BREWBOT: DESIGN AND IMPLEMENTATION OF COLLABORATIVE ROBOTIC ARM (DOBOT CR3) SYSTEM FOR TURKISH SAND COFFEE MAKING

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ABSTRACT

This study explores the integration of automation into traditional culinary practices by designing and implementing BREWBOT, a collaborative robotic arm system that uses the DOBOT CR3 to automate Turkish sand coffee preparation. The primary objective is to replicate the traditional brewing process with high accuracy and consistency, focusing on ingredient dispensing and timing. The research addressed two main problems: (1) evaluating the DOBOT CR3's accuracy in dispensing coffee, water, and sugar within traditional standards, and (2) assessing the consistency of brewing operations across multiple trials. Using an experimental design, 30 trials were conducted with an Arduino-based dispenser, a custom gripper, a sand-heating station, and block-based programming. Descriptive statistics and one-sample t-tests showed that coffee and water dispensing were within acceptable ranges, and operations remained consistent. However, sugar dispensing deviated significantly from the target ($p = 0.013$), indicating the need for calibration. Despite this, the system demonstrated high accuracy and reliability in replicating traditional brewing. The findings suggest that robotics can support cultural preservation while improving consistency and efficiency in food preparation. BREWBOT offers practical applications in both commercial settings and heritage-based culinary innovation.

Keywords: collaborative robot, DOBOT CR3, Turkish sand coffee, food automation, cultural preservation

INTRODUCTION

Automation is quickly becoming an important element for development. It lessens the need for human labor and increases the efficiency of tasks and workplace productivity. Automation is mostly seen in large enterprises focused on manufacturing and is also used to build sophisticated equipment like medical devices, refrigerators, and automobiles. One of the most used automation systems in industrial settings is the robotic arm.

The robotic arm is a specialized mechanism typically mounted on a stable stand with end-effectors that allow it to grasp and move objects. These arms can be Cartesian, Cylindrical, Polar, SCARA, or Articulated, each varying in motion and application. End-effectors such as vacuum, magnetic, or force-controlled grippers enhance the arm's ability to handle a range of objects. These components work together to provide enhanced precision, reduce human error, and ensure safety in complex tasks.

Various designs have been proposed to automate repetitive or precise tasks. For instance, robotic arms that use machine learning, RFID systems for library automation, and Arduino-based Bluetooth-controlled arms have demonstrated promising applications in different fields. However, many of these systems are limited in function, require significant calibration, or focus on specific object types or environments.

The coffee shop industry in the Philippines has grown significantly in recent years. Coffee culture continues to expand, especially among younger consumers and those with increased disposable income. Local cafes and coffee artisans are now seeking ways to blend tradition with innovation. One such tradition is Turkish sand coffee, a historical and cultural method of coffee preparation that involves heating a cezve in hot sand to achieve a rich, foamy brew.

The preparation of Turkish sand coffee requires precision in heating, timing, and ingredient measurements. Its cultural significance and unique brewing process make it a suitable candidate for automation through robotics. However, the integration of robotics into this traditional process must preserve the sensory and quality attributes of the beverage.

This study focused on the design and implementation of a robotic system using the DOBOT CR3 collaborative robotic arm to automate the preparation of Turkish sand coffee. The researchers aimed to evaluate the system's accuracy and consistency in dispensing the correct amounts of coffee, water, and sugar, and in performing the required steps in the brewing process. The system was tested through multiple trials to determine its capability in maintaining the essential qualities of Turkish sand coffee, with the goal of combining traditional brewing with modern automation.

