Automated crêpe preparation with collaborative robot

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Abstract

Driven by the demand for consistent, effective, and unique crêpe preparation methods we dug into the automation of the process itself. This paper presents the development of a collaborative robotic cell used for crêpe-making automation. The objective of the research was to develop a fully functional robotic cell that can fulfill all of the above-mentioned qualities. Our approach consists of an advanced collaborative robot mechanism, which exploits the potential of computer vision methods to solve the challenges related to crêpe-making. The application consists of batter dispensing, rolling, and serving the crêpes. The integrated vision system provides the robot with information about the crêpe's location, which allows precise rolling. The tests of the application showed promising results. Our robotic cell offers solid groundwork for future research on this topic.

1 Introduction

Automating food preparation using robots presents challenges in manipulation, computer vision, tactile sensing, and human-robot interaction, crucial for achieving a fully automated robotic food preparation [1, 2]. The integration of robots in the food industry has revolutionized production quality and process efficiency [3]. Augmenting the human with a collaborative robot in the process of food preparation improves its consistency, eliminates the possibility of human error, and frees the human from the repetitive and time-consuming nature of the tasks [4, 5]. In particular, the challenge of automating pancake preparation has sparked research efforts aimed at automating the pancake-making process. Making pancakes requires manipulation actions with effects that go far beyond the effects of pick-and-place tasks in terms of complexity [6].

The challenge of automated crêpe preparation has motivated research into the automation of the crêpe-making process. This paper focuses on the development of a collaborative robotic cell specifically designed for crêpe automation. The objective of our research is to create a fully functional robotic system capable of achieving consistent, accurate, and efficient crêpe-making. Our approach combines an advanced collaborative robot mechanism with computer vision techniques to address the challenges associated with crêpe preparation.

2 Methodology

To automate crêpe preparation, we designed a robotic cell that incorporates a collaborative robot, a vision system for crêpe recognition, and a safety scanner.

2.1 Hardware setup

A professional crêpe machine (Oprema OMO, Mostar, Bosnia and Herzegovina) is used to make crêpes. It includes a batter dispensing cart as well as a 2 kW heating element with thermal regulation. A crêpe measuring $48\,\text{cm} \times 20\,\text{cm}$ can be prepared in under 30 seconds when operated by a human. Robotic cell is presented in Fig. 1

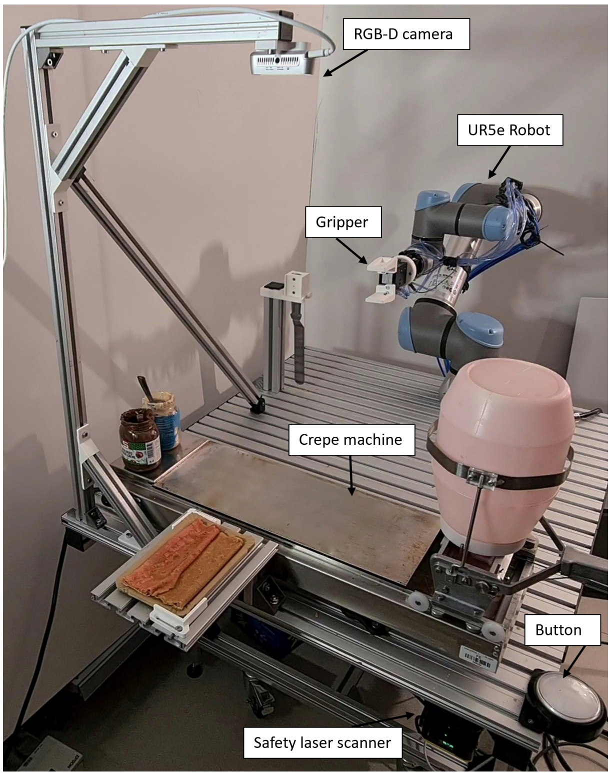

Figure 1: Collaborative robotic cell for crêpe automation

The robotic cell comprises of the Universal Robots UR5e collaborative robotic manipulator equipped with the Zimmer MGP812N pneumatic gripper. The gripper features 3D printed fingers that enable both manipulation of the batter dispensing cart and gripping of the spatula for crêpe handling. For computer vision tasks, we utilize the Intel RealSense D435i RGB-D camera, supported by artificial lighting to optimize visibility. The camera is positioned at an optimal height and angle relative to the crêpe machine, ensuring complete depth information in all captured pixels. To further enhance safety, we have integrated the 2D safety laser scanner SICK NanoScan3 into the system.

