Journal of Mechatronics and Robotics

Original Research Paper

RoboBrew: The Fully Autonomous Coffee Machine

[1]Anthony Achkar, [1]Maroun Hannoun, [1]Rita Younes, [2]Jose Javier Serrano Olmedo and [1]Roy Abi Zeid Daou

[1]*Department of Mechatronics Engineering, Faculty of Engineering-Polytech, Université La Sagesse, Furn El Chebbak, Lebanon*
[2]*Laboratory of Bio Instrumentation and Nano Medicine, Center for Biomedical Technology, Universidad Politecnica de Madrid, Madrid, Spain*

Article history
Received: 26-08-2024
Revised: 30-08-2024
Accepted: 08-09-2024

Corresponding Author:
Roy Abi Zeid Daou
Department of Mechatronics Engineering, Faculty of Engineering-Polytech, Université La Sagesse, Furn El Chebbak, Lebanon
Email: roy.abizeiddaou@uls.edu.lb

Abstract: Robotics has emerged in several domains in the current century. However, in the restoration field, mainly in coffee shops, applications are still limited. Therefore, RoboBrew presents a groundbreaking fully automated system poised to transform the restaurant and coffee industries into a new era. At its core, RoboBrew features an advanced coffee maker system designed to deliver exceptional performance. This system precisely doses coffee beans to ensure consistency in every brew, while a cutting-edge robot arm manages cup handling with high precision. Customers interact with a user-friendly LCD interface to place their orders, and RoboBrew efficiently moves the cup through the preparation process, from placement to delivery. The system's objectives include precise dosing, temperature regulation, robotic coordination, and seamless system integration to achieve a quick, effective, and delicious coffee experience. Initially considering stainless steel for durability and hygiene, the choice of premium plastic and wood materials balances cost-effectiveness with performance. Testing reveals that RoboBrew performs admirably in all aspects except response time, with no significant errors observed and a cost of less than 500 US dollars, far below competing systems. This system enhances customer satisfaction, and operational efficiency, and provides valuable insights into robotics and automation. RoboBrew not only supports academic and professional goals but also innovates the coffee industry, delivering a superior coffee experience through advanced technology.

Keywords: Coffee Machine, User-Friendly Interface, Robotics System, Automation in Restauration Systems High-Precision

Introduction

Coffee was introduced to Europe around 1615 when Venetian traders acquired it from the Ottoman Turks. The first European coffee house outside Istanbul was established in Venice in 1645. Approximately 50 years after its introduction to Europe, coffee became available in the Netherlands, England, France, Vienna, and Germany, with the Dutch beginning cultivation in their colony of Ceylon (now Sri Lanka). Over the next 285 years, France played a pivotal role in developing and popularizing new coffee preparation methods Kathryn (2010). By the 21st century, Italy had become renowned for its espresso, a concentrated coffee form known for its robust flavor and stimulating effects. Initially, coffee preparation in 1645 involved a process similar to the traditional Turkish method: Finely ground coffee was combined with water and sugar in a cezve, a small copper pot with a long handle, and then poured into a cup, with the grounds settling at the bottom. The evolution from this method to the complex, machine-dependent espresso culture of today illustrates significant technological advancement (Tuomi, 2021; Anjee, 2024).

Thus, the initial section of this study sets the stage for the research by exploring the growing interest in combining coffee with innovative technologies and automation. Inspired by revolutionary robotic systems across diverse industries, the proposed RoboBrew system incorporates a range of advanced concepts and designs. For instance, Ari *et al*. research on an Arduino-controlled coffee maker with a robotic arm allowed remote operation via smartphone, featuring components for water monitoring, voice notifications, and brewing (Ari *et al.*, 2021). Moreover, Vladimir *et al.* design utilized Xilinx software to create an automated coffee maker with six operational modes, handling tasks such as dispensing water and milk, adding sugar, stirring, and self-cleaning, with each function timed and independently controlled (Vladimir *et al.* 2022) in

DOI: 10.3844/jmrsp.2024.31.38

addition, F&P Robotics' Barney, an automated cocktail machine, mixed various drinks and served wine and beer, addressing the increased demand for automation due to health concerns and incorporating a barista-style coffee version (Oliver and Lea, 2023). Furthermore, a study by Korbuakaew and Vongvit, using the Self-Assessment Manikin (SAM), found that interactive waiter robots evoke the most positive emotional responses, enhancing the dining experience through novelty and engagement (Korbuakaew and Vongvit, 2023). Finally, Dobot's CR3 coffee robot operated in a mobile cart, leveraging machine learning to replicate barista movements and created artistic designs on coffee, offering efficient, hygienic, and flexible coffee preparation (Ardiansyah and Dimas Mahendra, 2023). However, all these systems were very costly, where their price could reach easily 15,000-20,000 US dollars. Therefore, RoboBrew is proposed to benefit from the previous innovations and integrate several functionalities in a single system while focusing on maintaining a considerable price.