METHODOLOGY

A. Research Design

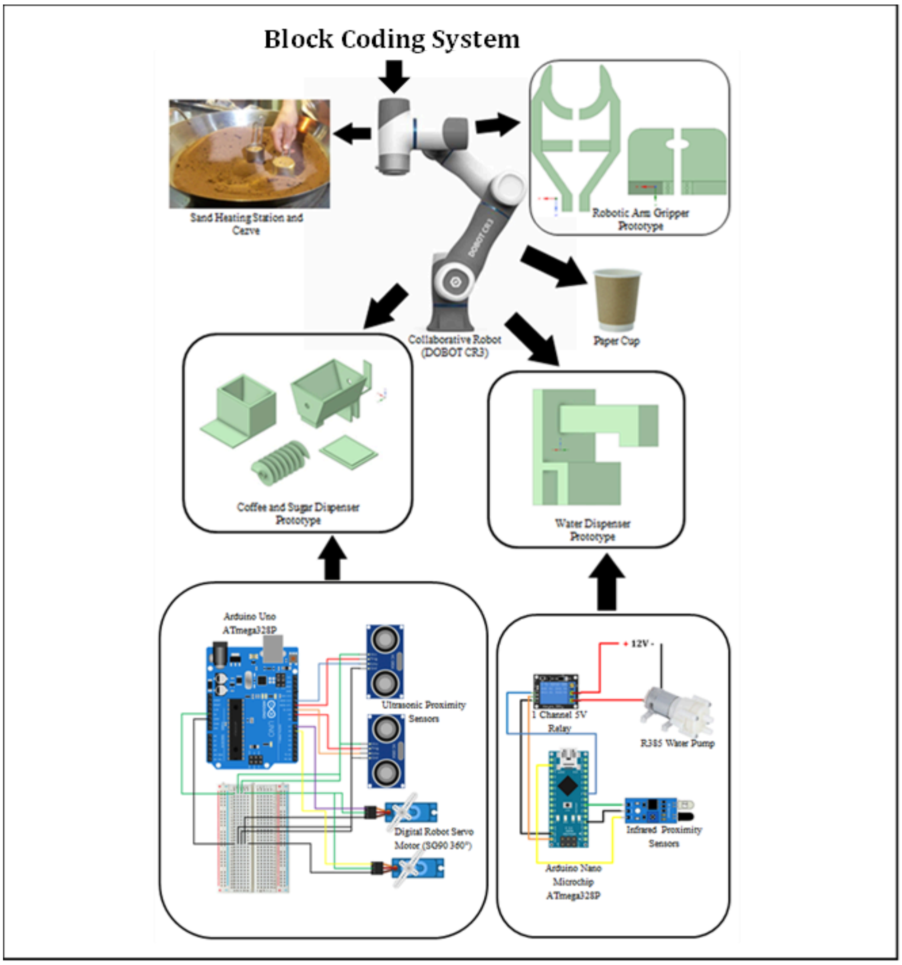
Hardware Design

Conceptual Framework

The figure below shows the conceptual framework of the BREWBOT system. The input was derived from the study's objectives. This process was subdivided into four main components: the hardware design and development, where the focus was on designing and assembling the DOBOT CR3 robotic arm with integrated dispensers and a Turkish sand coffee heating station; the software design, which involved developing block-based programming to control the robotic arm's operations; the integration of sensors and gripper mechanisms to ensure accurate handling and movement of the cezve; and the execution of multiple test trials to validate the system's performance. After going through these processes, the output is a functioning robotic system that automates the traditional Turkish sand coffee-making process while maintaining accuracy, consistency, and cultural authenticity in the preparation of the beverage.

The configuration of the BREWBOT system used to automate the Turkish sand coffee-making process is presented in Figure 1. The input data are triggered through sensor-based dispensers that dispense measured amounts of coffee, water, and sugar. These dispensers interact with the DOBOT CR3 collaborative robotic arm, which is programmed using a block-based visual interface. The robotic arm performs a series of tasks including grasping the cezve, moving it to each dispensing station, placing it into the heated sand for brewing, and transferring it to the final serving area. The sensors located near each dispenser detect the presence of the cezve and activate the release of ingredients accordingly

Figure 1
Conceptual Framework of the System



Designing the Ingredient Dispensing System

The dispensing system includes three separate stations for coffee, water, and sugar. Each station is equipped with an infrared sensor that detects the approach of the robotic arm. Once detected, the sensor triggers a mechanism to dispense the specific amount of the corresponding ingredient. This ensures consistency in quantity and timing during each trial.

Designing the Hand Gripper

A custom hand gripper was designed and 3D printed using heat-resistant ABS filament. It was specifically shaped to grip the handle of the cezve securely and withstand the high temperatures of the brewing process. The gripper allows the DOBOT CR3 to transfer the cezve from one station to another with stability and precision.