2.2 Crêpe detection

The vision algorithm aims to identify a reference points on the side of the crêpe and determine its x coordinate within the coordinate system of the crêpe machine.

The RealSense camera is factory calibrated and offers the advantage of performing a transformation from a pixel in the 2D color image to a corresponding 3D point in the camera's coordinate system, utilizing information from the depth image. To achieve this, we first established the transformation between camera and robot coordinate systems.

To determine the transformation, a chessboard pattern was used, defining three points (Fig 2). By establishing vectors between these points and utilizing their cross-product, we were able to define the coordinate system of the crêpe machine. This allowed us to calculate the transformation between the camera's coordinate system and the crêpe machine.

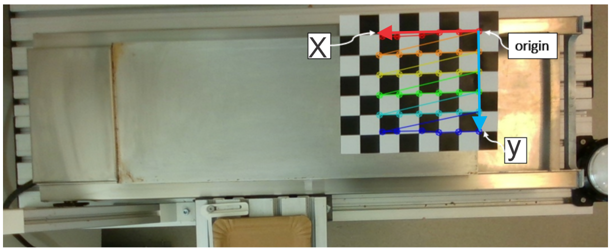

Figure 2: Calibration for transformation between the camera's and crêpe machine's coordinate system

The image processing algorithm primarily relies on background subtraction. The process begins by capturing a reference image of the crêpe machine at the start of the cycle. Once the crêpe batter is dispensed, another image is captured, and images are subtracted. Since the crêpe is the only new object in the scene, the resulting image displays the crêpe against a black background. To mitigate potential noise, additional filtering is applied. To further isolate the crêpe, a thresholding technique converts the grayscale image into a binary image. This binary image enables us to identify the contour that outlines the crêpe. Next, we approximate the contour with a rectangle. By calculating the aspect ratio of the rectangle, we can estimate the size of the crêpe. Additionally, we determined a threshold value for the aspect ratio through experimental calculations, which indicates whether the crêpe has been fully rolled or requires further flips. Finally, the midpoints of each side of the rectangle are computed. Among these midpoints, the point with the highest x value corresponds to the desired point for performing the crêpe flip.

This process is repeated after each flip until the crêpe is fully rolled. The output results of each stage can be observed in Fig 3.

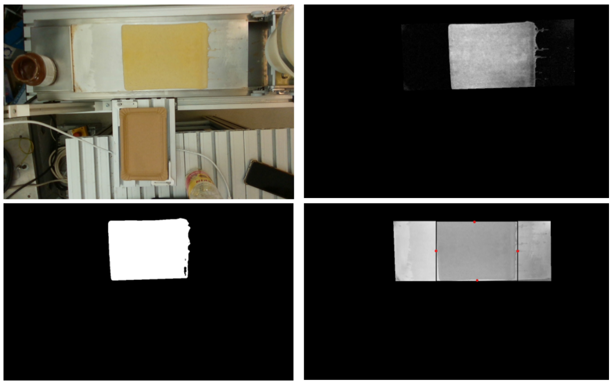

Figure 3: Output results from each stage of the image processing algorithm. Input image (top left), subtracted image (top right), thresholded image (bottom left), the crêpe contour with midpoints (bottom right).

2.3 Hand-tracking for custom crêpe size

For custom-sized crêpes, we have implemented a feature that allows users to indicate their desired crêpe length to the camera.

The core of this algorithm is the hand-tracking solution by the MediaPipe framework [7], which enables real-time detection and tracking of human hand landmarks from video input. This functionality relies on an integrated deep learning-based model.

The starting point of the crêpe is fixed and predefined. For a custom-sized crêpe, the user uses one hand to point where the crêpe should end. The algorithm leverages the hand-tracking solution to calculate the pixel above the index finger landmark (Fig 4.). This pixel position is then transformed into a corresponding 3D point within the camera's coordinate system. Next, the algorithm maps this 3D point to the crêpe machine's coordinate system. Finally, x coordinate of the detected point is then sent to the robot, indicating the desired end point of the crêpe.

Figure 4: Detected pixel above the index finger landmark from the hand-tracking solution.

