ECE 445 Senior Design Lab Proposal: Pancake Flipper

Team 54: Jason Kim, James Lu, David Lin

1 Introduction

1.1 Problem

Making pancakes at home can be frustrating for even the most patient chefs due to potential problems. Pancake flipping, in particular, is prone to issues such as tearing, folding, and burning. Achieving the perfect golden-brown outside without overcooking is a delicate balance. Deformed pancakes can also detract from their appealing texture. A more flexible solution is needed, emphasizing the necessity for pancake-making equipment that accommodates various tastes, ensuring a fun and easy cooking experience.

1.2 Solution

The proposed solution is a robotic pancake flipper equipped with a spatula, designed to automate the flipping process and ensure perfect pancakes every time. This device integrates an electric griddle and a mechanical system comprising a linear drive, a linear actuator, and servos. The electric griddle cooks the pancake, which is then moved towards the spatula by a linear actuator. The spatula, capable of side-to-side motion via a linear drive, positions itself beneath the pancake.One servo lifts the spatula and the other flips it, flipping the pancake to cook evenly on both sides. This automated system aims to eliminate common pancake-making issues by precisely controlling the cooking and flipping process, ensuring consistent and satisfactory results.

1.3 Visual Aid

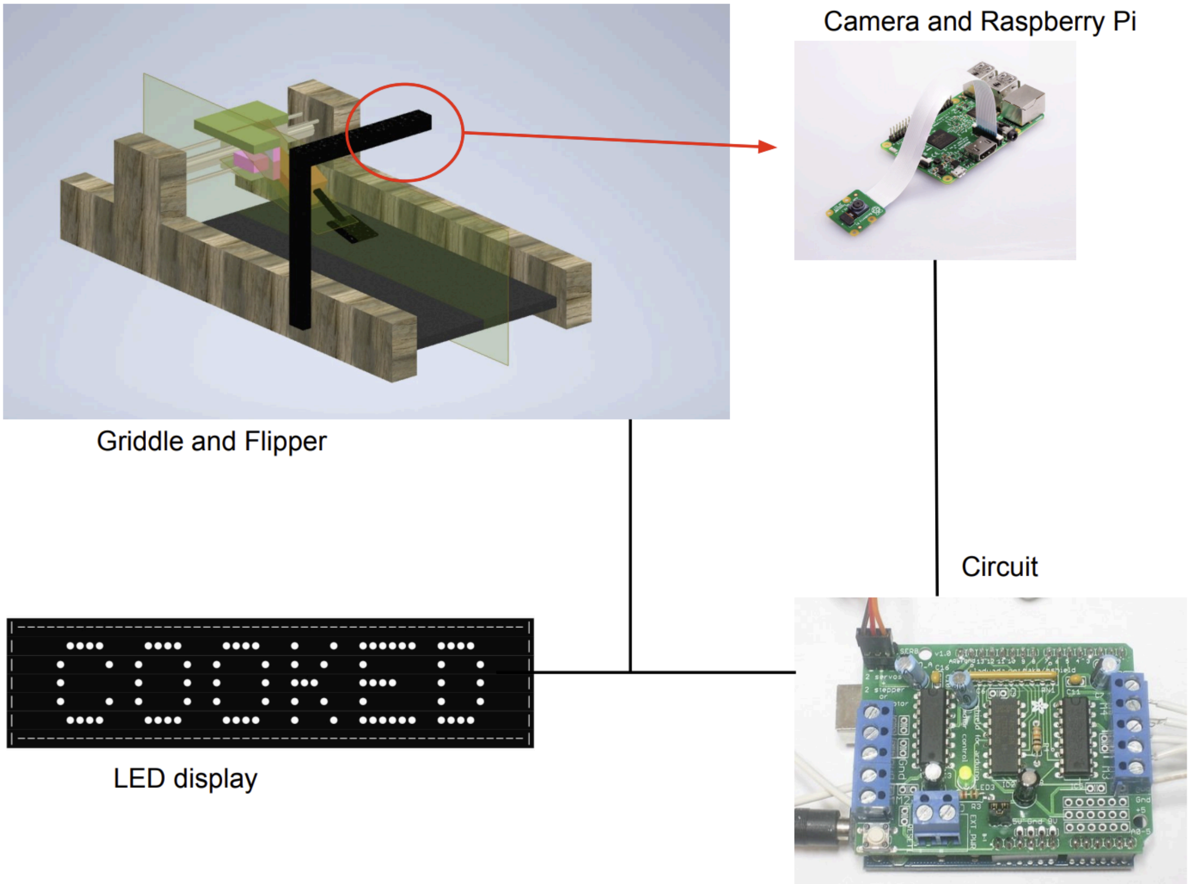

Figure 1: Preliminary CAD for pancake flipping device

1.4 High Level Requirements

- **Pancake Flipping Accuracy**: The robotic spatula must flip pancakes with a precision that ensures minimal tearing of the pancake. Any tears must be kept under 0.5 inches.
- **Bubble Detection for Flipping Cue**: The camera module should detect when there are 5 unclosing holes, with a margin of plus or minus 3 holes, as an indicator that the pancake is ready to be flipped. Upon reaching this threshold, the system will initiate the griddle's movement towards the robotic spatula for flipping.
- **Post-Flip Action Notification**: After the pancake has been flipped and the griddle returns to its original position, the device will display a "Remove Pancake" message on the screen. This message will remain visible for 15 seconds to ensure the user has ample time to react. This 15 second period can have a margin of error of 2 seconds.

