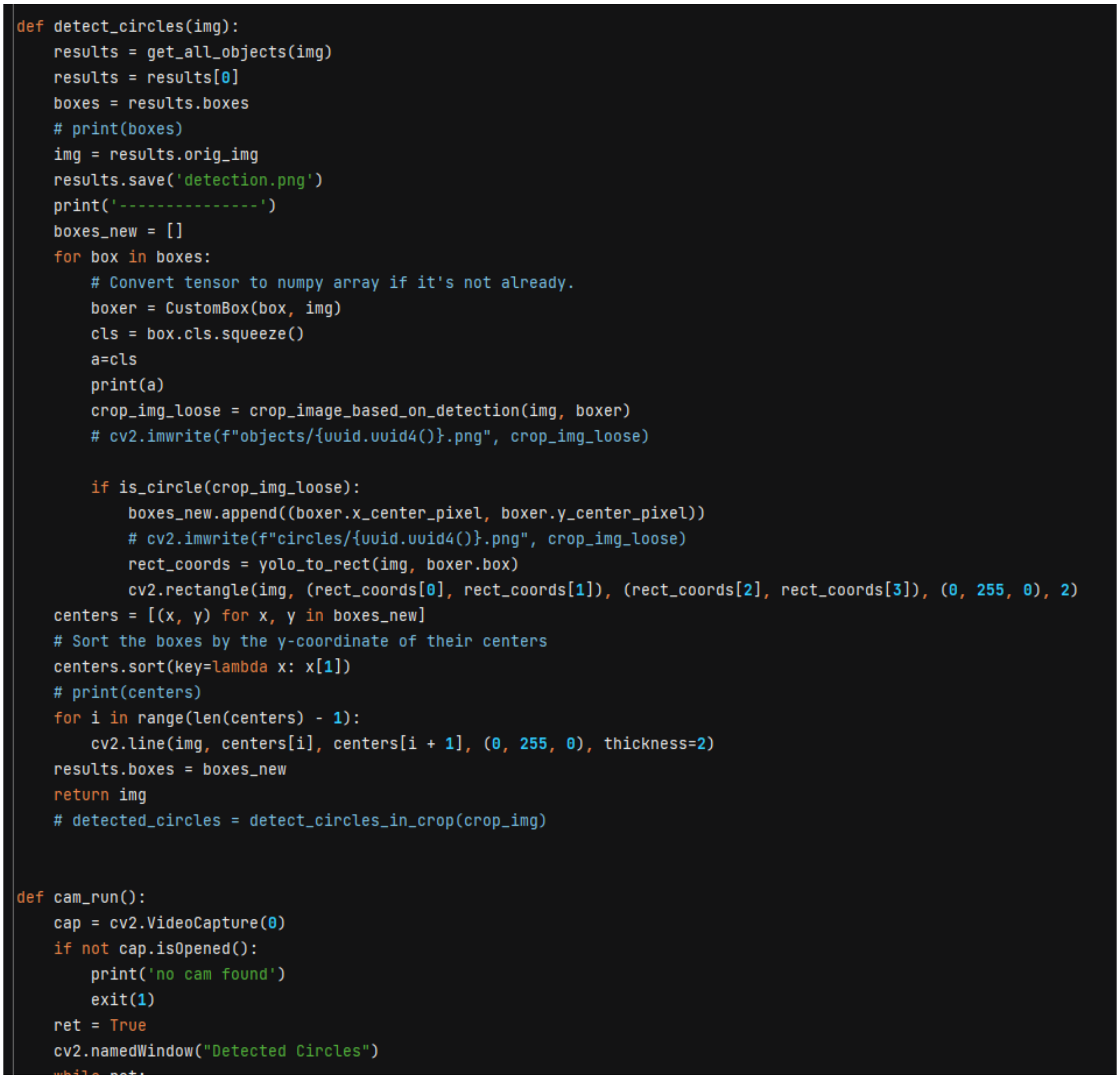
3.8.2. Computer Vision

The image processing algorithm is implemented in two primary scripts: circle_detection.py and yolo_detection.py. These scripts work together to supplement the gyroscope-based correction mechanism for the robotic arms by detecting visual markers and potential gear slippage using a Hawkeye camera. Below is a detailed explanation of how each script functions and their roles in the control system.

3.8.2.1. Circle Detection Script:

In the circle_detection.py script, OpenCV and various custom utilities are utilized to detect circles in the camera feed. This detection is crucial for identifying visual markers that indicate the position and orientation of the gears, aiding in correcting any slippage. The script begins by importing necessary libraries, including OpenCV for image processing, UUID for generating unique identifiers, and custom utilities such as step_type_matching, is_circle from circle_detector, get_all_objects from fast_sam, and functions from yolo_utils.

The main function, detect_circles, captures an image and uses get_all_objects to detect all objects in the image with a pre-trained model. For each detected object, it creates a CustomBox instance, crops the image around the detection, and checks if the cropped image contains a circle using is_circle. If a circle is detected, it records the center coordinates of the circle and draws a rectangle around it in the original image. The detected circles' centers are sorted by their y-coordinates, and lines are drawn between consecutive centers for better visualization.