Designing the Turkish Sand Coffee Heating Station

The heating station consists of a stainless steel container filled with fine sand, which is heated using an electric coil. A thermostat regulates the temperature of the sand to ensure proper brewing conditions, typically around 200°C. This design allows for even heat distribution and supports the gradual heating required to produce the characteristic foam of Turkish coffee.

Programming the DOBOT CR3

The robotic arm was programmed using block coding to define its sequence of movements. These included approaching the dispensers, controlling the dwell time under each station, placing the cezve in the sand for brewing, and finally transferring the finished product to the serving area. The system was calibrated to mimic the manual brewing process in timing and sequence as closely as possible.

Software Design

The researchers used the following software in designing and testing the system: Arduino Integrated Development Environment (IDE) for microcontroller programming, Minitab Statistical Software for data analysis, and DOBOT Studio Pro for block-based programming of the robotic arm.

Figure 2 below shows how the device automates the preparation of Turkish coffee. It begins by picking up the Cezve (a coffee pot) and moving it to the water dispenser to fill it with water. Then, it moves the Cezve to the coffee powder dispenser, where the coffee powder is added, followed by the sugar dispenser for adding sugar. Afterward, the Cezve is transferred to the sand heating area, where the temperature of the sand is checked. Once the sand is at the correct temperature, the heating process begins by placing the Cezve in the sand. The device waits for the brewing process to complete, and finally, it moves the Cezve to the serving area, where the coffee is ready to be served. This step-by-step process ensures efficient and consistent preparation of Turkish coffee.

Figure 2
Flowchart of the DOBOT CR3

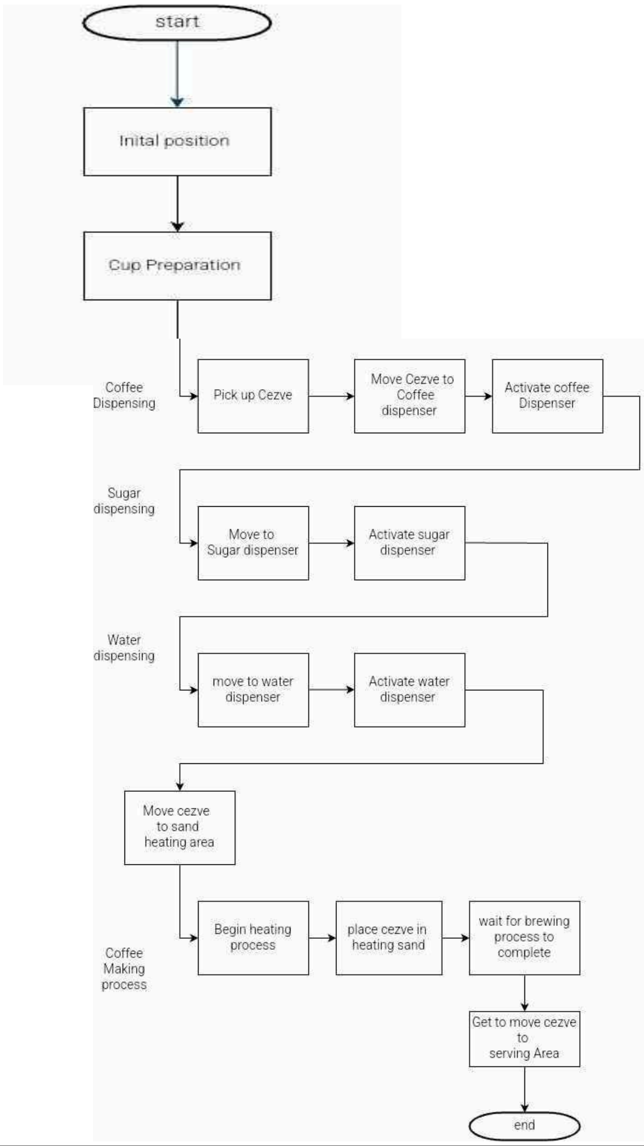
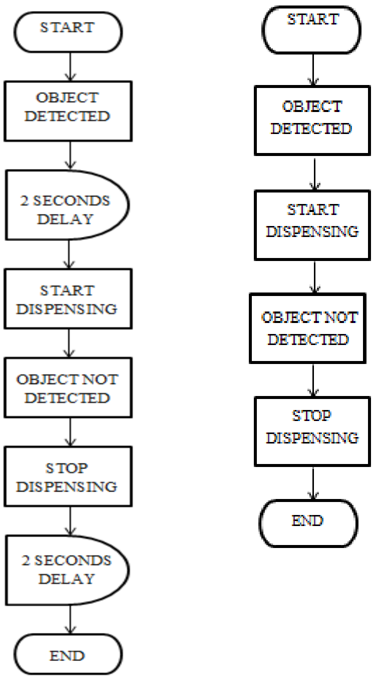