Therefore, the proposed system introduces a groundbreaking approach to transforming the traditional coffee shop experience. By automating the entire process from ordering to serving, it eliminates the need for human intervention such as servers, runners, or baristas. Imagine entering a coffee shop where you can browse the menu, choose your drink, and place your order with a single click. The system ensures precise dosing of coffee, milk, and other ingredients, consistently delivering fresh and high-quality beverages. It features advanced control over water quantity and temperature, guaranteeing that every drink is both delicious and uniform.

Moreover, the robotic arm integrated into the system manages cup handling with accuracy, smoothly moving empty cups into position, filling them with brewed coffee, and then retrieving the full cups without mishaps. This minimizes the risk of errors and accidents, ensuring that each serving is perfect. Additionally, an innovative transfer unit efficiently delivers the prepared drinks to customers' designated seating areas, adjusting its height and reach to accommodate various locations.

In addition, RoboBrew significantly reduces human interaction by automating the coffee-making process, from the initial cup handling to the final serving. It involves multiple machines working in harmony, requiring precise control and coordination to ensure seamless operation. This system not only enhances the speed and accuracy of coffee preparation but also improves customer satisfaction with faster service and consistently high-quality beverages.

As for the technical overview, the RoboBrew system integrates mechanical, electrical, and software design components to optimize coffee production. High-quality mechanical parts, such as dosing screws and efficient components, ensure reliability and minimal coffee preparation time. The electrical design focuses on energy efficiency and consistent power supply, with sensors and actuators meticulously controlling the brewing and serving processes. On the software front, algorithms are developed to fine-tune brewing parameters for optimal flavor, while an intuitive interface allows users to customize their coffee preferences.

Block Diagram

As stated previously, the proposed system is divided into four major parts:

- The user interface, including the menu that will be printed on an LCD screen seamlessly the payment option
- Coffee machine development, focusing on designing and constructing the coffee machine with dosing screws and water control mechanisms
- Robot arm system is used to handle the cup smoothly and safely through advanced control and complex development
- Lead-screw transfer unit, utilized for smooth transportation of the coffee cup to the right location

Moreover, Fig. (1) shows the block diagram of the system where the different components are presented.

The block diagram shows the smooth operation of the RoboBrew system, designed to optimize the coffee preparation and delivery process in coffee shops and restaurants. The front line of this system is interacting with customers while viewing menus and prices displayed on an LCD screen. From there, selecting and ordering the drink consists of pressing the appropriate item on a keypad connected to the system. A robotic arm then moves to pick up the empty cup and place it precisely under the coffee maker so it can be poured. The coffee machine accurately weighs the coffee beans and pours the brewed coffee into a waiting cup. When the coffee is brewed and the cup is filled, the robotic arm picks it up and carefully places it on the transfer unit. The transfer unit transports the cups smoothly to the customer's desired location, ensuring efficient and timely delivery. This consistent integration and coordination between the various components of the RoboBrew system enables smooth and efficient coffee preparation and delivery for both customers and service providers.

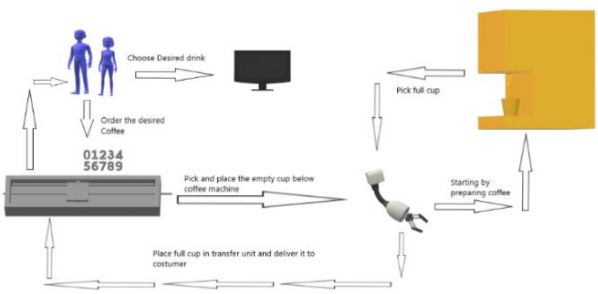

Fig. 1: Block diagram of the whole system

DOI: 10.3844/jmrsp.2024.31.38

Algorithm

The process begins when the customer arrives and chooses a location, then selects a drink from the available options. A signal is sent from the transfer unit controller to the coffee machine controller to start making the drink. Simultaneously, another signal is sent to the robot arm controller to pick up an empty cup from the cup keeper and place it under the coffee maker's valve.