2 Design

2.1 Block Diagram

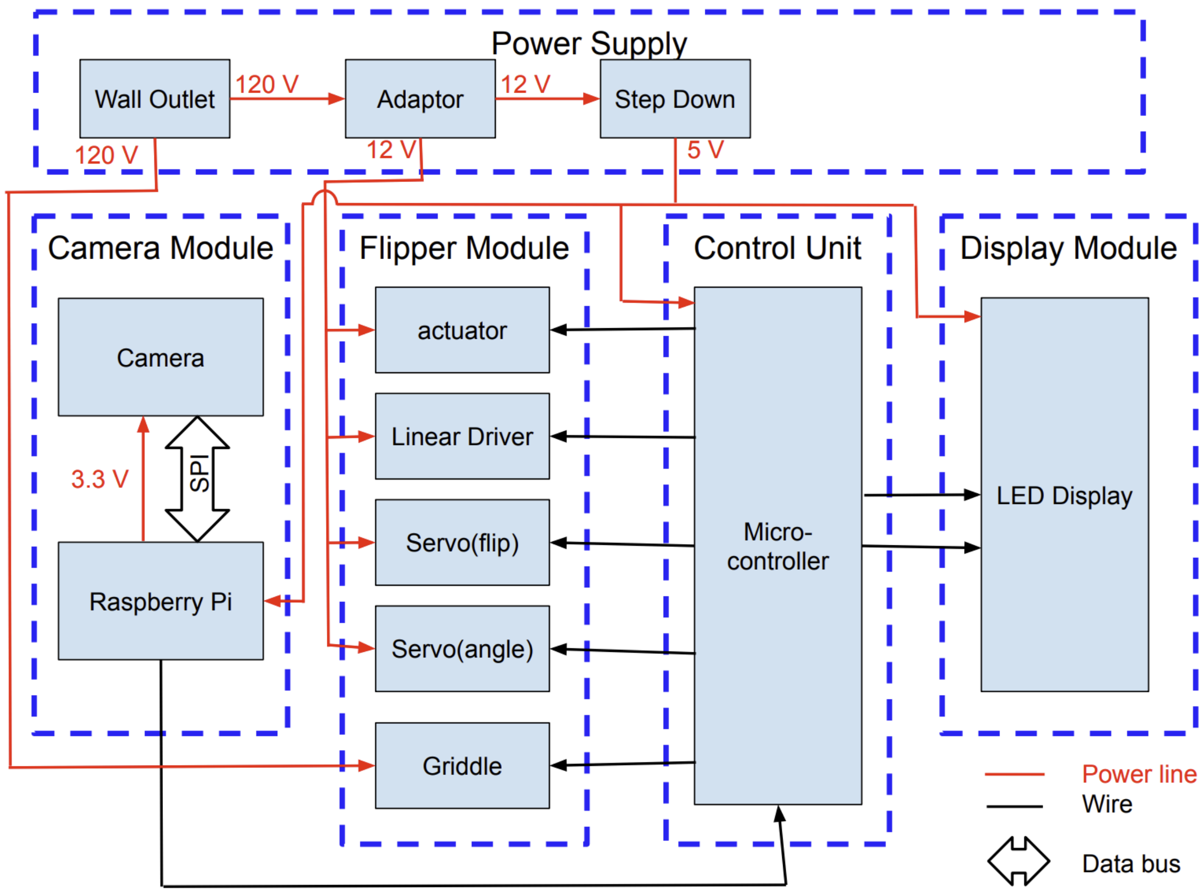

Figure 2: High-level block diagram of pancake flipping device

2.2 Subsystem Overview

- This section details the components of the robotic spatula system, focusing on the functionality and interaction between subsystems to achieve seamless operation.
- **Power Supply:** The power supply subsystem is crucial for distributing the appropriate voltages to various components of the system. It receives AC power from a wall outlet and uses an adapter to convert this into a 12V DC voltage. A regulator converts the 12V to 5V. The 5V output powers the Raspberry Pi, microcontroller, and LED display, ensuring low-voltage components operate safely. The 12V output is dedicated to higher power requirements, such as the linear actuator and servos, which are integral to the physical manipulation of the pancake. The griddle, requiring more substantial power, is

directly connected to the wall outlet, bypassing the internal power supply to handle its high power consumption efficiently.

- **Camera Module:** The camera module serves as the system's visual input, comprising a camera attached to a Raspberry Pi. This module captures real-time images of the pancake, which the Raspberry Pi analyzes using a binary AI classifier to determine the pancake's readiness for flipping based on specific criteria, such as surface bubble coverage. Once the pancake is deemed ready, the Raspberry Pi communicates this to the microcontroller with a single signal, initiating the flipping sequence. This direct communication ensures timely and coordinated action between the visual assessment and the physical flipping mechanism.
- **Flipper Module:** The main component of the physical operation is the flipper module, which includes an actuator, and two servo motors—one for executing the flip motion and the other for adjusting the spatula's angle. The angle adjustment servo positions the spatula precisely under the pancake. The actuator then moves the griddle forward, sliding the pancake onto the spatula. Following this, the angle servo lifts the pancake and the flipping servo flips the pancake. The movement of each component is coordinated by the microcontroller which sends individual signals to each component.