Figure 3 shows the flowchart of how the dispenser operates. It starts by first initializing the system, during which an LED indicator lights up to signal that the device is active and ready for use. It then waits for an object to be detected. Once an object is identified, the system initiates a brief delay to stabilize the process before starting the dispensing mechanism. During the dispensing phase, another delay ensures smooth operation. The device continuously monitors for the presence of the object, and when the object is no longer detected, the dispensing process stops. Finally, the system concludes its operation, completing the cycle efficiently and accurately.

Figure 3

Flowchart of the Dispenser (coffee and sugar on the left and water on the right)



B. Research Locale

The prototype development and data collection for this study were conducted at Saint Mary's University (SMU), located in Bayombong, Nueva Vizcaya, Philippines. Specifically, the trials and testing of the robotic arm system were carried out at the Technology Transfer and Business Development Office (TTBDO) of the university. This facility was selected due to its availability of resources, equipment, and a controlled environment suited for technical experimentation and evaluation.

C. Research Locale

This study did not involve any external human participants. Due to the technical nature of the research, the researchers themselves performed all procedures related to prototype testing and data collection. The primary objective was to assess the accuracy and consistency of the BREWBOT system in performing Turkish coffee preparation. All trials focused exclusively on evaluating the robotic arm's dispensing precision and timing performance during repeated brewing simulations.

D. Research Instruments

Several instruments were employed to facilitate the data collection process for this study. The primary tool used was the DOBOT CR3 Robotic Arm, a robotic equipment granted by the Department of Science and Technology (DOST) to Saint Mary's University as part of its support for the advancement of innovation in science and technology within higher educational institutions. This was evaluated for its precision in positioning, timing, and movement to ensure accurate and repeatable task execution. Ingredient dispensers were also utilized to automate the delivery of coffee, water, and sugar, and were assessed based on their accuracy and consistency in dispensing the specified measurements required for the brewing process.

Moreover, a gas stove equipped with a thermostat served as the primary heating element for this study. It was carefully monitored to verify its ability to maintain the consistent sand temperature necessary for the preparation of traditional Turkish coffee. Additionally, various sensors were integrated into the system to automate the triggering of ingredient dispensing. The end effector attachment, fitted to the robotic arm, was evaluated for its effectiveness in gripping, maneuvering, and handling the coffee pot throughout the brewing procedure. Each instrument was selected and assessed based on its contribution to maintaining the fidelity and reproducibility of the brewing process in an automated setup.

E. Data Gathering Procedure

The data collection involved recording quantitative measurements to evaluate the BREWBOT system's performance in preparing Turkish coffee. A data log sheet was used to document the amounts of coffee, water, and sugar dispensed, the timing of each operation (dispensing, heating, and brewing), and the temperature maintained during the process. These data were analyzed to assess the system's accuracy and consistency.

In addition to quantitative records, the researchers also took observational notes during each trial. These included the robotic arm's movement precision, any malfunctions, and necessary adjustments made to the end effector. The observations helped verify the system's performance in handling the cezve, transferring it between stations, and completing the brewing process. Together, these methods ensured a thorough evaluation of the system's technical reliability and operational consistency.

Table 1
Quantitative Accuracy and Consistency Test for the Robotic Arm in making a Turkish Sand Coffee

Metric	Trial 1 to Trial 30	Average	Acceptable Range
Dispensing Accuracy			
Coffee (g)		—	9-11 g
Water (ml)		—	120 ml
Sugar (g)		—	9- 10 g
Timing Operations			
Dispensing		—	60 seconds
Heating Stabilization		—	5 seconds
Heating (Brewing over hot stove)		—	7 minutes
Total Time		—	8 minutes and 5sec

The data gathered from the trials were analyzed using descriptive statistical methods. The mean and standard deviation were calculated to evaluate the accuracy and consistency of the BREWBOT system in dispensing ingredients and performing brewing operations. The mean determined the average quantity dispensed and the average brewing time, while the standard deviation measured the variability of the results in relation to the mean. These values were used to assess whether the system's performance remained within the acceptable operational range defined in the study.