2.4 Crêpe making process

The process begins with the robot dispensing crêpe batter onto the crêpe machine. The robot then retrieves the spatula and waits for a brief 12-second cooking wait, followed by a request to the camera. The image processing algorithm calculates the starting coordinates for the crêpe flip. The robot executes the flip accordingly. This repeated process continues until the crêpe is completely rolled. Once rolled, the robot serves the crêpe on a plate positioned in front of the crêpe machine, finalizing the preparation. The system is then primed and ready to fulfill a new order.

The software was organized into three separate programs. The initial program, developed using URScript programming language, served as the main robot program. The second program focused on computer vision and played a crucial role in the overall operation. Lastly, a graphical user interface (GUI) was implemented, providing users with the ability to initiate the process and select whether they desire a standard or custom-sized crêpe.

2.4.1 *Robot program*

The robot program is designed to execute a single application cycle, involving dispensing the crêpe batter onto the hot plate, rolling the crêpe, and serving it on a plate. To ensure seamless operation, the main program is divided into four synchronized subprograms, each responsible for a specific task within the cycle. The main robot workflow is depicted in Fig. 5.

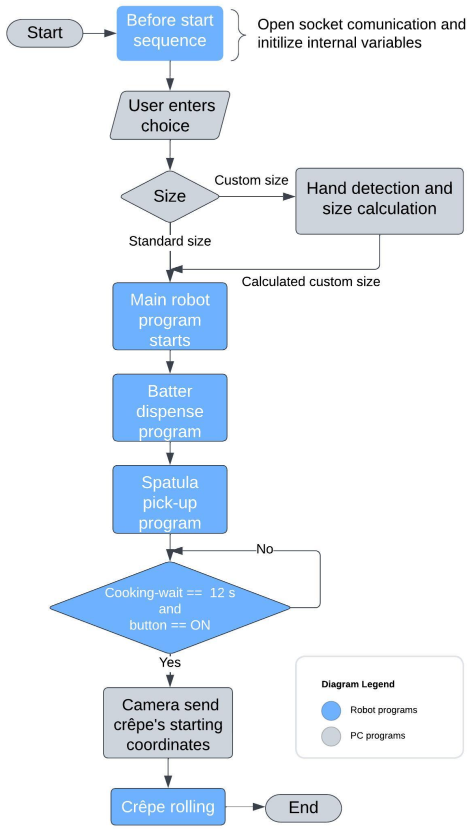

Figure 5: Diagram of the main robot program

1. Main robot program: This program serves as the core, coordinating the execution order of subprograms and facilitating socket communication for data transfer between the robot and the camera program.
2. Batter dispensing program: In this subprogram, the robot utilizes an empty gripper to pour the crêpe batter onto the hot surface of the crêpe machine with the assistance of the batter cart. Crêpe length parameter is determined based on the user's choice. It is either the custom size set by the user or the predefined size in the program, in case the user selected a standard size crêpe.

3. Picking up the spatula: After dispensing the batter, the robot changes its tool by gripping the spatula, preparing for the rolling technique execution.
4. Crêpe rolling: This subprogram executes the rolling cycle based on information provided by the camera. The robot receives coordinates of the crêpe's starting position and awaits new start coordinates after each flip. The rolling continues until the crêpe is fully rolled, after which the robot picks it up and serves it. The process of crêpe rolling is illustrated in Fig. 6.

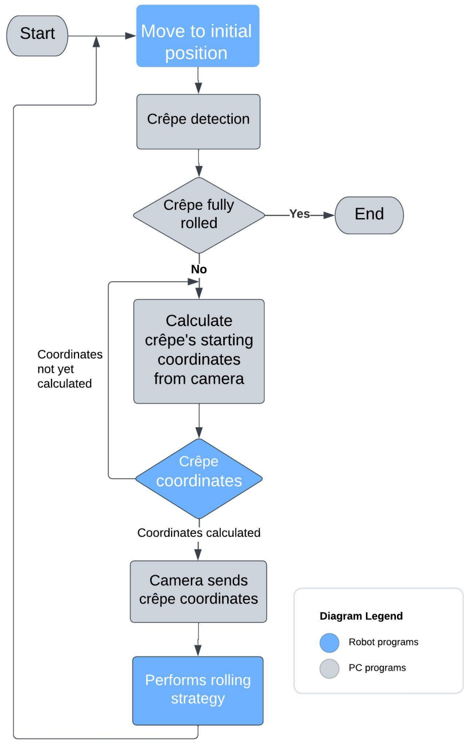

Figure 6: Diagram of crêpe rolling

During the cooking-wait, human enters the robotic cell in order to spread the topping on the crêpe. In that period the robot is in stand-still mode, waiting on the button confirmation by the user, that the action is concluded. The robot program is also configured to switch to safety mode, in case the safety sensor is triggered. Safety mode settings ensure lowering of the tool and elbow speed of the robot to velocities that are safe for the human inside the collaborative workspace.