- **Control Unit:** The control unit, powered by a microcontroller, acts as the central command center. It interprets the signal from the Raspberry Pi to commence the flipping process and orchestrates the movements of the flipper module. By moving the linear driver and activating the servos, the microcontroller ensures the pancake is flipped with precision. Additionally, it communicates with the Display Module to provide real-time updates on the system's status, enhancing user interaction.
- **Display Module:** An integral part of user interaction, the LED display module offers real-time status updates concerning the pancake's cooking and flipping stages. While the specifics of the displayed messages ("Place Batter," "Pancake Cooking," "Flipping," "Cooked") will be refined throughout the project's development, this module ensures the user is informed of the current state of operation, facilitating a user-friendly interface that complements the automated process. The display module receives two signals from the control unit. It decodes the two signals to decide which message to display.

2.3 Subsystem Requirements:

- **Power Supply Subsystem**

  This subsystem contains an adaptor that converts AC to DC and supplies the linear actuator, the Raspberry Pi, and microcontroller. The power lines must be capable of handling the current without significant voltage drop over the length of the wire. Connectors should provide secure, stable connections to prevent power disruption.

Requirements	Verification

Adaptor supplies at least 3A at 12 V +/- 0.2V for the linear actuator and at least 1.5A at 5V +/- 0.1V for the Raspberry Pi and microcontroller.	Use a multimeter to measure the output voltage of the adaptor under a load simulating the linear actuator's consumption and the output voltage of the adaptor under a load simulating the combined consumption of the Raspberry Pi and microcontroller.
The power lines must be capable of handling the current without significant voltage drop over the length of the wire.	Perform a voltage drop test by measuring the voltage at the beginning and end of the power lines under maximum expected load.