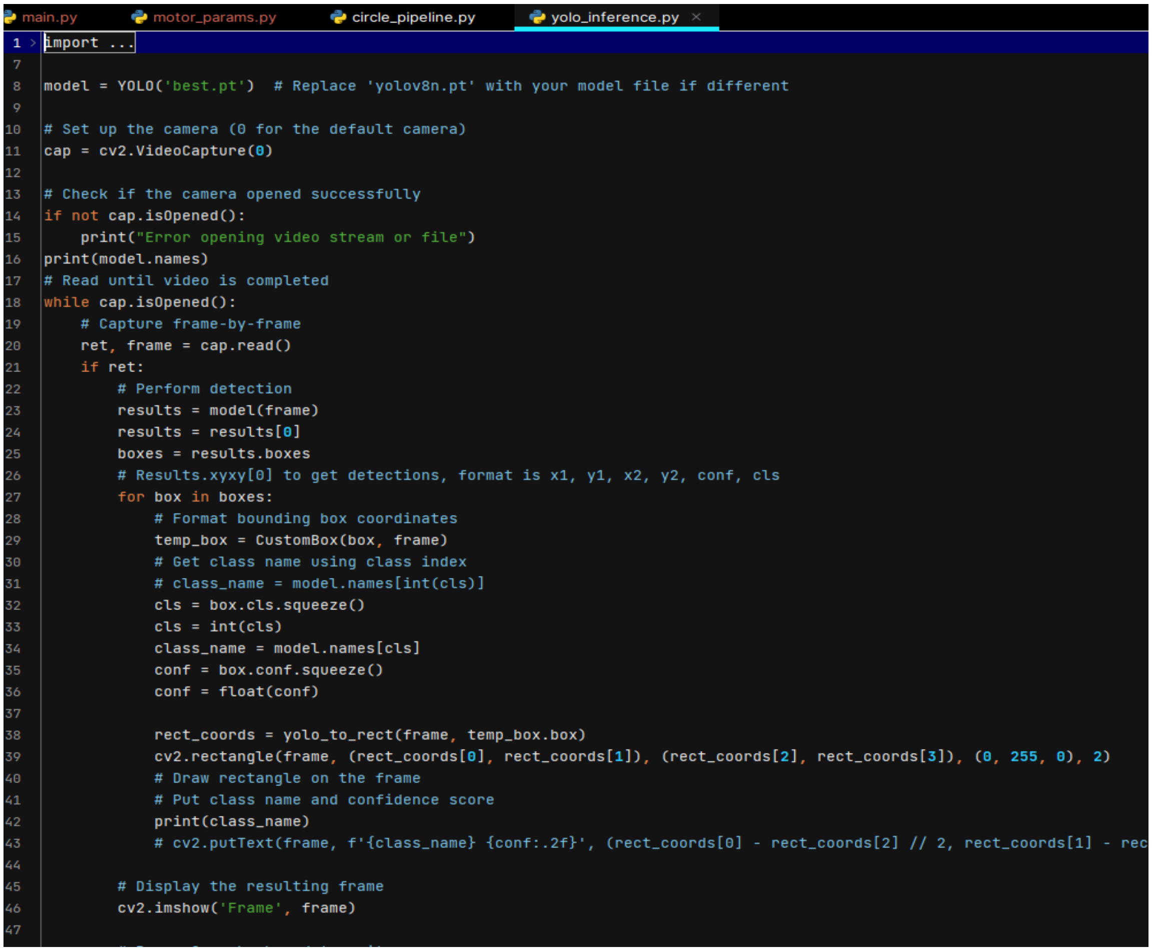
```python
def detect_circles(img):
    results = get_all_objects(img)
    results = results[0]
    boxes = results.boxes
    # print(boxes)
    img = results.orig_img
    results.save('detection.png')
    print('---------------')
    boxes_new = []
    for box in boxes:
        # Convert tensor to numpy array if it's not already.
        boxer = CustomBox(box, img)
        cls = box.cls.squeeze()
        a=cls
        print(a)
        crop_img_loose = crop_image_based_on_detection(img, boxer)
        # cv2.imwrite(f"objects/{uuid.uuid4()}.png", crop_img_loose)

        if is_circle(crop_img_loose):
            boxes_new.append((boxer.x_center_pixel, boxer.y_center_pixel))
            # cv2.imwrite(f"circles/{uuid.uuid4()}.png", crop_img_loose)
            rect_coords = yolo_to_rect(img, boxer.box)
            cv2.rectangle(img, (rect_coords[0], rect_coords[1]), (rect_coords[2], rect_coords[3]), (0, 255, 0), 2)
    centers = [(x, y) for x, y in boxes_new]
    # Sort the boxes by the y-coordinate of their centers
    centers.sort(key=lambda x: x[1])
    # print(centers)
    for i in range(len(centers) - 1):
        cv2.line(img, centers[i], centers[i + 1], (0, 255, 0), thickness=2)
    results.boxes = boxes_new
    return img
    # detected_circles = detect_circles_in_crop(crop_img)


def cam_run():
    cap = cv2.VideoCapture(0)
    if not cap.isOpened():
        print('no cam found')
        exit(1)
    ret = True
    cv2.namedWindow("Detected Circles")
```

Figure 9: Circle Detection Script

The cam_run function initializes a camera feed using OpenCV, continuously reads frames from the camera, processes them to detect circles using detect_circles, and displays the result in a window. The loop runs until the user presses 'q', at which point it releases the camera and closes all OpenCV windows. The img_run function reads a static image file, processes it to detect circles using detect_circles, and saves the result to a new file.

