Designing a waffle making robot

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Introduction

To attract more students to engineering, the University Of Agder wanted to obtain a product that could showcase mechatronics in a fun and engaging way. A waffle making robot was chosen as a suitable demonstration. The project focuses on automating the processes of opening/closing the iron, greasing the iron, pouring in batter and serving the finished product. Eating the waffles was not automated, leaving the job to humans. The core innovation made by this project was the inlusion of machine vision to make the system adaptable to changes in the environment.

State of the art

When automating the process of waffle-making, more hardware is needed compared to making waffles by hand. A ViperX 300S, six degree of fredom, robotic arm was used as a primary actuator. A RealSense D455 camera was used to sense objects. The control of these components was performed using a Jetson Orin Nano microcomputer. These three components together form a system following the sense-think-act (camera-microcomputer-robot) model of robotics.

The software was developed on top of existing frameworks. The robot was hosted on the Robot Operating System (ROS) using MoveIt and a open-source API provided by the manufacturer of the robot to control movements. The camera software used the OpenCV computer vision library to locate objects in 3D space. The novel designs made to adapt the system for automation relied heavily on 3D printing technology for manufacturing. Special heat resistant filaments like Onyx were used where needed.

Design

The system was made on top of a plywood base plate with a tablecloth. The layout consisted of four zones. Closest to onlookers, a serving station was placed. Here, finished waffles would lie in wait of mouths to feed. Next to it was the preperation zone. Here a batter bowl and grease was placed. Right behind the preperation zone lied the waffle iron. The waffle iron had a custom set of rod inserts that would be baked into the waffles, allowing for easy extraction when they were done. In the opposite corner, the electronics needed to drive the hardware was placed. These electronics were placed in a protective housing, shown in figure 1. The housing had a lid, on top of which the robot was placed. Each of the mechanical components had special modifications made that made it easier for the robot to interact with its environment.

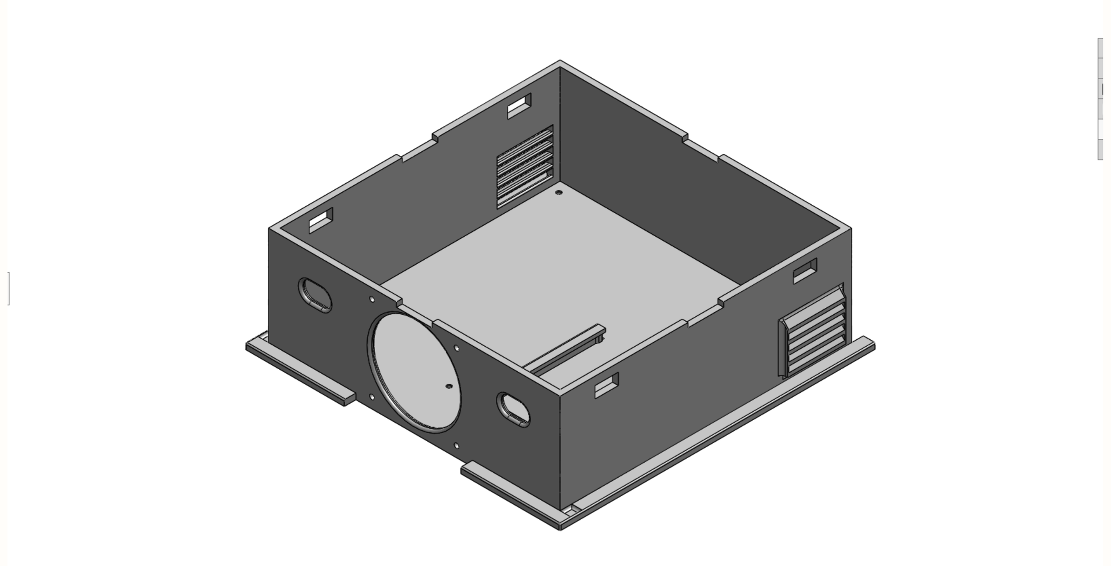

Figure 1: The housing used to mount electronics.

The control software used was based on the principle of moving the robot by hand and recording its positions. When the record button was pressed, the camera would simultanously take a picture. Each object of relevance had an ArUco marker attatched to itself. Image processing was used to find the positions of the marker. The position of the marker would be referenced against the position of the robot to record the relative pose from marker to robot. The offsets were computed using equation (1) and played back later with (2).

$$\mathbf{O} = \mathbf{M}^{-1}\mathbf{A} \tag{1}$$

$$\mathbf{A} = \mathbf{M}\mathbf{O} \tag{2}$$

This setup allowed the robot to follow along with the marker if it moved. The concept is shown in figure 2.