Table 1: Requirements and verification of power supply subsystem

- **Camera Module Subsystem**

We are using Raspberry Pi to process the camera feed in real-time and run the binary AI classifier to determine pancake readiness. Our camera will capture images at a resolution sufficient for the AI classifier to determine the cooking status.

Requirements	Verification
Raspberry Pi requires a stable 5V power supply and must interface with the camera using the Camera Serial Interface (CSI). The Pi must process the camera feed in real-time and run the binary AI classifier to determine pancake readiness.	• Use a multimeter to measure the voltage at the Raspberry Pi's power input while it is running. • Verify the physical connection between the Raspberry Pi and the camera module through the CSI port. Test the interface by capturing a series of test images or video to confirm successful communication and data transfer.
Camera needs to capture images at a resolution sufficient for the AI classifier to determine the cooking status accurately.	Determine the minimum resolution required by the AI classifier for accurate cooking status determination. Test the camera by capturing images at this resolution and running them through the classifier to verify accuracy.

Table 2: Requirements and verification of camera module subsystem

- **Flipper Module Subsystem**

This subsystem contains an actuator and a linear driver and they must provide precise control of the spatula’s position. We will also be using two servos, one is the flip servo and the other is the angle servo. They must provide precise torques in order for the system to run accurately.

Requirements	Verification

Actuator and linear driver must provide precise control of the spatula's position with a positional accuracy of +/- 1 mm and must operate at 12V.	Perform multiple operations to ensure the actuator maintains the specified positional accuracy of +/- 1mm. Verify the operation voltage of the actuator and linear driver is consistently at 12V using a multimeter.
Servos are required to rotate accurately within a 1-degree precision and operate on a 5V power supply. The torque needed for the flip servo is approximately 0.3 Nm, while the angle servo requires about 1.5 Nm. The flip servo must achieve a 180-degree rotation, and the angle servo should reach 90 degrees.	● Use a protractor or an angle measurement tool to verify that the servo can achieve rotations with 1-degree precision. ● Confirm the servos operate at a stable 5V supply voltage using a multimeter. ● Test each servo by applying a load equivalent to the required torque specification and measure the actual torque output to ensure it meets the 0.3 Nm for the flip servo and 1.5 Nm for the angle servo. ● Measure the rotation angle using a protractor or digital angle finder to ensure the flip servo reaches a full 180-degree rotation and the angle servo achieves a 90-degree rotation.
The mass of the flip servo must be under 0.12 kg	The specification on the mass for the flip servo will be checked before purchasing. The mass can be verified using a scale.

Table 3: Requirements and verification of flipper module subsystem

- **Control Unit Subsystem**

The control unit subsystem contains a microcontroller that handles multiple input/output operators with the camera module, flipper module, and display module simultaneously. We will ensure that the microcontroller provides timely flipping.

Requirements	Verification
Microcontroller requires a 5V power source and must be capable of handling multiple input/output operations	● Use a multimeter to confirm the microcontroller is receiving a stable 5V power supply. ● Conduct a stress test by simultaneously triggering various input and output tasks programmed into the microcontroller and observe if it can manage without errors or resets.
Microcontroller must process Raspberry Pi signals and control the Flipper Module within 100 milliseconds to ensure timely	● Implement a test script on the Raspberry Pi that sends signals to the microcontroller, simulating the

flipping.	commands to flip. • Measure the response time from signal reception to the initiation of the Flipper Module's action using a logic analyzer or timing software.
Must include digital I/O for controlling the Flipper Module and a serial or I2C connection to the Display Module.	Physically inspect the microcontroller to confirm the presence of the required digital I/O pins and either a serial or I2C interface for connections.

Table 4: Requirements and verification of control unit subsystem

- **Display Module Subsystem**

  The display module subsystem contains a LED display that presents information legibly in various lighting conditions. It will receive data from the microcontroller to display the pancake and griddle status. The display will update the user with real time status.