3.8.2.2. YOLO Detection Script:

In the yolo_detection.py script, the YOLO (You Only Look Once) object detection model is used to detect various objects, which can include visual markers on the gears. This detection helps in identifying specific features and potential slippage. The script imports necessary libraries, including OpenCV and the YOLO model from the ultralytics package, and custom utilities such as step_type_matching and functions from yolo_utils. The YOLO model is loaded with pre-trained weights (best.pt), and the camera is set up using OpenCV to capture video feed. The script enters a loop where it continuously reads frames from the camera and performs object detection using the YOLO model.



```
import ...

model = YOLO('best.pt')  # Replace 'yolov8n.pt' with your model file if different

# Set up the camera (0 for the default camera)
cap = cv2.VideoCapture(0)

# Check if the camera opened successfully
if not cap.isOpened():
    print("Error opening video stream or file")
print(model.names)
# Read until video is completed
while cap.isOpened():
    # Capture frame-by-frame
    ret, frame = cap.read()
    if ret:
        # Perform detection
        results = model(frame)
        results = results[0]
        boxes = results.boxes
        # Results.xyxy[0] to get detections, format is x1, y1, x2, y2, conf, cls
        for box in boxes:
            # Format bounding box coordinates
            temp_box = CustomBox(box, frame)
            # Get class name using class index
            # class_name = model.names[int(cls)]
            cls = box.cls.squeeze()
            cls = int(cls)
            class_name = model.names[cls]
            conf = box.conf.squeeze()
            conf = float(conf)

            rect_coords = yolo_to_rect(frame, temp_box.box)
            cv2.rectangle(frame, (rect_coords[0], rect_coords[1]), (rect_coords[2], rect_coords[3]), (0, 255, 0), 2)
            # Draw rectangle on the frame
            # Put class name and confidence score
            print(class_name)
            # cv2.putText(frame, f'{class_name} {conf:.2f}', (rect_coords[0] - rect_coords[2] // 2, rect_coords[1] - rec

        # Display the resulting frame
        cv2.imshow('Frame', frame)

```

Figure 10: YOLO Detection Script

It processes each detected object to format the bounding box coordinates, class index, and confidence score, creating a CustomBox instance for each detected object and drawing a rectangle around the detection in the frame. The class name and confidence score of each detection are printed for verification. The processed frame is displayed in a window, and the loop runs until the user presses 'q', at which point it releases the camera and closes all OpenCV windows.

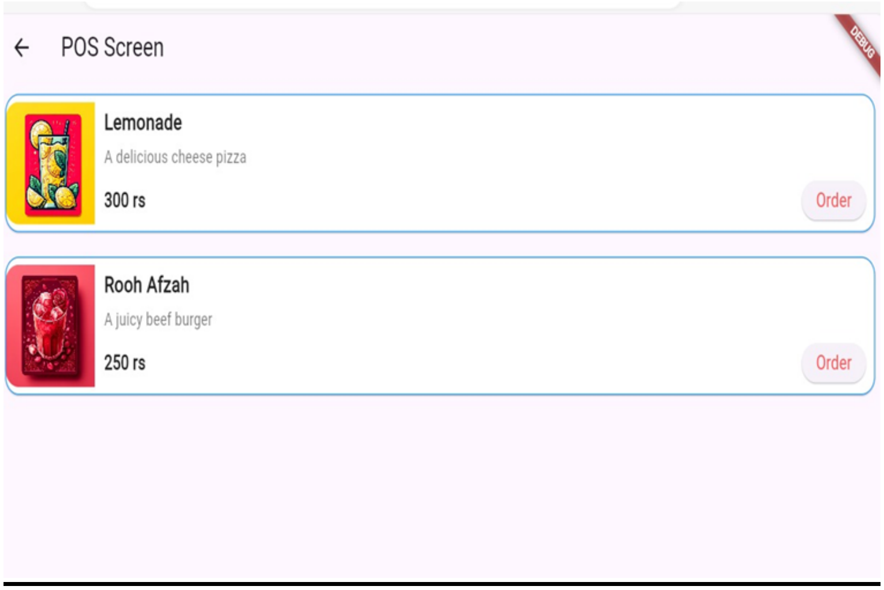
These scripts together provide a robust visual feedback mechanism for robotic arms. The circle detection script identifies specific visual markers, such as circles, which can be used to track gear positions. The YOLO detection script adds an additional layer by detecting various objects and features that can indicate slippage or misalignment. The detected visual markers and objects supplement the gyroscope data, providing an additional layer of verification and correction. If the gyroscope indicates a potential slippage, the visual feedback from the camera can confirm and help correct the exact position of the gears. This integrated approach ensures precise and reliable operation of robotic arms, enhancing their accuracy and reducing the risk of errors due to gear slippage.

3.8.3. Mobile Application Development

Our mobile app development is based on Flutter for a very stable UI and effective communication with the server so that interaction with our system is smooth and not long. The app interfaces with prolific ease and quality, making users navigate smoothly to execute commands. Now, our server and application are run locally to improve the development and testing process. We have run the server on the NVIDIA Jetson TX2 to fully realize high processing power for superior performance and reliability. This configuration is expected to provide the server with the ability to execute intensive tasks and to respond in real time to user commands.