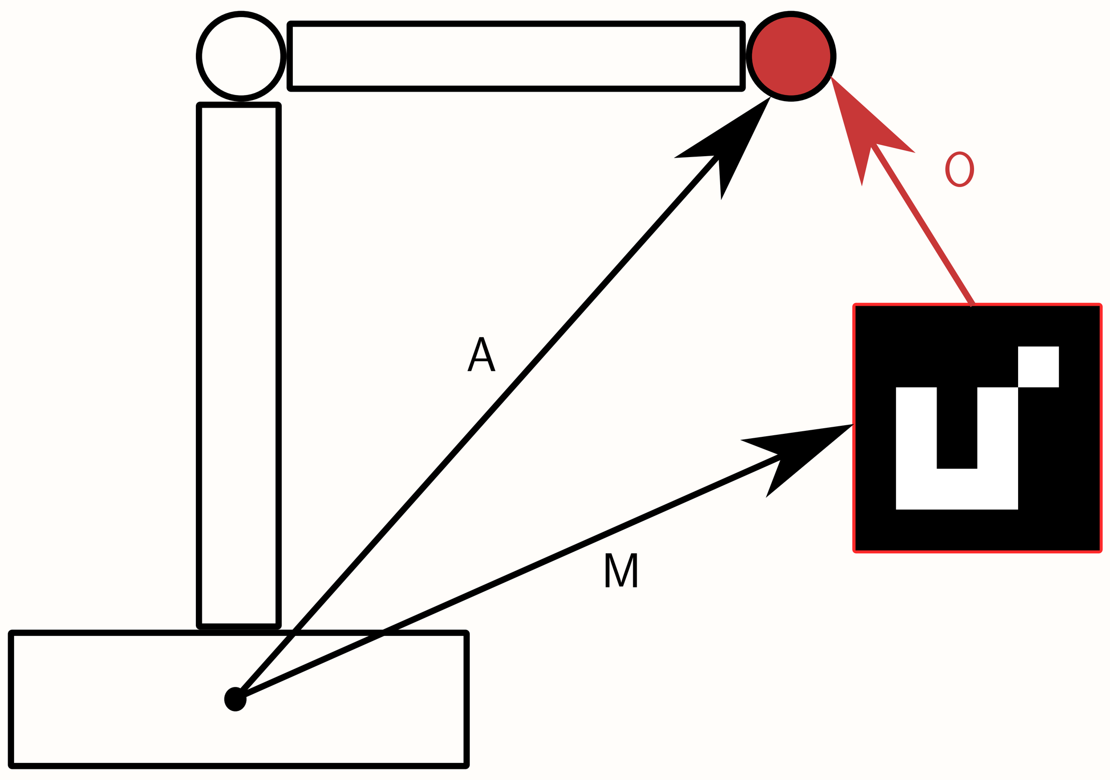

Figure 2: Concept of recording the offset O with a marker M and arm position A.

This technology was also repurposed to create an alternate activity for the robot to perform when it was waiting for the waffle iron to finish cooking. By using the position a marker, the camera would order the robot to move such that it was always pointing towards the marker. The idea behind this specific game is that it would give users a way that they themselves were controlling the robot, creating an interactive experience.

The robot also had multiple ways of handling potential collisions due to moved objects, although this was limited to objects that were trackable with the camera.

A touchscreen with a human–machine interface (HMI) was also developed, allowing the user or operator to order a waffle. The touchscreen was connected to the Jetson with a HDMI cable and a micro usb. A protective case for the screen was 3D printed.

Only the operator has access to control the robot's state machine, which dictates the sequence of actions the robot performs. For example, if an error occurs, the operator can stop the process and revert to a previous state to resume the waffle-making procedure. An emergency stop button was implemented on the HMI as a safety precaution, given that the robotic arm has the potential to cause injury in the event of a malfunction. A photograph of the touchscreen with the HMI is shown in figure 3.

Figure 3: Ingcool 7IP-CAPLCD 7-inch touchscreen display

Result and discussions

To get realistic data on how the system would perform in action, a stand to showcase the product was held in the cafeteria of the University of Agder. A picture of the stand is shown in figure 4

Figure 4: Waffle stand in action

The stand was a success, both in terms of technical performance and marketing potential. On the technical side, the robot achieved a 100% success rate, at a total cooking voume of one batch o' batter. On the marketing side, the stand drew a crowd estimated at 15 people looking onto the robot during its startup phase, settling down to an average of 5 onlookers during the first two hours of operation. Onlookers were primarily interested in the parts of the process where the robot prepared the waffle for cooking, and the final serving of the waffles. The marker tracking entertainment mode that was used did not raise interest in the stand significantly. The HMI was developed but not fully integrated to the system at the time, so a proof of concept of the HMI was shown. The feedback of the HMI was fortunately positive, the spectators were able to see operator page on the HMI.

The system was significantly more reliable when the robot used its fallback mode of predetermined positions. The camera assisted mode was only capable of performing small sets of movement reliably. Large-scale camera integrated tests led to edge cases that were not accounted for, and therefore tended towards failure. When motion sequences were tested induvidually, observed reliability increased and movements tended towards successful execution.

Summary and conclusions

The waffle making robot performed well at its primary task, but failed at its secondary tasks. The system made waffles in a consistent and reliable fashion, and it had an entertainment mode that could be used to attract onlookers. It had two modes, one consisting of predetermined movements and the other using a camera to inform its movements. The concept of camera assisted movement showed promise, but ultimately failed in execution. Camera detection of markers worked accurately. Robot pose recording did not. A servo for operating spray grease was planned, but never implemented due to electronics issues.

The project drew attention when tested in a marketing situation. The attention was highest at the start and end of the cooking process, when the robot was actively working on waffle making.