Requirements	Verification
The LED display must operate on a 5V supply and be able to present information legibly in various lighting conditions.	• Use a multimeter to verify that the LED display operates with a 5V power supply. • Place the LED display in environments with differing light levels (e.g., bright sunlight, dim light) and confirm that the information displayed remains clear and readable from a reasonable distance.
Must receive data from the microcontroller via I2C or a similar protocol to display the pancake and griddle status.	Send test data from the microcontroller to the display, representing various pancake and griddle statuses. Verify that the display accurately reflects the sent data and correctly represents the status information.
The display should update within 500 milliseconds of receiving new data.	Simulate real operation by continuously sending updated status data from the microcontroller to the LED display. Measure the time interval between sending the data and the display update using a stopwatch or a software tool capable of timing the update latency.

Table 5: Requirements and verification of display module subsystem

Each of these subsystems must meet their respective requirements to ensure the robotic pancake flipper operates as intended, fulfilling the high-level requirement of providing a reliable, automated pancake-cooking experience.

2.4 Tolerance Analysis:

One of the critical aspects that poses a risk to the successful completion of the robotic pancake flipper project is the torque of the angle servo within the Flipper Module. The servo is responsible for adjusting the angle of the spatula. Not having enough torque could result in not being able to successfully flip the pancake or damaging the device itself.

Servo (Flip)

Variable	**Description**	**Value**
m_p	Mass of pancake	≤ 0.12 kg
r_p	Radius of pancake	≤ 0.10 m
m_s	Mass of spatula	≤ 0.11 kg
l_s	Length of spatula	≤ 0.30 m
m_f	Mass of flipping servo	≤ 0.12 kg
g	Acceleration of gravity	9.81 m/s^2

Table 6: List of variables for torque calculation

Assuming the worst case where all the weight is distributed the furthest away from the axis of rotation of the angle servo ($l_s + r_p$), the torque needed to perform the lift can be calculated using the following formula.

$$\begin{aligned}\tau &= (m_p + m_s + m_f)*g*(l_s + r_p)\\ &= (0.12 + 0.11 + 0.12)*9.81*(0.30+0.10)\\ &= 1.37 \text{ Nm}\end{aligned}$$

The torque requirement for the angle servo is set at 1.5 Nm. If the torque requirement and the requirement for the mass of the flip servo to be under 0.12 kg are met, the angle servo should be able to lift the pancake.

Incorporating the specific power requirements of 12V 3A for the linear actuators, servos, and 5V 5A for the Raspberry Pi, microcontroller, and LED display into our thermal analysis adds a layer of precision to our approach, ensuring that we account for the actual operational demands of the robotic pancake flipper system.

Detailed Thermal Analysis with Specific Power Requirements

Given the system's power requirements of 12V 3A for certain components and 5V 5A for others, we can further refine our thermal analysis to anticipate the heat generation and manage the thermal load effectively.

12V 3A Components: The components operating at 12V and drawing 3A of current will have a power consumption of P=V×I=12V×3A=36WP=V×I=12V×3A=36W. This substantial power draw necessitates efficient heat dissipation mechanisms, especially for the linear actuators and servos, which perform high-power mechanical operations that can generate significant heat.

5V 5A Components: Similarly, the components requiring 5V and drawing 5A consume P=V×I=5V×5A=25WP=V×I=5V×5A=25W. The Raspberry Pi and microcontroller, which are critical for processing and control tasks, fall into this category. Although these devices are less likely to generate as much heat as mechanical components, their continuous operation can still lead to elevated temperatures, requiring careful thermal management.

Applying Thermal Management Strategies

With these specific power requirements in mind, the project will implement targeted thermal management strategies:

For 12V 3A Components:

Implementing larger heatsinks with higher thermal dissipation capacity to manage the 36W power consumption. Active cooling solutions, such as small, efficient fans, may also be considered to enhance airflow around these components, particularly in enclosed spaces where heat may accumulate.

Using thermal interface materials (TIMs) to improve the thermal contact between the components and their heatsinks, ensuring efficient heat transfer.