In other words, through the app, a user may place an order, it is to be automatically forwarded to the server through the MQTT protocol. The lightweight messaging protocol is appropriate for IoT applications in that it guarantees agile and reliable communication between the mobile app and the server.

After the server is issued with a command, it communicates directly with the ESP modules to achieve its intended action. The communication between the ESPs and gyro sensors is through this very efficient and correct data transfer protocol in the I2C (Inter-Integrated Circuit) protocol. In that way, it realizes effective control and monitoring in the movement and operation of the system, proving it to be robust and very responsive to user experience. Overall, the mobile application will be layered over advanced technologies and protocols so that the system is user-friendly but at the same time allows coherent communication among its components for implementation. All of these would boost the utility and reliability of our project, which has versatile and powerful operations for users.



Lemonade

A delicious cheese pizza

300 rs

Rooh Afzah

A juicy beef burger

250 rs

Figure 11: App UI

The above image shows the frontend of the app developed using Flutter. Currently our project only supports 2 drinks which also operate each arm. The order can be placed from there and there is also an admin panel from which the arm can be controlled manually using teach pendant.

Chapter 4 – EXPERIMENTAL RESULTS AND ANALYSIS

In the findings and analysis of the trial, we have concentrated in three big areas to determine how our robotic arm performed. First, we tested the efficiency and load-handling capability of the NEMA 23 motor through its current draw and force output. Second, we performed an experiment on the geared and non-geared NEMA 17 motors by comparing the current consumption with the force exerted to have a better understanding of the effect of the gearbox on the motor performance.

We could then compute the present draw versus the weight lifted by the entire arm, which gave information about the total power needs and operational limits of the robotic system. From these findings, further improvements or design optimizations in the future can provide a sense of mechanical and electrical performance cues.

4.1. Experimental Setup

The entire experimental setup was designed under three primary domains of investigation to qualify the working and effectiveness of the system. In the first domain, a series of experiments were conducted to analyse the effectiveness and load-carrying ability of the NEMA 23 motor to determine the effectiveness of the current draw and the force production under different loading conditions. This study aimed to determine the extent to which the motor could efficiently transmit electric power to mechanical power while subjected to vertical loads to a known capacity.

In addition, comparative studies were conducted to ascertain how much gearboxes affect the performance of NEMA 17 motors. Analysis based on current consumption and the force output of geared and non-geared arrangements allowed the research to deduce insights into the impact of gearboxes on motor torque, speed, and energy economy. This will further enable calculations to be carried out that give answers to what concerning the complete power requirements that need to be built into the robotic system and will have to set the operational limits in terms of weight handling capacity and power consumption. These findings have important implications in establishing optimization for the design and performance parameters of evolving generations of the robotic arm system.

4.2. Data Collection

The data obtained had a variety of critically important information in assaying and analyzing the performance of the robotic arm system. For example, sensors provide current draw data, taken using ACS current sensors to provide information on the characteristics of motor performance and its handling capacity at different loads. The BNO055 Gyro (IMU) enhanced position data to accurate precision, giving useful information for effective control and maneuvering of the robotic arm. More critically, the recorded voltage and current readings enabled the detailed energy use and operating cost analysis of the system. Therefore, basing on these diversified data sources, a comprehensive data set was collected for in-depth analysis in assessing the performance and efficiency of the robotic arm system.

A lot of critical approaches went into data collection on the work dynamics of the robotic arm system. Some of these solutions involved the ACS Current Sensors, BNO055 Gyro (IMY) to give real-time measurements to the user for any important parameter, such as Current Draw and Absolute Location. Furthermore, those dedicated systems were integrated, which can enable proper and reliable data logging from several parts of the robot arm. In addition to that, the sensor-based method is coupled with the manual checking that was also being practiced along with the measurements during the entire set of experiments to provide some supplement to the outcome with the sensor data and to validate those results which were achieved through automatic methods.

