ECE 445

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Senior Design Project Proposal

NuChef AI Culinary Assistant

Team 62
Tony Liu, Griffin Kelley, Jackson Brown

TA: Aniket Chatterjee

1. Introduction

1.1 Problem:

The processed food industry has become increasingly toxic due to chemical flavor additives (12%-32% higher cancer risk), yet cooking often intimidates new chefs when preparing. Therefore, students and working professionals may rely on convenient but unwholesome meals. Most available ‘smart cooking’ tools do not provide a real-time experience that guides users through the process from raw ingredients to the finished dish. This reduces the likelihood that the user will learn. It is also inefficient to design recipes that can be adjusted to the user's available ingredients. Users will waste food, and recipe creation is an expert skill that is difficult to customize. Spices are especially difficult to measure and control in a dish while often being the most important for flavor. A healthy and delicious diet is important for increased productivity and long-term health, but it is difficult to accomplish.

1.2 Solution:

We propose an AI-Nutritious Culinary Assistant that recognizes available ingredients and generates a personalized recipe with interactive, step-by-step guidance. Using the Meta Quest 3 as the user interface and sensor front-end, the system streams video and voice commands to an edge vision processor running an ingredient recognition pipeline. In addition to vision, the device integrates an environmental sensor module that measures ingredient weight for portion verification. Finally, the appliance includes a circular seasoning dispenser driven by stepper motors for proportional seasoning action, enabling closed-loop “dispense to target grams” assistance during cooking. The spice containers will also contain IR sensors, allowing users to see the percentage they have left and receive an alert when running low.

1.3 Visual Aid:

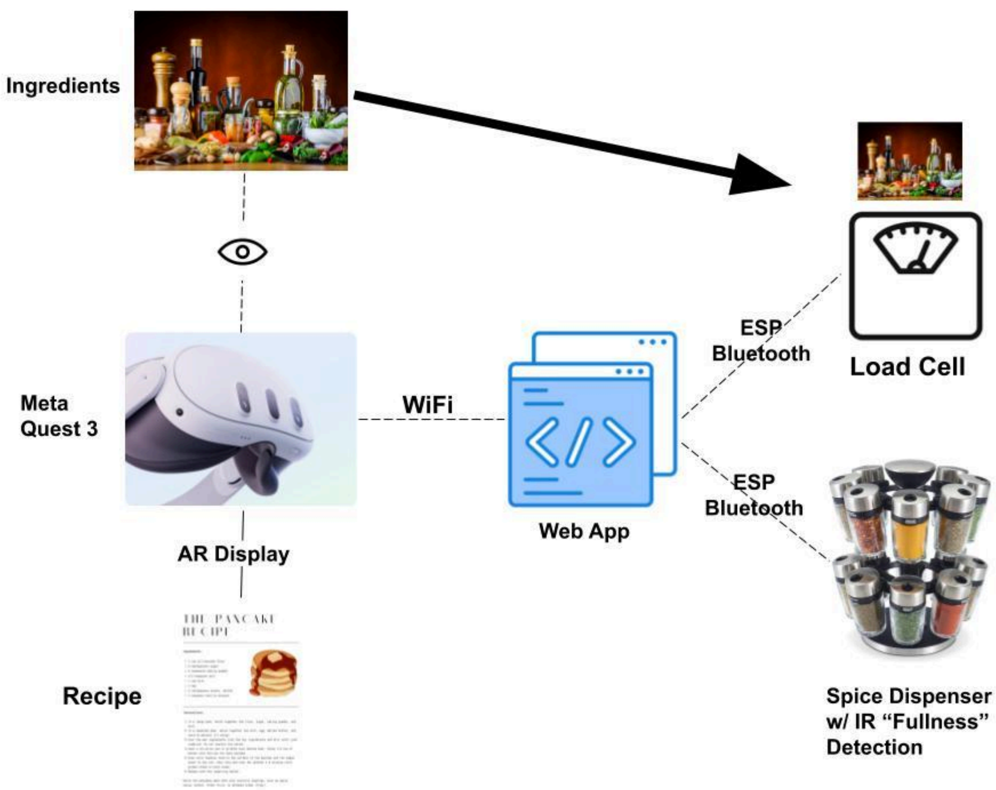

Figure 1: Visual aid demonstrating the recipe creation and spice dispensing process

1.4 High-Level Requirements List:

1. This project will use AI and computer vision to select a recipe based on the ingredients that the user has available. The CV + LLM model will be accurate in recognizing

ingredients and will generate sensible recipes. The precise benchmarking for this will need to be adjusted based on feasibility.