First, at the coffee maker, the software checks the quantity of ingredients. If any of the ingredients is low, an LED lights up, prompting the operator to refill it. If all components are at the desired level, the water heater begins heating the water if the temperature is below 50°C. If the temperature is already at the required level, the water pump dispenses the necessary amount of water into the blender barrel. The dosing motor then measures the correct amount of tamper, and the blender mixes the drink. A proximity sensor at the front of the coffee maker ensures the cup is correctly placed. If the cup is not detected, the valve remains closed. Once the cup is in the correct position, the valve opens and fills the cup. A signal is sent from the coffee maker controller to the robot arm controller to remove the filled cup and place it on the transfer unit.

After placing the cup in the transfer unit, a signal is sent from the robot arm controller to the transfer unit controller. The transfer unit then delivers the coffee cup to the customer's location. Proximity sensors at each location detect the cup's arrival and whether it has been removed. If the cup is removed, the transfer unit returns to its original position, guided by an infrared sensor. If the cup is not removed, the platform remains stationary until the cup is removed.

Figure (2) represents the overall flowchart of the complete process as explained earlier.

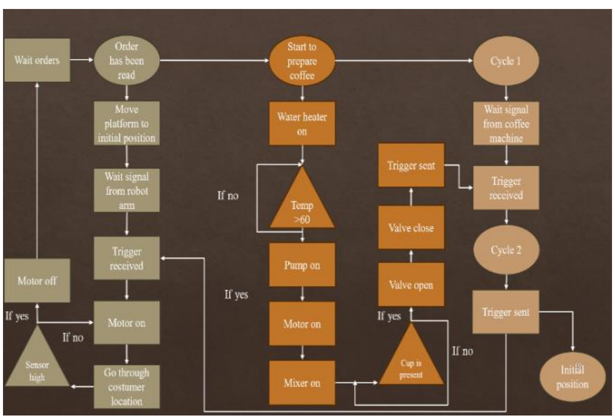

Fig. 2: Flowchart of the complete process

System Implementation

In this part, we will examine the complex details of mechanical construction, electrical connections, and design, emphasizing how the different modules in our system function together, focusing on the mechanical design, integration of sensors, microcontrollers, and communication between these devices.

Starting with the coffee machine, the framework was carefully designed with component dimensions in mind. The water heater area was isolated from electrical components and strategically placed with the pump. The electrical components were allocated a separate area, designed for easy wiring and access. The top of the machine was designed to hold more than three coffee powder tanks, with dosing screw mechanisms arranged symmetrically around a central hole. A mixing motor occupies the fourth corner. The mixing tank, located below the central hole, was securely fixed in place by aligning two holes to its height. The side cover of the machine accommodates a proximity sensor, while an inclined steamer fits easily beneath the valve, between the side covers. The pump was positioned above the water heater to prevent humidity exposure and minimize tubing length to the heater and mixing tank. For the dosing screw mechanism, the motor was mounted on a bracket, with the screw inserted into the dosing tank and connected to the motor shaft, ensuring efficient operation and secure installation of each component within the system. The complete setup is displayed in Fig. (3).

The lead-screw design was selected for the transfer unit due to its ability to smoothly and precisely transfer the cup. An 8 mm rectangular nut is fitted into the traverse, allowing slight play to reduce friction if the rod is not perfectly straight. An 8 mm diameter threaded rod with a 1.5 mm pitch and a 70 cm length was inserted into the nut. Two bearings were positioned at the rod's ends within the machine's side covers to ensure optimal alignment and minimal friction. Symmetrical aluminum guides were fixed on both side covers to provide additional support and stability.

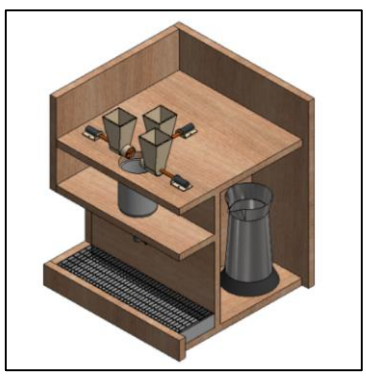

Fig. 3: Coffee machine assembly

DOI: 10.3844/jmrsp.2024.31.38

Fig. 4: Transfer unit assembly

For coupling components, a custom coupler was designed to match the motor's star-shaped shaft. The rods were machined with a key shape and corresponding drill holes: One end of the coupler fits the motor, while the other end accommodates the rod, secured with a pin to ensure a solid connection. The motor was fixed using a motor bracket, resulting in a smooth and precise operation of the transfer unit. This setup is displayed in Fig. (4).

