Designing a waffle making robot

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Introduction

To attract more potential students towards the field of 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 inclusion 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 freedom, 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 2) 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 mechanical 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 built on top of a plywood base plate with a tablecloth. The layout consisted of four zones. On the side facing onlookers, a serving station was located. Here, the finished waffles would lie in wait of mouths to feed. Next to it was the preperation zone. Here, a batter bowl and a can of spray 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 that made it easier for the robot to interact with its environment.

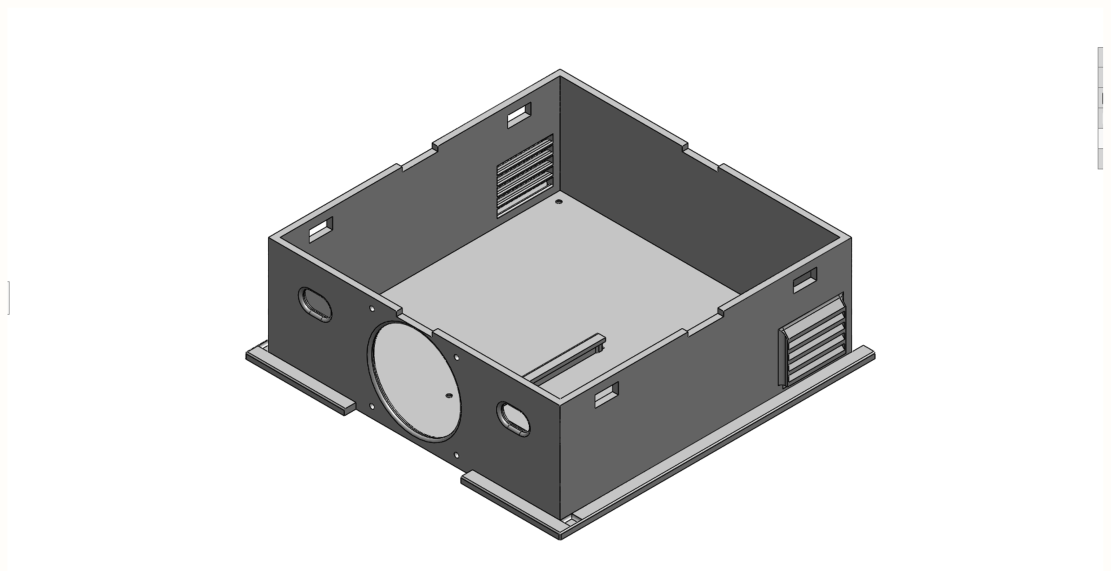

Figure 1: The housing used to mount electronics

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 simultaneously 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 the marker to the 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.

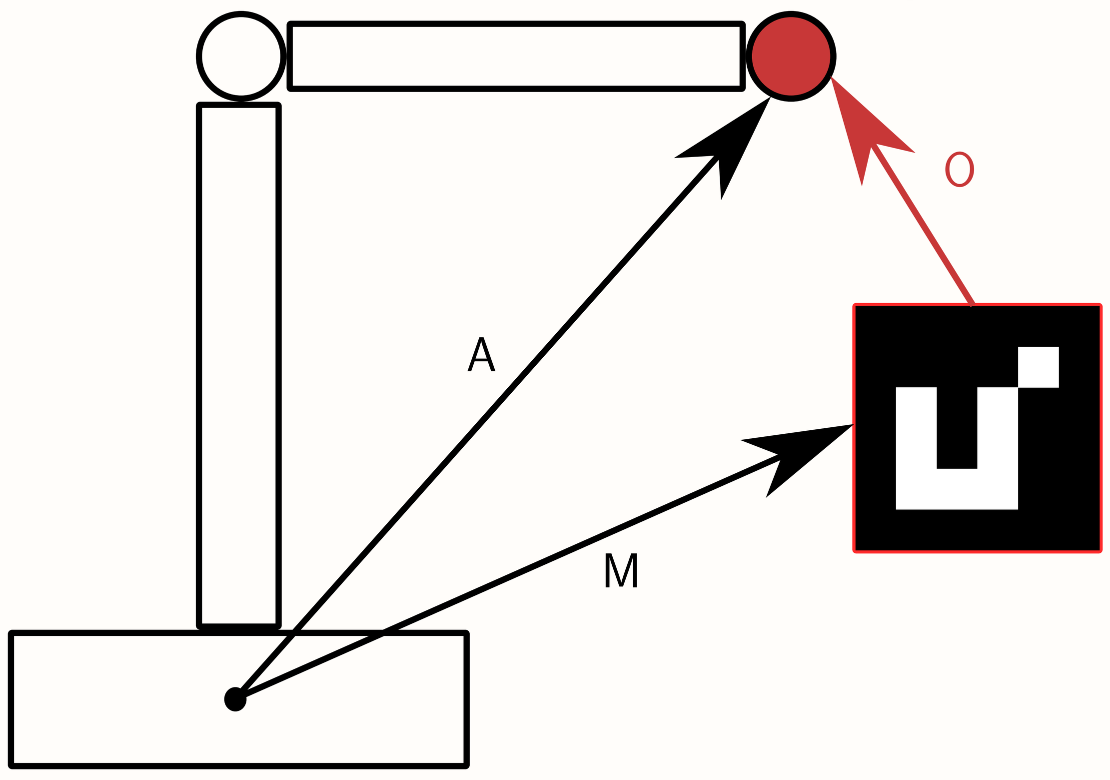

Figure 2: Concept of recording the offset O with a marker M and arm position A.

This technology was also repurposed to create an alternative activity for the robot to perform when it was waiting for the waffle iron to finish cooking. By using the position of 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 to order a waffle. The touchscreen was connected to the Jetson with an 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, as 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 was set up to showcase the product. The stand 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 cooking volume of one batch of batter. On the marketing side, the stand drew a crowd estimated at 15 people looking onto the robot during its initial startup, settling down to an average of 5 onlookers during the first two hours of operation. The spectators were most interested in the parts of the process where the robot prepared the waffles for cooking and the final serving of the waffles. The marker tracking entertainment mode that was used did not draw significant interest in the stand. The HMI was developed but not fully integrated into 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 the 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 tests where the camera was integrated 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 was never implemented due to electronics issues.

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