2. The spice dispenser must be rechargeable and dispense the correct amount of spice with a maximum error margin of 1 gram.
3. The Meta Quest 3 and the Spice Controller will be able to communicate through a shared web app, exhibiting connection speeds of sub 10 seconds and a range of 100 feet.

2. Design

2.1 Block Diagram

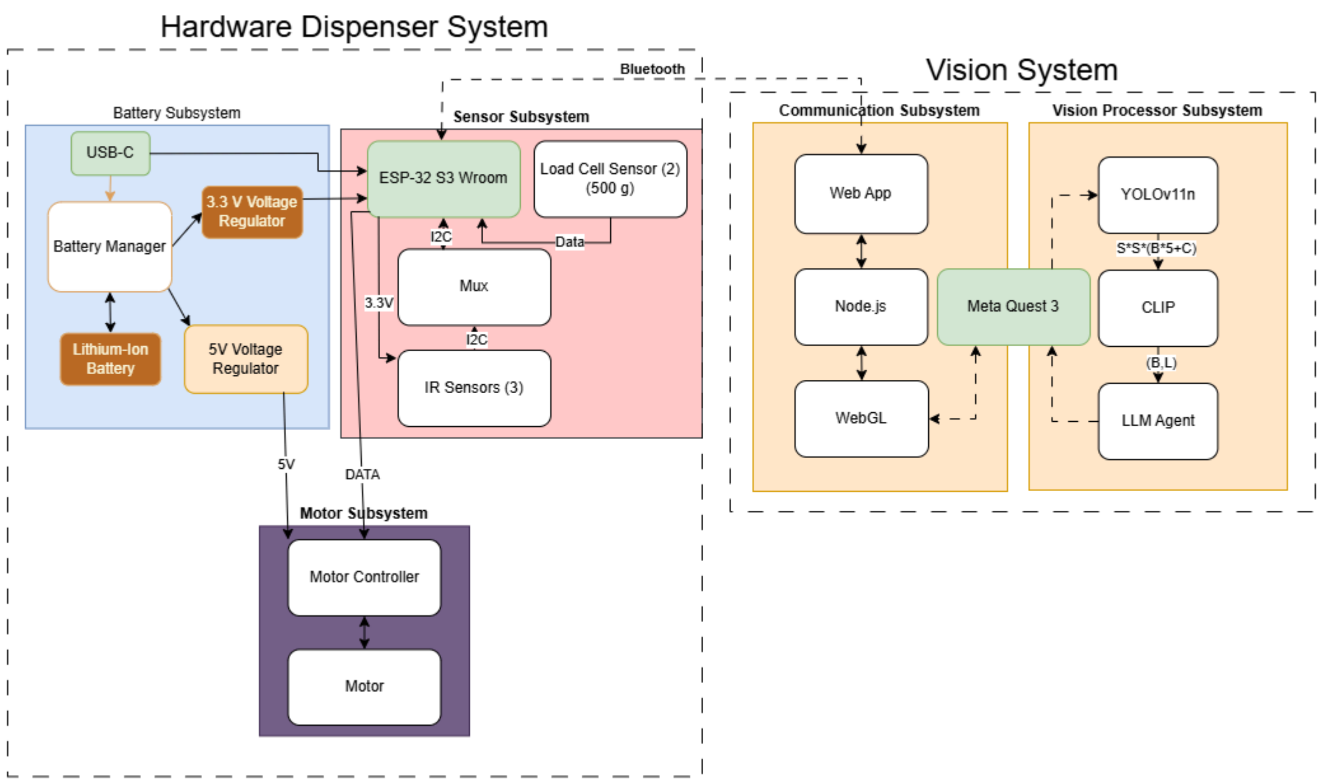

Figure 2: High-Level block diagram of the system

2.2 Hardware Dispenser Subsystems and Requirements

2.2.1 Subsystem 1: Battery System

This subsystem powers the device from a rechargeable battery, supports charging via USB, and generates stable rails for logic and actuation. It provides regulated 3.3 V for ESP32/sensors and 5–6 V for servo/actuators while preventing brownouts during motor current spikes.