The control and implementation strategy for the robot arm began by identifying the destination as well as the restricted area that the arm should avoid. With the coordinates of these locations already determined, reverse kinematics is used to calculate the necessary angles for reaching these points. The process started by selecting an empty spot and placing an object there. However, a challenge arose when the gripper couldn't securely hold the cup due to insufficient friction. To solve this, we added a gripping material to the gripper to improve its hold. Next, the full cup was filled up with a smoother and slower motion compared to the initial step of picking and placing the empty cup. Once secured, the full cup was carefully transferred to its designated location on the transfer unit. Between these steps, the robot returned to its initial position. This precaution was taken to minimize potential damage in case any coffee spilled during the transfer process, especially if the cups weren't precisely aligned with the valve.

Before starting the system assembly, we started by setting up a solid platform measuring 90×120 cm. These dimensions, mainly for the transfer unit, were used for the prototype. We selected high-quality, sturdy wood to ensure durability and support for the entire system. This platform served as a reliable base for all subsequent assembly tasks. After establishing the platform, the system was positioned with several important factors in mind. Ensuring easy access to electrical wiring locations was a priority to make maintenance and troubleshooting straightforward. For the electrical box, we aimed to balance accessibility with secure installation to protect delicate components while allowing easy reach. Similarly, the keypad was positioned to be user-friendly and comfortable to operate. The screen's location was chosen for clear visibility and easy access, enhancing the overall user experience during system operation. Additionally, every component was strategically placed to allow the robot to navigate seamlessly throughout the system, contributing to the system's functionality and performance.

Concerning the wiring and communication, power was supplied using a transformer that steps down the voltage from 220 to 12 V, and a 220 V phase was used to power the water heater, controlled through a relay. The transformer's 12V output was divided into six parallel lines. Two lines powered the motors for the dosing screws and mixer, one line powered the transfer unit motor, another supplied power to a pump through a relay, and one line powered a valve through a relay. The final line was connected to a step-down power supply that reduced the voltage from 12 to 5 V, ensuring reliable and regulated power distribution. The 5 V output from this supply powered the Arduino controllers for the coffee machine and transfer unit, while the robot arm had its own 5 V -4 a power supply.

The overall system implementation is illustrated in Fig. (5).

Inside the coffee machine, the pump, water heater, and valve are each connected to distinct relays that are normally open and activate when the controller sends a high signal. The motors for the dosing screws and mixer are connected to two motor drivers, which control the motors' speed and direction by linking their Enable (EN) and Input (IN) pins to the Arduino's PWM and digital pins. The coffee machine includes a laser transmitter and receiver; the transmitter acts as an output, whereas the receiver behaves as an input. When a cup is detected, the laser receiver sends a low logic state to the Arduino.

Six trigger pins are connected to the coffee machine's Arduino for communication. Trigger 1 sends an input signal to the coffee machine when the robot arm places an empty cup below the valve. Trigger 2 sends an output signal to the robot arm when the coffee is ready. Trigger 3 sends an input signal to the coffee machine when a customer orders a coffee. Trigger 4 sends an input signal to the coffee machine for a Nescafe 3 in 1 order. Trigger 5 sends an input signal to the coffee machine for a Nescafe 2 in 1 order. Trigger 6 sends an input signal to the coffee machine when it needs washing. These triggers can be extended when additional items are added to the menu.

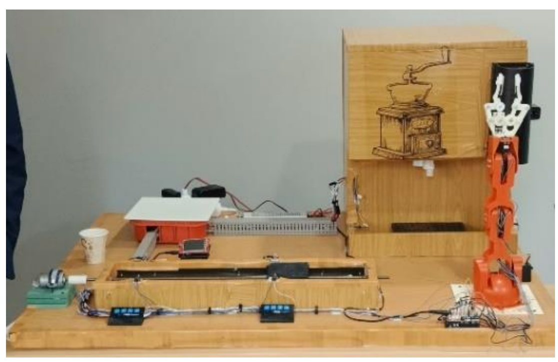

Fig. 5: Overall system implementation

DOI: 10.3844/jmrsp.2024.31.38

For the transfer unit, two keypads are used, each with five pins. They connect to the transfer unit's Arduino using eight different input pins, four for each keypad, with one pin from each ground. The motor is controlled by the BTS9870 motor driver. Two laser transmitters and two receivers are used, with one set for each customer location to detect cup arrivals, helping to distinguish between different customer seating positions. Keypads are also used to differentiate between drink orders and customer locations, with each case assigned a specific pin on the Arduino for clear identification.