4.3. Analysis of Results

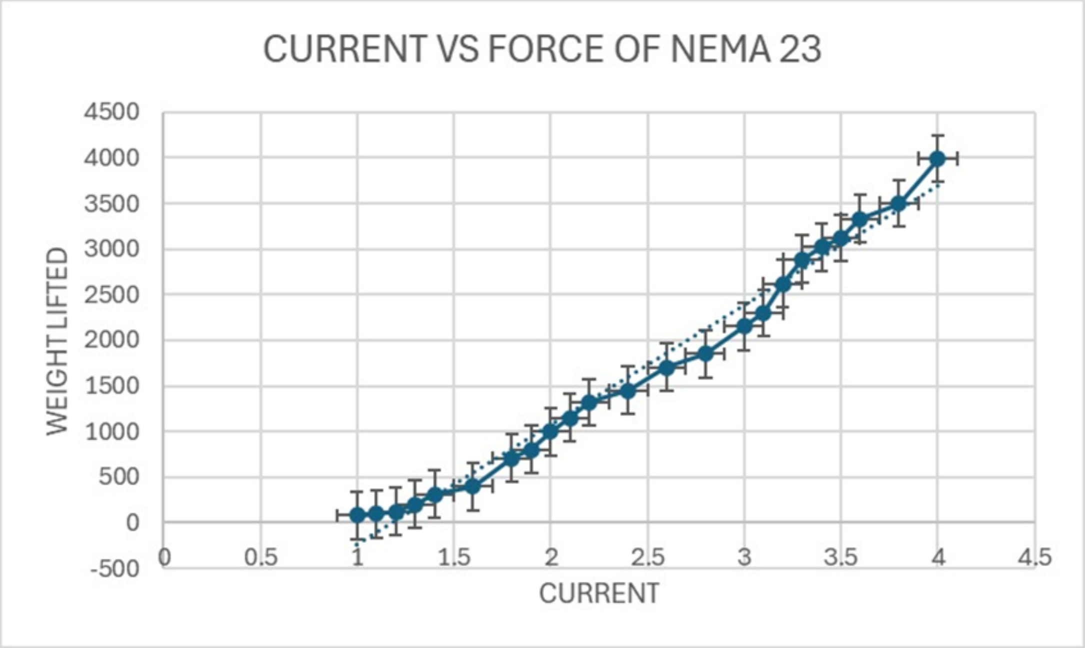


Figure 12: Current vs Force for NEMA 23

Interpretation of the "Current vs. Force of NEMA 23" graph provides evidence that there is a positive linear correlation between the mass a NEMA 23 motor is loaded with and the current it carries. The first thing we can notice is that the relationship nearly linear up to approximately 2.5 A; beyond that point, one would assume the force should increase in a very predictable manner with the current. After 2.5 A, the force increases further while being more irregular, so that non-linear effects might set in due to saturation of the motor or other inefficiencies that become critical for higher currents. As the current further increases, a plateau of force seems to appear around 4 A, which may mean the motor is close to its maximum load capacity. The error bars around each measurement show variability in possible measurement inaccuracy that increases as the current does, thereby suggesting greater uncertainty in higher loads.

The ACS current sensors provide useful information about how much current is being drawn. This is very critical in understanding the point at which the load limit of a motor is realized. Hence, marginally increasing the margin of error would mean that the sensors are becoming noisy or less precise at higher currents. With the BNO055 position sensors installed, it is possible to ensure the perfect positioning of arms, regardless of current fluctuations, whereas the load cell with Arduino offers another type of feedback originating from the actual weight lifted. This may permit the modification of the system and validation of data from other sensors.

In terms of power efficiency, the motor seems efficient up to about 2.5A, with a consistent increase in weight lifted per ampere. Beyond this point, efficiency may drop as the increase in weight lifted per additional ampere diminishes. Power consumption, calculated as P=V×I, increases linearly with current, with the power consumption at 4A being 24×4=96W. This implies that operating at higher currents could lead to increased heat generation, requiring effective thermal management to maintain performance and prevent damage.

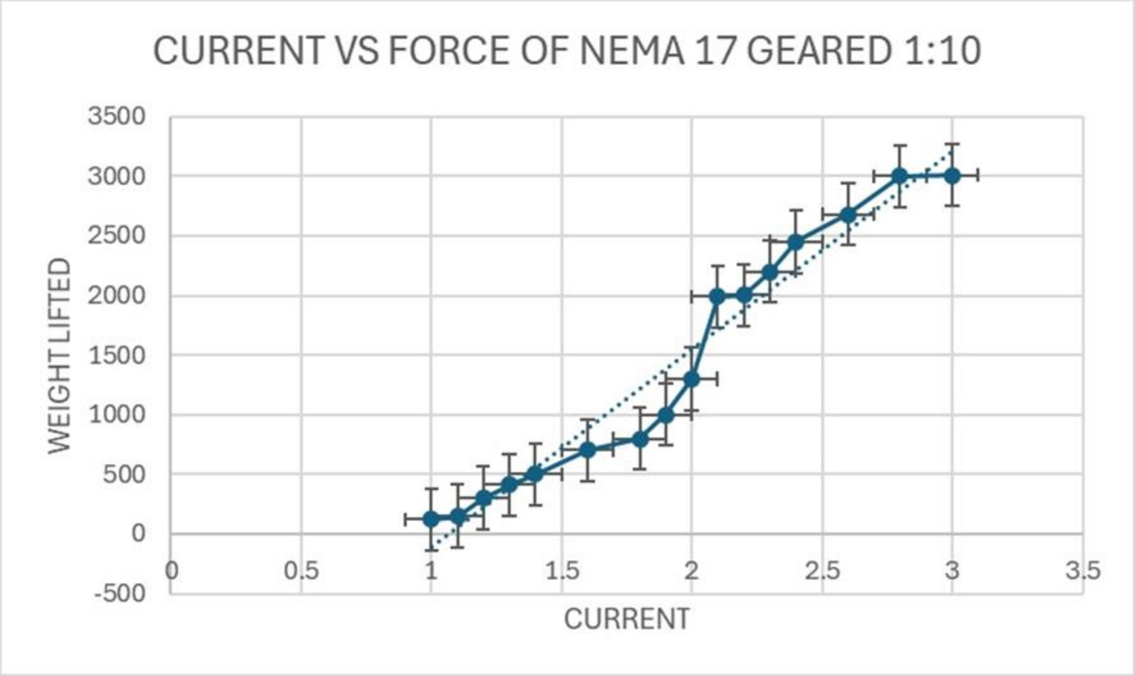


Figure 13: Current vs Force for NEMA 17 Geared

The plotted graph of "Current vs. Force of NEMA 17" geared at a ratio of 1:10 exposes the positive correlation between the current supplied to the NEMA 17 motor and the weight it lifts. First, it is almost linear up to about 2 A, which proves the increase in force with the current. It goes on increasing over 2A, maybe due to some kind of nonlinearity or inefficiency at higher currents. The rise is above average variance, about 3A plus and over; this brings the suggestion that maybe the motor is close to carrying its highest possible load. Error bars defined around each point characterize the variability and probable measurement errors, where large widths clearly define a large uncertainty of measurements with increased current.