Requirements:

-The battery manager must be able to recharge the battery through USB-C
-The voltage regulators must be able to supply 3.3V/5V +/-5% respectively to all other components consistently
-The battery must be able to supply enough current to drive the entire system. We anticipate the total system requiring a maximum of 2A discharge, mostly to drive the batteries.

Parts:

- Battery Manager: MCP73871
- 3.3V LDO Voltage Regulator: AP2112K-3.3
- 5V Buck Converter Voltage Regulator: TPS6380
- USB-C Port: Generic 16-pin part

2.2.2 Subsystem 2: Sensor Subsystem

This subsystem measures ingredient mass for more accurate recipes and measurements. The subsystem also measures the mass of dispensed spices for calibration and accuracy purposes. Finally, IR sensors inside the spice containers detect the level of spice within the container. The ESP32 reads the sensors, filters/calibrates the data (tare + scale factor), and forwards measurements to the main motor controller and web application.

Requirements:

-The load sensors must be able to weigh the ingredients and spices +/- 1 gram for the spices and +/- 2-3 grams for the ingredients
-The IR sensors must accurately measure and signal the distance to the spice level, accurate to 1% of the spice container size
-The ESP32 must communicate over GPIO with the sensors and over Bluetooth with the web app to allow for proper readings and control

Parts:

- Microcontroller: ESP-32-S3-Wroom-1
- 2x Load Cell Sensors: TAL220B
- I2C switch: TCA9548A
- IR Sensors: VL53L4CD

2.2.3 Subsystem 3: Motor Subsystem

This subsystem uses 3 stepper motors to dispense 3 different spices into a central funnel and cup. The motors are used to turn a wide cylinder blocking the opening of the spice containers. The cylinder has a notch in it, allowing a measurable amount of spice to be dispensed upon each rotation. The motors are controlled by the ESP32, using the sensors to dispense proper amounts of spice.

Requirements:

-The motors must be controlled by the ESP32 using GPIO and allow for precise rotations +/- 1^{o}

Parts:

- Motor Controller: HX711
- Stepper Motors: Generic NEMA 17 model

2.3 Vision Subsystems

2.3.1 Communication Subsystem

This subsystem is a lightweight local web application that acts as a communication hub between the Meta Quest 3 interface and the ESP32 scale module. The app receives user inputs from the Quest (e.g., button clicks indicating which spice or ingredient is being added, confirmations, step navigation) and receives real-time weight measurements from the ESP32 over Wi-Fi. It timestamps, validates, and maintains the current “cooking state” (selected spice, tare status, current grams, stable reading), then forwards this state and event stream to the Vision Processor/Recipe Planner subsystem for step logic and recipe updates. The subsystem can also relay feedback back to the headset (e.g., “target reached,” “add 2g more,” “confirmed”) to keep the AR/VR overlay synchronized with physical actions.

Requirements:

- Low-latency event forwarding: Must receive Quest spice-selection/step events over Wi-Fi and forward them to the Vision Processor with end-to-end latency ≤ 150 ms and capacity ≥ 10 events/sec.

- Connection reliability: Must maintain simultaneous connections to Quest + ESP32 for ≥ 30 minutes and auto-recover from disconnects with reconnect ≤ 5 s.

Parts:

- Meta Quest 3
- Wi-Fi

2.3.2 Vision Processor Subsystem

This subsystem performs the core perception and recipe-planning computation on the edge compute unit. It receives camera frames from the Meta Quest 3 and first detects/segments candidate ingredient regions using a real-time model (YOLO for bounding boxes, or FastSAM for masks). Each candidate region is then cropped (or masked) and passed through a CLIP-style vision encoder to generate an image embedding. In parallel, the system maintains a library of text embeddings for ingredient labels (e.g., “tomato”, “onion”, “spinach”). By comparing image embeddings to text embeddings (cosine similarity), the processor assigns the most likely ingredient label to each detected region, enabling more flexible recognition than closed-set detection alone. The final output is a structured ingredient list (label + confidence + location/mask), which is then provided to the LLM agent to generate step-by-step recipes and instructions that are sent back to the headset.