Materials and Methods

This section will present the key components of the RoboBrew system, including the microcontroller, sensors, actuators, and manufactured equipment. All components, whether mechanical or electrical, are chosen with accuracy and purpose, supported by precise calculations and selection criteria. Understanding these components is our first step toward reinforcing the originality and innovative thinking that define our system, rather than simply focusing on technical specifics.

Regarding the mechanical equipment**,** the coffee machine sub-system is designed for speed and accuracy, completing the coffee ordering process in 30 sec. The dosing screw plays a key role, with the first five seconds used for dosing the coffee powder. The screw rotates at 1 round per second (RPM), or a motor speed of 90 RPM, delivering a flow of 1 gram per second. This is based on a coffee powder *density* of 0.309 g/cm³ and a pitch volume of 5.65 cm³. On average, the actual volume of coffee powder in the screw is 3.2 cm³. Therefore, the weight calculation is defined as follows:

$$M = Density \times Vactual = 0.309 \frac{g}{cm^3} \times 3.2\ cm^3 = 0.9888g \quad (1)$$

Thus, to achieve the desired output, the screw should rotate at 1 RPM. The tanks used in the system are designed to complement the dosing screw, featuring a curved bottom to reduce dosing errors and ensure accurate dispensing. Moreover, each tank can hold up to 300 grams of coffee powder, allowing for the production of about 60 cups of coffee, while minimizing space usage.

Moreover, the motor bracket is custom-designed to reduce costs and fit specific dimensions, offering a cost-effective alternative to pre-made options. The mixer tank is designed to prevent spills and handle high temperatures, being made from durable resin material. Its curved bottom ensures complete liquid drainage.

The traverse is an integral part of the transfer unit, facilitating the passage of the screw and nut. It serves three main functions: Supporting the wheels by securing the wheel rod, holding the rectangular nut in place, and supporting the platform with designated screw holes.

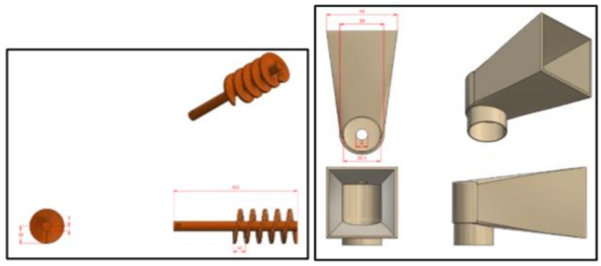

Fig. 6: Mechanical design of RoboBrew

To sum up, Fig. (6) shows the mechanical design of some components of the proposed system as the screw (figure to the left), and the coffee powder tank (figure to the right) where both items were designed and printed using a 3D printer.

As for the actuators, several factors were considered when selecting the motor for the dosing screws to meet the requirement of dispensing 1 gram of coffee powder per second. The motor must have the appropriate speed, as well as sufficient torque and power to function properly. It should also be compatible with the voltage source while offering durability.

Each thread of the dosing screw delivers approximately 0.9 grams of coffee powder, and each cup requires between 5 and 6 grams, with an average of 5.5 grams for optimal taste. Thus, the screw must make about six rounds to dispense the required amount of coffee powder. This is calculated as follows:

$$Rounds\, required = 5.5g \,/\, 0.9g/round \approx 6\, rounds \quad (2)$$

Therefore, the motor needs to turn six rounds at a speed of 90 RPM, accounting for potential errors in electrical components and mechanical design.

To find the load torque (T_c), three forces are considered: The friction force (F_f) between the dosing screw and the coffee powder, the force required to push the powder (F_r), and the force at the center of gravity of the screw (F_g).

In more detail, the force required to push the powder is calculated as follows:

$$Fr = M_c \times g = 0.0197\, N \quad (3)$$

where, M_c is the weight of coffee powder per pitch.