3 Experimental crêpe preparation

The collaborative robotic cell underwent an experimentation protocol to assess its performance. The experimentation consisted of 15 consecutive cycles, with each cycle involving the preparation of a single crêpe using the same batter batch. To ensure consistency, the lighting conditions remained unchanged throughout the experiment. Additionally, the crêpe length was pre-defined to adhere to a standard size of 26 cm.

The results for the average duration and their corresponding standard deviations are presented in Table 1. The table provides a summary of the cycle duration as well as the duration of each individual phase within the cycle.

Table 1: Duration of different phases of crêpe preparation presented as average time (standard deviation)

Cycle phase	**Duration / s**
Batter dispensing	28.2 (1.3)
Crêpe cooking	13.4 (2.3)
Crêpe rolling	30.5 (2.7)
Total cycle	79.1 (3.3)

4 Discussion

This paper presents an automated crêpe preparation system that utilizes a collaborative robot with additional safety measures. The experimentation process involved tests on crêpe rolling methods with and without the use of a camera. The findings emphasize the crucial role of the camera in the robotic cell's operation.

An observed issue was the inconsistency in crêpe batter, resulting in uneven flips despite repetitive robot movements. This made it difficult to accurately determine the required number of flips to roll the entire crêpe. However, integrating a camera addressed this problem by providing adaptive flips through continuous monitoring of the crêpe's starting location after each flip. The camera also solved the fixed number of flips problem by allowing an adaptive number of flips based on the crêpe's size.

While the camera integration offers benefits, it introduces drawbacks and challenges. The cycle duration increases due to the ongoing processing and verification of the new starting position after each flip, requiring sending of new coordinates to the robot. Stable lighting conditions become crucial for the algorithm to function effectively.

The process of crêpe-making on the crêpe machine was repeated multiple times by both the robot and humans. Based on the measurements, we observed uneven flips, as indicated by a relatively high standard deviation of 2.7 seconds in the crêpe rolling procedure, which correlates with a higher number of required flips. Additionally, the crêpe cooking time significantly contributed to the variations in cycle duration, as it varied based on the time needed by the human to fill the crêpe. Apart from these two factors, the other phases were completed in a relatively consistent time duration during each cycle and did not have a significant impact on the standard deviation of the overall cycle duration.

In terms of consistency, the robotic application demonstrated a higher level of quality across batches due to its precise and consistent execution, unlike humans who may exhibit variations in pouring technique and rolling timings. The most noticeable difference was detected in the accuracy of the batter pouring. Humans tend to have more problems with dosing, due to variation of hand velocity. On the other hand, the robot has no problem with maintaining desired velocities, which results in better consistency of the pouring.

Another aspect to consider is the efficiency of the process. Robot-assisted approaches have been known to enhance efficiency, especially in high-volume food industry. During our testing in the laboratory, we observed that humans are more likely to require breaks, which can lead to interruptions in the workflow. On the contrary, robots can work continuously without breaks, resulting in reduced overall time and increased productivity.

Further research has the potential to enhance the capabilities of the robotic cell significantly. A key area for improvement lies in developing a mechanism to automate the filling of crêpes with desired flavors. While currently reliant on human intervention, integrating automated filling dispensing solutions will enable the realization of a fully autonomous robotic cell.

In addition, the repetitive cycles of crêpe preparation can lead to batter residue accumulating on the dispenser, compromising the even distribution of the mixture on the stove. To address this, it is essential to incorporate a cleaning mechanism for the batter dispenser. This will ensure consistent performance and quality throughout multiple cycles.

5 Conclusion

In conclusion, our research has resulted in the successful development of a collaborative robot application for crêpe-making.

Through the implementation of a well-designed rolling strategy and the valuable insights from the camera, we have achieved improved precision in crêpe rolling. The tests demonstrated the advantages of our robotic application, particularly in terms of consistency and accuracy, especially during the batter pouring task.

Our work sets the foundation for future advancements in this field, showcasing the potential of computer vision to address challenges in the realm of crêpe-making.

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