In the matter of power efficiency, the motor is efficient up to around 2 A, with a lifted weight added per extra ampere. Beyond that point, efficiency starts to lower, as an elevated weight is lifted with respect to the addition of just one more ampere. Power consumption, calculated as P=V×I, is linear with respect to current values, and the power consumption at 3 A is equal to 24V×3A=72W. This means that higher currents result in increased heating, and effective thermal management must be in place for such performance to be maintained without compromising the structure's integrity. If the maximum performance is being sought from the system, it should generally work within the linear range up to 2A, wherein the increase in force can be predicted and the sensor feedback remains reliable. To maintain efficiency and ensure overloading does not occur, minimize the operation beyond this range. Such analysis is important since it gives insights into the performance of the motor; therefore, accurate sensor feedback and management helps to optimize the benefits from the motor performance and enhance system reliability.

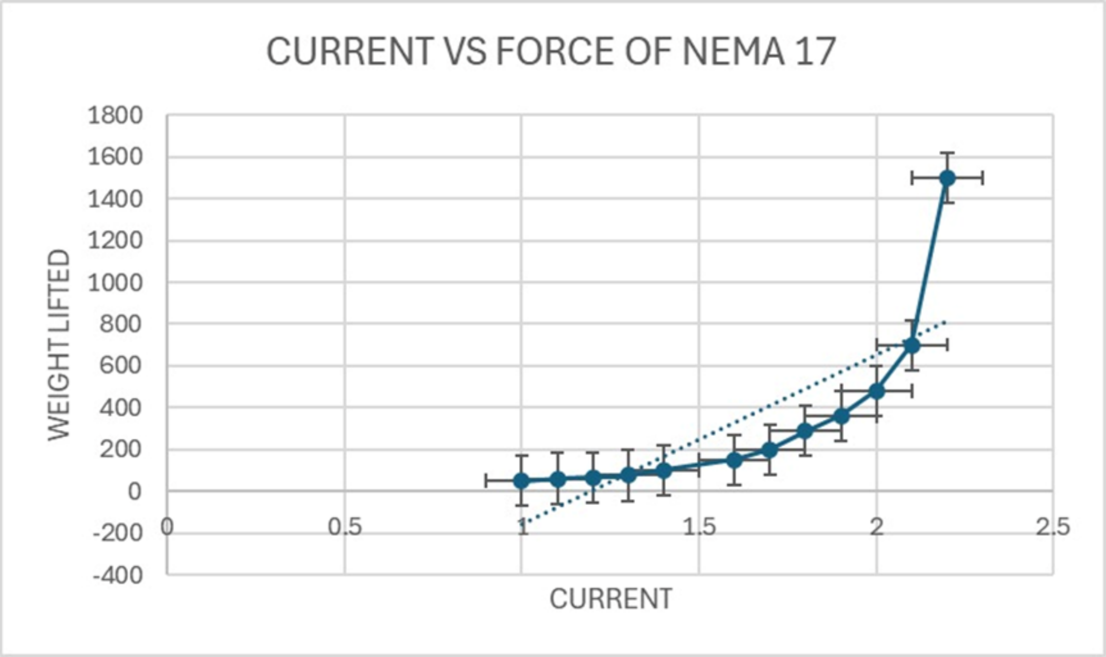


Figure 14: Current vs Force of NEMA 17

It can really be observed from the "Current vs. Force of NEMA 17" graph that there is a relationship in the carried weight and current supplied to the NEMA 17 motor. The force remains nearly constant with very little or no rise right from the start as current is increased up to about 1.5A; hence this might be the region where the motor in operation shows low efficiency, or the output force is inadequate to lift heavy weights. Above 1.5A, the force is seen to greatly increase, pointing to a non-linear relationship apparently yielding far much better results regarding current inclination of approximately 2A and above. The steepness of the force contribution speaks of high motor operation for increased currents where the weight lifted plots a sharp increment at currents of about 2.5A. The force attains maximum levels at approximately currents of 2.5A; this means the motor is tending in the direction of being in an overload state.