The friction force is found using the friction coefficient (μ = 0.6) between plastic and powder. Thus, the normal force (N) and the friction force are calculated as follows:

$$N = weight \times gravity \times cos(30°) \quad (4)$$

$$Ff = \mu \times N = 0.0102\, N \quad (5)$$

Finally, the force at the center of gravity of the screw is expressed as follows:

DOI: 10.3844/jmrsp.2024.31.38

$$Fg = M_s \times g = 0.1373\,N \quad (6)$$

where, M_s is the weight of the dosing screw at the center of gravity. By combining all required forces, the total force is expressed as follows:

$$F_t = F_f + F_r + F_g \approx 0.17\,N \quad (7)$$

Therefore, the required torque is:

$$T = F_t \times radius\ of\ the\ screw \approx 2.4 mN \cdot m \quad (8)$$

Finally, the required power is calculated as follows:

$$Power = \frac{rotational\ speed\ of\ the\ motor \times Torque}{9.55} = 0.027\,W \quad (9)$$

The chosen motor meets these requirements, considering speed, torque, and power, as well as compatibility and durability.

In the RoboBrew system, water is pumped from the water heater to the mixing tank. The decision to integrate a pump was based on several critical factors. Firstly, the pump was required to achieve a high flow rate to meet specified cycle times. Secondly, it was essential that the selected pump could withstand elevated water temperatures effectively. Lastly, compatibility with the voltage source was carefully considered to ensure optimal performance.

A valve is employed to regulate flow within the mixer tank. The decision to select this valve was influenced by several key factors. First, it needs to withstand high-temperature liquids effectively. Secondly, the valve had to be capable of handling liquids with medium viscosity. Furthermore, a water heater was utilized to heat water to achieve the ideal temperature.

The mixer motor function consists of mixing water and coffee powder at the bottom of the mixing tank. The selection of this motor was based on one crucial factor: It needed to have a 90-degree angle shape to fit our design, making an L-shaped motor the preferred choice.

Moreover, the transfer motor was used to drive the transfer unit, selected for its high torque and power, ensuring effective operation. Durability was a key consideration for long-term reliability, and compatibility with the voltage source was evaluated for consistent performance.

As a result, the friction force (F_{f_nr}) between the nut and the rod was calculated using the formula:

$$F_{f\_nr} = N \times \mu = m \times g \times \mu \quad (10)$$

where, N denotes the normal force, m represents the mass, g the gravity, and μ the friction coefficient, as displayed in Fig. (7).

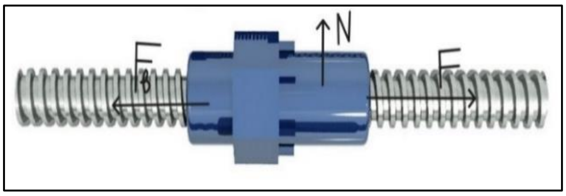

Fig. 7: Lead-screw applied force

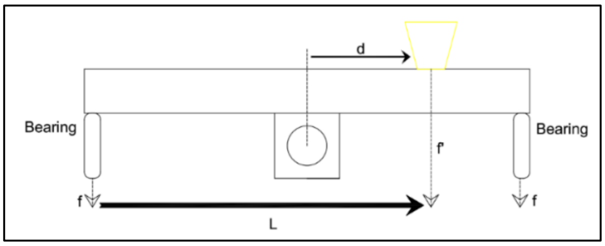

Fig. 8: Force diagram of the platform in the transfer unit

Furthermore, the force concentrated between the bearings and the guide, due to the weight of a full cup not centered on the platform, is computed as follows:

$$f \times L = m \times g \times d \quad (11)$$

where, L is the distance and d is the offset distance. The force f can then be computed as shown in Fig. (8).

To find the torque required for the lead screw, the standard formula is expressed as follows:

$$T_1 = 1/2\pi \times P \times F + \Sigma F_{external} \quad (12)$$

where, P is the pitch of the screw, and:

$$\Sigma F_{external} = 2 \times f \times \mu \times R \quad (13)$$

With R representing the radius.