A one-sample t-test was also conducted using Minitab Statistical Software to evaluate whether the mean values for coffee, water, and sugar dispensing, as well as timing operations, differed significantly from the target values. The test values were based on accepted standards from related literature in robotics and food processing, which recommend using a central value within a specified range for consistency.

All computed results were interpreted to determine the BREWBOT system's overall performance in automating the traditional Turkish sand coffee-making process. The statistical outcomes served as the basis for evaluating accuracy and identifying potential areas for improvement.

F. Treatment of Data

A one-sample t-test was used to determine the accuracy and consistency of the BREWBOT system in dispensing coffee, water, and sugar, and in performing timing operations related to Turkish sand coffee preparation. This statistical method was applied to compare the system's mean output values against the target or acceptable reference values identified in the study.

All statistical analyses were conducted using Minitab Statistical Software. A significance level (α) of 0.05 was used as the threshold for hypothesis testing. If the computed p-value was less than 0.05, the result was considered statistically significant and the null hypothesis was rejected. If the p-value was greater than 0.05, the result was considered not statistically significant and the null hypothesis was accepted.

Descriptive statistics, including the mean and standard deviation, were also used to evaluate the system's overall performance. These metrics helped assess whether the BREWBOT system operated within the acceptable operational ranges and supported the identification of areas needing calibration or improvement.

RESULTS

Table 2
Analysis of Coffee Dispensing

Descriptive Statistics

μ: population mean of coffee

Test

The average amount of coffee dispensed over 30 trials was 10.44 grams, which falls within the acceptable range of 9–11 grams. A one-sample t-test showed no significant difference from the target value of 10.5 grams ($p = 0.440$). Therefore, the null hypothesis is accepted.

Table 3
Analysis of Coffee Dispensing

Descriptive Statistics

μ: population mean of water

Test

The average water dispensed was 120.47 ml across 30 trials. A one-sample t-test showed no significant difference from the target value of 120.5 ml ($p = 0.797$). The null hypothesis is accepted, indicating the system dispensed water consistently within the acceptable range.

Table 4
Analysis of Sugar Dispensing

Descriptive Statistics

μ: population mean of sugar

Test

The average sugar dispensed was 10.15 grams over 30 trials. A one-sample t-test showed a significant difference from the target value of 10 grams ($p = 0.013$). The null hypothesis is rejected, indicating the system dispensed slightly more sugar than intended.

Table 5

The accuracy and consistency of the DOBOT CR3 robotic arm system in dispensing Specific Ingredients

Variable	Target Value	Mean Value	t-value	p-value	Qualitative Interpretation
Coffee	9-11 g	10.44 g	-0.78	.440	Not Statistically Significant, Falls within the acceptable range
Water	120-121 ml	120.47 ml	-0.26	.797	Not Statistically Significant, Falls within the acceptable range
Sugar	9-10 g	10.15 g	2.64	.013	Statistically significant, slightly deviates from the acceptable range

A total of 30 samples were analyzed for each ingredient. Coffee (mean = 10.44 g, p = 0.440) and water (mean = 120.47 ml, p = 0.797) showed no significant difference from their target values, indicating accurate dispensing. Sugar (mean = 10.15 g, p = 0.013) showed a significant difference from the 10 g target, indicating a slight over dispensing. The BREWBOT system performed accurately for coffee and water but requires calibration for sugar.

Table 6

Analysis on the Timing of Operations in dispensing

Descriptive Statistics

μ: population mean of dispensing

Test

The average dispensing time was 60.07 seconds over 30 trials, within the acceptable range of 59 to 61 seconds. A one-sample t-test showed no significant difference from the target value of 60 seconds (p = 0.774). The null hypothesis is accepted, indicating accurate and consistent dispensing time.

Table 7

Analysis on the Timing of Operations in Heating Stabilization

Descriptive Statistics

μ: population mean of heating stabilization

Test

The average heating stabilization time was 5.07 seconds, with a standard deviation of 0.58 seconds. A one-sample t-test showed no significant difference from the target value of 5 seconds (p = 0.536). The null hypothesis is accepted, indicating consistent heating stabilization time within the acceptable range.