The error bars placed around each data point provide support for the inaccuracies in measurements resulting from variability. The higher the current, the larger it appears, showing that larger currents come with higher uncertainty in the measurements. With the help of the ACS current sensors, essential feedback can be obtained about the drawing of current to be used for the monitoring and control of motor performance. At least increased error margin at higher currents against noise or lost precision in those sensors. All of these are supported by the BNO055 position sensors, which ensure precise arm positioning, maintained to be consistent despite fluctuations that could happen in the current. The load cell, in turn connected to the Arduino, would add further feedback in terms of the actual weight lifted to help with the system calibration and data validation of the current sensors. In terms of power efficiency, however the motor is highly inefficient, reaching 1.5A with no perceptible increase in weight lifted per additional ampere. After this point, however, efficiency goes through the roof, as indicated by the very steep increase in weight lifted per additional ampere of current. Since the formula is P=V×I, power consumed varies linearly with current, and consumed power at 2.5 A will be 24 V x 2.5 A = 60 W.

That is, it draws lots of power when working with higher currents and gives a lot of force outputs, but that is at the cost of getting hot. This would mean efficiency in power consumption is correlated to increased output, only with the risk factor that it has the potential for overheating and a dire need for excellent thermal management to sustain output and avoid harm. High performance would be current levels above 1.5 A, although these will not reach the maximum current capacity, with very strong increases of force output. Such analysis evidently culminates in insight into the performance of a motor when combined with accuracy in sensor feedback for power management that brings about efficiency and guarantees reliability and assurance of effective system performance.

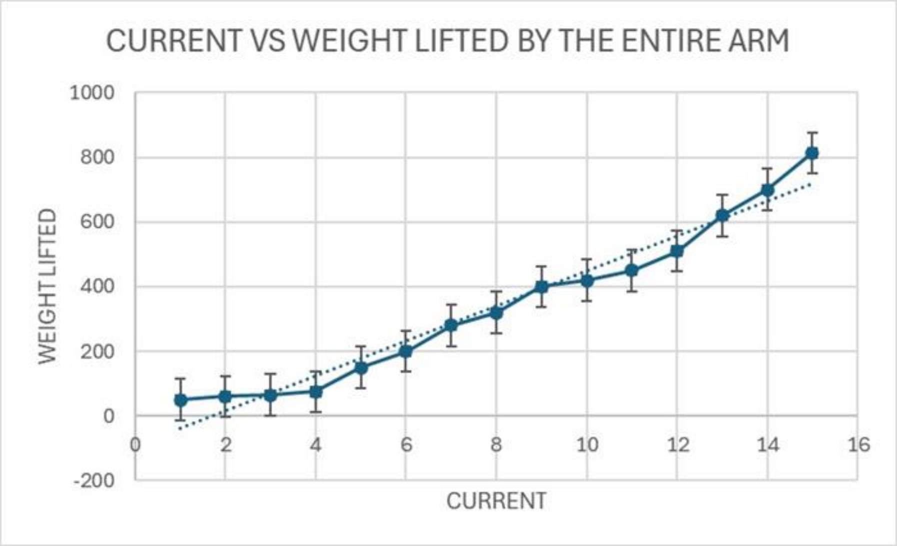


Figure 15: Current vs Weight Lifted

The graph presents the relationship between the current supplied to the robotic arm and the weight it can lift, indicating a positive correlation where the weight lifted increases with higher current. Initially, the weight lifted increases linearly up to around 8-10 units of current, but beyond this point, the relationship becomes non-linear as the system approaches its operational limits. The error bars highlight measurement variability, with smaller error bars at lower currents suggesting higher sensor accuracy under lighter loads. As the current increases, the error bars widen, reflecting greater variability and potential inaccuracies in the sensors at higher loads.

The magnitude of this variation is a testimony to the pivotal role that ACS current sensors and load cells, designed into the system for its proper feedback operation, play in keeping it maintained within an illuminated operational threshold. From the power dissipated section, we can note that the robotic discharge is fine from low current, and the value of the power dissipated increases linearly.

Further on, the system reflects a demand for power that increases disproportionately with load, as it is seen that both current and load tend to reflect non-linear growth, which points to very poor returns in power efficiency at higher loads. Though the sensors and feedback are functioning optimally in all other respects, their accuracy reduces with heavier loads, and the power efficiency goes down with increasing current, which translates into additional electrical power consumed just to lift more weight. This result indicates room for further optimization, especially toward enhancing sensor precision and improving ABMS power efficiency under high-load conditions.

4.4. System Reliability and Robustness:

Testing under other settings: The dependability and robustness of the ABMS were tested incisively under diverse operational settings, going from loads to the temperature, humidity, operational intensity, and other ambient factors that would test the overall competence and facility of the system for performance limitations and verification in giving consistent, precise, dependable service. The loading motor, slip-sticking, and belt slippage are some of the more specific problems considered herein. These classes of issues were improved upon by trend vision-based coordinate detection and a gyro to bring higher levels of precision into the positioning of the system. Mechanically, it could compensate and hold these really minute movements against nonuniformity using visual clues and gyro telemetry that assured repeatability of its operation in multiple environments.

Error Detection and Correction: Major aspects contributing to the reliability of the ABMS depended on good error detection and correction. The current-draw monitoring was in real-time. This was possible using ACS current sensors, which allowed the system to sense abnormalities such as overloading or unexpected resistance. Wherein, based on readings of the currents, whenever something fishy is detected, it would execute the corrective measures—now, it may be able to increase the power of the motor or reposition the arm because of the readings picked from the BNO055 position sensors and load cells. The Load cells parts were connected to an Arduino with input to the weight being lifted reduced to the nth degree of accuracy such that identification and error correction could be done in real time.