As a result, the required torque T_1 is set to be 0.6 *N.m.*

Additionally, the torque needed to turn the rod, considering the inertia displayed in Fig. (9), is expressed as follows:

$$T_2 = J \times d\omega/dt \quad (14)$$

where, J is the inertia and $d\omega$ denotes the speed difference. Thus, the total required torque T_t is expressed as follows:

$$T_t = T_1 + T_2 \approx 0.9\,N \cdot m \quad (15)$$

Concerning the sensors, a laser transmitter module and an *IR* sensor are used as proximity sensors. The purpose of using these types of sensors involves several considerations. A proximity sensor is positioned on the front side of the coffee machine, where the cup should be placed.

DOI: 10.3844/jmrsp.2024.31.38

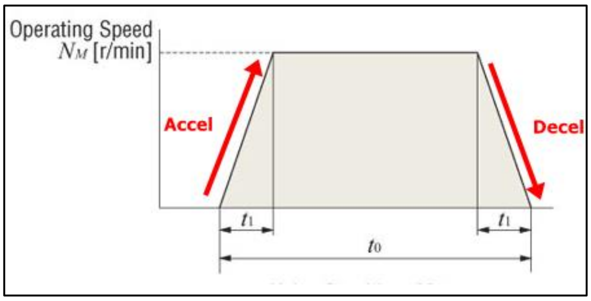

Fig. 9: Operating speed of motor

Additionally, this sensor is placed on the transfer unit at each location where a customer is seated. When the transfer unit reaches the customer's location, the sensor detects this and sends a signal to the controller to stop the transfer unit. Finally, the *IR* sensor on the transfer unit ensures that the plate stops at the exact initial position after each operation. A temperature sensor is also employed to measure the water temperature within the heater. The sensor is designed to be waterproof, guaranteeing solid operation even in damp situations.

Concerning microcontroller**s,** a study was conducted to identify the ideal microcontroller for our system, which includes a coffee machine, a robot arm, and a transfer unit. Key factors in the selection process included communication between microcontrollers, given that each machine requires interaction through multiple signals. The availability of I/O pins was crucial due to the numerous components, such as actuators and sensors, necessitating a microcontroller with ample I/O capabilities and the potential for expansion via peripheral interfaces. The Braccio robotic arm in our system uses a specific microcontroller to manage its six servo motors, requiring precise control to send accurate signals at the correct times. Usability and maintainability were also priorities, leading to the choice of a microcontroller with an intuitive interface and programming language. This choice is supported by a strong community, forums, and detailed documentation, facilitating troubleshooting and updates. Ultimately, the Arduino microcontroller was chosen to meet these requirements, with Arduino Mega used for the coffee machine and transfer unit, and Arduino UNO for the robotic arm.

Concerning the drive modules, two types of drive modules were deployed. For the coffee machine motor, which operates with low torque and requires minimal current for acceleration, the L298N motor driver module was selected. The motor driver utilized in the proposed system incorporates the double h-bridge L298N chip, designed to operate within specific parameters. It supports a maximum motor supply voltage of 12 V and can handle a current of 2 A.

As the motor of the transfer unit has high torque and power, a driver module suitable for this demand should have a high current capacity; therefore, the compatible driver module is BTS 9870. The motor driver features an input voltage range of 6-27 V_{DC} and is capable of handling peak currents up to 43 a.

Concerning the power supply, assuming the whole system is working at the same time, which means that all the sensors, actuators, and Arduino controllers are working, the maximum required current can be defined as follows:

$$I_{Max} = I_{MT} + 3 * I_{MC} + I_{Pins} + I_{Sensors} + I_{Valve} + I_{Pump} = 6.02\ A \quad (16)$$

Therefore, a 120 *W* power source is chosen for this system; moreover, a power supply unit capable of converting the standard 220 V_{AC} input to a stable 12 V_{DC} output is used. This power supply also has a large current output of 10 *A*, providing a considerable margin for accommodating additional components in the future without exerting undue pressure and risking overheating.

Finally, a step-down power supply module used to optimize the power distribution for our electronic components is employed. By connecting the module to the 12 *V* power supply, it is utilized to efficiently step down the voltage to a stable 5 *V*. This voltage drop is crucial for supplying power to the sensors and processing units, ensuring they operate within their specified voltage range.

Results and Discussion

It is noteworthy to mention that the full system was continuously tested over six hours with an average rate of 27 orders per hour. The findings show that along all the tests, two errors showed up: The first one was encountered when the number of remaining cups in the dispenser was limited to 1. The robot arm was not able to handle it precisely. The second problem was encountered with the delays when the customer did not pick up his order from the transfer unit. The first problem was resolved by adding a counter and delivering an alarm when the number of cups became smaller or equal to five. As for the second issue, audible and visual alarms were added near the LCD screen used to input the orders. These alarms will be generated when the order reaches its destination.