For 5V 5A Components:

While passive cooling may suffice for these components, monitoring their temperature in real-time using embedded sensors will allow for dynamic thermal management. If temperatures approach critical thresholds, the system can throttle processing power or activate additional cooling measures.

Ensuring adequate ventilation in the design of the device's housing to allow for effective ambient cooling, preventing hot air from stagnating around these components.

Integration and Safety Measures

Incorporating voltage regulation mechanisms that can respond to fluctuations in power demand will help stabilize the thermal environment within the device, preventing scenarios where voltage drops lead to excessive current and, consequently, heat generation.

Furthermore, integrating safety mechanisms like thermal fuses or shutdown protocols triggered by temperature sensors ensures the system can protect itself and the user from overheating risks. This proactive approach to managing the thermal output based on the specific power requirements of 12V 3A and 5V 5A components enhances the system's safety, reliability, and performance.

By thoroughly analyzing and addressing the thermal implications of the robotic pancake flipper's power requirements, the project demonstrates a commitment to ethical engineering practices, emphasizing user safety and device longevity. This detailed thermal management plan, aligned with the project's power demands, ensures that the device operates within safe thermal limits, safeguarding both the technology and its users.

3 Ethics and Safety

Ethical Considerations

The development and deployment of a robotic pancake flipper raise several ethical considerations that necessitate careful attention. These include concerns regarding user safety, data privacy (especially relevant if the device is connected to the internet or a smartphone), and the potential impact on employment within commercial settings. Addressing these issues is crucial to ensure the project aligns with the IEEE Code of Ethics, which advocates for prioritizing the welfare, health, and safety of the public, as well as the ACM Code of Ethics and Professional Conduct. Both codes emphasize the importance of:

- **Avoiding Real or Perceived Conflicts of Interest**, ensuring that any decisions or actions taken in the course of the project prioritize the public interest and welfare above personal or commercial gains.
- **Maintaining Privacy and Confidentiality**, especially in the handling of data collected or transmitted by the device, to protect users' personal information in accordance with IEEE's guidance on professional conduct.
- **Mitigating Negative Societal Impacts**, including addressing concerns related to job displacement in commercial environments by engaging with stakeholders to understand and, where possible, alleviate these impacts.

Safety Issues and Regulatory Compliance

Safety and compliance with regulatory standards are paramount to the ethical deployment of the robotic pancake flipper:

- **Physical Safety**: Design features such as guards around hot or moving parts, automatic shut-off mechanisms, and clear safety warnings are essential. The project will aim for compliance with UL (Underwriters Laboratories) and CE (Conformité Européenne) standards, reflecting the IEEE's commitment to minimizing the risk of harm and ensuring the safety and health of the public.

- **Regulatory Standards**: Adherence to FDA regulations for kitchen appliances will be ensured, particularly concerning the safety and non-toxicity of materials in contact with food, aligning with the IEEE's ethical principle of safeguarding public welfare.
- **Campus Policy**: The development process will comply with campus policies on laboratory safety and electronic device use, ensuring a safe environment for all project participants.

Mitigation of Safety Concerns

To address potential safety concerns:

- **Design Review and Testing**: The project will implement regular safety reviews and rigorous testing, consistent with the IEEE's emphasis on identifying and mitigating potential hazards to prevent harm.
- **Training and Documentation**: Comprehensive user manuals, safety warnings, and maintenance routines will be provided, aligning with the IEEE's ethical principle of making stakeholders aware of safety measures and maintenance practices to prevent accidents and injuries.

Avoiding Ethical Breaches

The project team commits to regular evaluations of practices, policies, and behaviors to identify and address potential ethical risks proactively. This includes thorough documentation of the project's processes, limitations, algorithms, and decision-making AI, ensuring transparency and accountability in line with IEEE ethical standards. As the project evolves, ongoing reassessment of ethical considerations will be conducted, taking into account feedback from teaching assistants, technological advances, and any new ethical dilemmas that may arise.

By adhering to the principles outlined in the IEEE Code of Ethics, the project team demonstrates its commitment to professional responsibility, public welfare, and ethical conduct throughout the development and deployment of the robotic pancake flipper.