Long-Term Performance Evaluation: The long-term performance of the ABMS was evaluated in terms of continuous monitoring and logging data over very long periods. Performance of motors, accuracy of sensors, and uptime of the system have been quantified. Durability: It was tested on how well the system could still operate even if wear and tear, environmental changes, and load conditions affect it. From these inspections, routine maintenance plans were developed to maintain the motors, belts, and sensors in proper working condition, including the other various components of the robot. Thirdly, the BNO055 sensor—one that held calibration data through reboots—brought a longer-term reliability of the system, where it had low drift and held accuracy across time. Again, the robotic arms and components were made of high-quality material with accurate engineering, thus making them last long and constantly perform well.

Although problems like belt slipperiness were addressed through vision-based and gyro solutions, current sensors and load cells were used to optimize error detection. Since then, ABMS has gone on to show high reliability and robustness, ensuring that it delivers a very consistent quality of service under vigorous long-term testing and under various and rigorous conditions. These combined strategies ensured that the system was compliant with the very stringent threshold of requirements for installation in the fast-paced hotel business.

Chapter 5: CONCLUSION

The thesis closes with a consideration of the noteworthy developments in the hospitality sector brought about by the creation of the Automated Bimanual Mixology System (ABMS). The ABMS's demonstration of automation and robots is a significant advancement in the process of altering beverage service paradigms. Through the utilization of an intricate web of technological elements ABMS optimizes service procedures while also improving client experiences in general.

5.1. Summary of Achievements

A. Design and Implementation: The ABMS project has successfully designed and implemented a pioneering solution for automated beverage service within the hospitality industry. This achievement is underpinned by the integration of advanced robotic mechanisms, meticulously selected technical components, and innovative sensor technology.

B. Efficiency Improvement: Through the utilization of automation and robotics, the ABMS significantly enhances service efficiency and operational processes. By minimizing human intervention and optimizing workflow, the system reduces the likelihood of errors and sets a new standard for service quality and engagement.

C. Sustainable Development Goals Alignment: The ABMS initiative is in line with the Sustainable Development Goals, namely SDGs 8 (Decent Work and Economic Growth) and 9 (Industry, Innovation, and Infrastructure). The project advances wider social goals by encouraging innovation in the hotel industry and providing chances for career growth and financial success.

D. Technical Challenges Overcome: The Sustainable Development Goals (SDGs) 8 (Decent Work and Economic Growth) and 9 (Industry, Innovation, and Infrastructure) are aligned with the ABMS program. By promoting innovation in the hotel sector and offering opportunities for professional development and financial success, the initiative achieves broader societal aims.

E. Future Implications and Recommendations: In terms of the future, the ABMS project establishes the foundation for developments in automated service solutions. It is advised to work with industry stakeholders and continuously improve the system in response to user input to promote wider adoption and integration into business environments.

5.2. Future Recommendations:

A. Continued Research and Development: This will be realized by investing more in research and development to automate the beverage service more. These include, amongst other initiatives, the conceptualization of new state-of-the-art technologies that can make a system smarter and more flexible in using machine learning and approaches to artificial intelligence.

B. Industry Collaboration: Strategic alliances with industry providers, for example, accommodation services and IT corporations can create value-added information and serve as a means for enterprise settings to adopt the ABMS. Alliances can be pursued, and pilot studies can be initiated in any functional effort to test the operation of the system and meet detailed operational needs.

C. User Feedback Integration: Optimizing system usability and resolving any usability concerns requires incorporating user feedback into the design and refining process. User testing sessions and staff and customer feedback gathering can yield important insights for enhancing the overall user experience.

D. Scalability and Adaptability: Scalability and adaptability throughout the ABMS's design will guarantee its applicability in a variety of hospitality environments. It encompasses the concepts of modular design, which provide effortless extension or customization to suit diverse operating requirements and settings.

E. Continuous Monitoring and Maintenance: Ensuring the long-term performance and dependability of the ABMS requires the implementation of a strong monitoring and maintenance program. Preventive maintenance, software upgrades, and routine inspections are crucial for resolving any problems and enhancing system performance over time.

F. Training and Support: Maximizing the efficacy of the ABMS requires offering extensive training and support programs to staff members who are in charge of running and maintaining it. This covers first training sessions, continuous support materials, and technical help for any queries or problems that could come up.

G. Market Analysis and Commercialization Strategy: Effective deployment and acceptance of the ABMS depends on carrying out market research to pinpoint prospective target markets and create a thorough commercialization plan. To optimize market penetration and revenue creation, this entails evaluating the competition environment, pricing strategies, go-to-market tactics, and market demand.

5.3. Final Thoughts

In conclusion, the creation and deployment of the Automated Bimanual Mixology System (ABMS) is nothing short of a technological wonder that surmises a promising future in the development of automated service solutions for hospitality. The system was creatively engineered and resulted from teamwork with careful planning, ensuring its implication not only for general client experiences but also for speeding up liquid dispensing procedures. The conclusion of the ABMS project shows how valuable innovation is and leaves a promise about what the future for hospitality automation could be. But this is just the starting block toward the wider implementation and adoption of automatic service solutions. The ABMS and related technologies have the potential to completely change not just how drinks are provided but also the nature of client involvement and interaction in the hospitality industry with further study, development, and improvement.

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