Conclusion and Future Work

This research paper has successfully integrated the design and development of the RoboBrew automated coffee system, highlighting both the complexity and achievements of the project. Despite facing several challenges, our commitment to innovation and precision led to the creation of a sophisticated and efficient system. The journey from conceptualization to realization

DOI: 10.3844/jmrsp.2024.31.38

involved extensive refinement, testing, and iterative adjustments to balance aesthetic appeal with technical accuracy. Our perseverance and dedication have resulted in a promising prototype that showcases the future potential of automated drink preparation.

Looking ahead, several opportunities exist for enhancing the RoboBrew system to better serve coffee shop environments and meet industry demands. Future developments will focus on improving the transfer unit to expand its coverage and capacity by installing multiple units at strategic intervals within the coffee shop. This adjustment aims to ensure comprehensive service coverage.

Incorporating Internet of Things (IoT) communication will significantly enhance functionality. By integrating QR codes and a comprehensive menu database, customers can easily place orders and specify their locations. This system will streamline the ordering process, manage inventory efficiently, and provide real-time alerts for ingredient replacement through an integrated alarm system. Transitioning to an Industrial-Grade Microcontroller, such as a PLC, will address the demands of continuous commercial use and improve durability.

Furthermore, implementing Uninterruptible Power Supplies (UPS) will ensure the system's resilience and continuous operation, minimizing disruptions and maintaining reliable service. These advancements will enhance the RoboBrew system's efficiency, functionality, and user satisfaction, positioning it as a leading solution in automated coffee preparation.

Acknowledgment

The authors wish to clarify that no funding agencies were involved in realizing this project; all financial support was provided by the authors themselves.

Funding Information

The authors would like to acknowledge all parties who contributed to the realization, testing, and validation of this study, including collaborators and technical support staff, whose expertise and dedication were invaluable throughout the process.

Author’s Contributions

Anthony Achkar and Maroun Hannoun: Design and implementation of the system. Draft the initial manuscript.

Rita Younes: Testing and validation of the system. Revision of the paper.

Jose Javier Serrano Olmedo and Roy Abi Zeid Daou: Supervision of the whole work. Finalize the paper.

Ethics

The authors affirm that the system described in this study was not applied to human subjects and has been designed to ensure that its use poses no harm or risk of injury.

References

Anjee, S. (2024). *Robotic Tech Innovations and Their Impact on the Restaurant Industry*. Colliers. https://knowledge-leader.colliers.com/anjee-solanki/robotic-tech-innovations-and-their-impact-on-the-restaurant-industry/

Ardiansyah, A. F., & Dimas Mahendra, B. S. (2023). Revolutionizing Robot Sorting: Unleashing the Power of Dobot Magician Arm’s Kinematics Inverse Transformation System with Depth Camera. *2023 IEEE International Conference on Communication, Networks and Satellite (COMNETSAT)*, 428–433. https://doi.org/10.1109/comnetsat59769.2023.10420575

Ari, W., Asni, T., & Sri, R. H. (2021). Robot Arm Design for Coffee Maker Arduino Based. *Advances in Engineering Research*, 438–442. https://doi.org/10.2991/aer.k.210810.076

Kathryn, M. (2010). *Coffee Preparation Through the Ages*. Comestibles. https://blog.kathrynmcgowan.com/

Korbuakaew, G., & Vongvit, R. (2023). Applying Self-Assessment Manikin (SAM) to Evaluate the Emotional Responses to the Service Robot Feature. *2023 8th International Conference on Business and Industrial Research (ICBIR)*, 568–572. https://doi.org/10.1109/icbir57571.2023.10147577

Oliver, B., & Lea, K. P. (2023). How can Bar Robots Enhance the Well-Being of Guests? *ArXiv*, arXiv:2304.14410. https://doi.org/10.48550/arXiv.2304.14410

Tuomi, A. I. (2021). *Designing Restaurants of the Future: Integrating Robots into Hospitality Service* [Doctoral Dissertation]. https://doi.org/10.15126/thesis.900166

Vladimir, H., Marin, Z., & Danail, S. (2022). Design of Automated Coffee Machine through Verilog HDL. *2022 International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT)*, 757–760. https://doi.org/10.1109/ismsit56059.2022.9932777