Requirements:

- Detection/segmentation output quality: For each processed frame, must output ≤ 20 ingredient regions with (x, y, w, h) boxes or pixel masks, and include confidence scores; must achieve ≥ 0.425 mAP.
- Recognition + interface to planner: For every region, must output a top-1 ingredient label and confidence, with top-1 accuracy≥ 70% on a held-out validation set; then must publish the structured ingredient list to the LLM/planner.

Parts:

- NVIDIA RTX
- Candidate region model: YOLO11 (det/seg) (bounding boxes or segmentation)
- Vision-language classifier: CLIP / OpenCLIP / MobileCLIP (region embedding + text embedding matching)
- LLM agent (recipe selection + instruction generation using detected ingredients)

2.4 Tolerance Analysis:

The load cell we are likely to use is the TAL220B. For the 1 KG model, there are a few specs that could be concerning. The repeatability is 0.05%, meaning the spread in measuring an identical unit many times could be as great as 0.5 grams in each direction. Likewise, the creep would be up to 1 gram per 3 minutes. There is also non-linearity, which at the gram range measurements we will be doing can be an issue, which is 0.05%, or around 0.5 grams of drift from the linear calibration at the midpoint. To alleviate this, we will calibrate the scale in the 1-10 gram range, which will remove the non-linearity effect in the range, but introduce a higher error in the 100-1000 gram range. This is acceptable, as we do not expect to measure spices in this quantity. Creep will be alleviated by quick dispensing, and also the mechanical fail-safe of calibrating the dispenser to dispense the correct amount, allowing the load cell to be a backup, and to allow the user to add new spices of unknown weight. This means we anticipate a combined error in dispensing of no more than 1 gram, accounting for load cell error, mechanical error, and deviance across samples.

3. Ethics, Safety, and Societal Impact

As we are working with food, one major consideration is whether the materials and processes are food-safe. This is especially important in a commercial context, as we can not sell something made for food that will cause harm to users. Because of this, we need to consider FDA compliance to make our product safe. The first consideration is the material. The containers must be in a material that has the NSF 51 Food Equipment Materials certification, for example, silicone. The material must also be able to withstand frequent exposure to cleaning compounds and sanitizing agents. Additionally, the material must withstand a range of temperatures without releasing anything dangerous into the food. These temperatures can vary, but for our purpose,s we would want a rating above 100 °C to allow dishwashing. All of these considerations impact FDA compliance, which is an important part of getting our product safe and marketable.

When considering the ACM code of ethics, 1.2 is the most vague but also very important to avoid harm. Since cooking involves a lot of sharp and hot objects, we must avoid hazards for the user. One important way is to make sure the recipe does not block the vision of the person cooking. Having impaired vision can lead to accidents and injuries in the kitchen. We may also have to suggest that the person remove the headset while they are cooking on an open flame. While it does make it more convenient to have the headset remain on, it could affect the chef's safety to have the recipe and any other things in their vision while cooking. These are considerations that we have to make to make sure users can avoid harm from our product.

4. References

[1] “ACM Code of Ethics and Professional Conduct” (2018), ACM, https://www.acm.org/code-of-ethics (accessed Feb 13th, 2026)

[2] “What are food contact substances and what’s their relationship to FDA compliance?” (2020), ISM, https://www.industrialspec.com/about-us/blog/detail/fda-compliant-food-grade-food-safe-meanings (accessed Feb 13th, 2026)

[3] “Guidance for Industry: Preparation of Premarket Submissions for Food Contact Substances (Chemistry Recommendations)” (2007), U.S. Food & Drug Administration, https://www.fda.gov/regulatory-information/search-fda-guidance-documents/guidance-industry-preparation-premarket-submissions-food-contact-substances-chemistry (accessed Feb 13th, 2026)