Table 7

Analysis on the Timing of Operations in Brewing over Hot Sand

Descriptive Statistics

N	Mean	StDev	SE Mean	95% CI for μ
30	419.600	1.850	0.338	(418.909, 420.291)

μ: population mean of brewing

Test

Null hypothesis	H_0: μ = 420
Alternative hypothesis	H_1: μ ≠ 420

T-Value	P-Value
-1.18	0.246

The average brewing time was 419.60 seconds, with a standard deviation of 1.85 seconds. A one-sample t-test showed no significant difference from the target value of 420 seconds (p = 0.246). The null hypothesis is accepted, indicating that the system consistently completes the brewing process within the expected time.

Table 8

Analysis on the Timing of Operations in Brewing over Hot Sand

The average total process time was significantly different from the target value of 485 seconds, with a p-value of 0.006. The null hypothesis is rejected. The 95% confidence interval (0.33 to 1.81) indicates a slightly longer process time, suggesting the BREWBOT system exceeds the target duration by a small but statistically significant margin.

Descriptive Statistics

μ: population mean of total time

Test

Table 9

Summary of Accuracy Data from the Timing of Operations

Variable	Target Value	Mean Value	t-value	p-value	Qualitative Interpretation
Heating Stabilization	5 min	5.07 min	0.63	.536	No significant difference from the target value. Heating time is stable and consistent.
Brewing Time (Heating)	420 sec (7 min)	419.60 sec	-1.18	.246	No significant difference from the target value. Sand brewing time is consistent.
Dispensing Time	60 sec	60.07 sec	0.29	.774	No significant difference from the target value. Dispensing is consistent and stable.
Total Time	485 sec (8 min 5 sec)	486.07 sec	2.95	.006	With significant difference. Total process time is slightly longer than expected but still reasonable.

Table 9 summarizes the timing accuracy of the BREWBOT system. Dispensing, heating stabilization, and sand brewing times showed no significant differences from their target values, confirming consistency and accuracy. However, the total process time showed a statistically significant difference, being slightly longer than expected. Despite this, the deviation remained minor, and the overall timing performance of the system is still considered consistent and reliable.

Discussion

The primary goal of this study was to evaluate the accuracy and consistency of the BREWBOT system in automating the traditional Turkish sand coffee-making process using the DOBOT CR3 robotic arm. The results demonstrated that the system met the expected standards for ingredient dispensing and timing operations, with minor exceptions that warrant further calibration.

In terms of ingredient dispensing, the system consistently dispensed coffee and water within the acceptable target ranges. The one-sample t-tests showed no statistically significant differences from the target values, indicating that the robotic system was capable of accurate and repeatable dispensing for these two ingredients. However, the dispensing of sugar slightly exceeded the upper boundary of the acceptable range, with a statistically significant difference observed ($p = 0.013$). Although the deviation was minimal, it suggests the need for calibration in the sugar dispenser mechanism to improve alignment with the desired measurement.

Timing operations were also found to be consistent with the expected values for individual steps. The dispensing time, heating stabilization time, and brewing time all showed no significant deviations, confirming that the robotic system can perform these tasks with precision and consistency. However, the total operation time of the system was found to be slightly longer than the target value, and this difference was statistically significant ($p = 0.006$). While this indicates a measurable deviation, the overall impact is minor and does not substantially affect the system's performance or the quality of the coffee produced.

The findings affirmed that the BREWBOT system can reliably replicate the traditional Turkish sand coffee-making process with high precision and repeatability. The successful integration of the DOBOT CR3 robotic arm with ingredient dispensers, a sand heating station, and block-based programming proved effective in maintaining the cultural and sensory attributes of the beverage. Furthermore, the ability to automate this culturally rich process opens opportunities for preserving traditional methods while introducing modern efficiencies into commercial and educational settings.

Despite minor discrepancies, the system's performance aligns well with the study's objectives. The results support the feasibility of using collaborative robotics in culturally significant culinary applications, bridging the gap between tradition and technology. Future improvements in dispensing accuracy and optimization of total operation time may enhance the system's functionality even further.

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