ECE 445 FA24
Project Proposal

Team 20: A Better Yogurt-Maker

Team

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1 Introduction

1.A Problem

Making yogurt at home is a popular and healthy hobby. However, many homecooks struggle with producing consistent tasting yogurt. Yogurt is fermented using lactic acid bacteria (LAB) that consume the sugars in milk and produce lactic acid. Yogurt is made at home using backslopping, a technique where a sample of a previous batch of yogurt is used as the starter for the new batch. However, using back slopping, we don't know the bacterial strain and amount of LAB in our starter batch.Thus it is impossible to fully predict the behavior of the yogurt during the fermentation process.

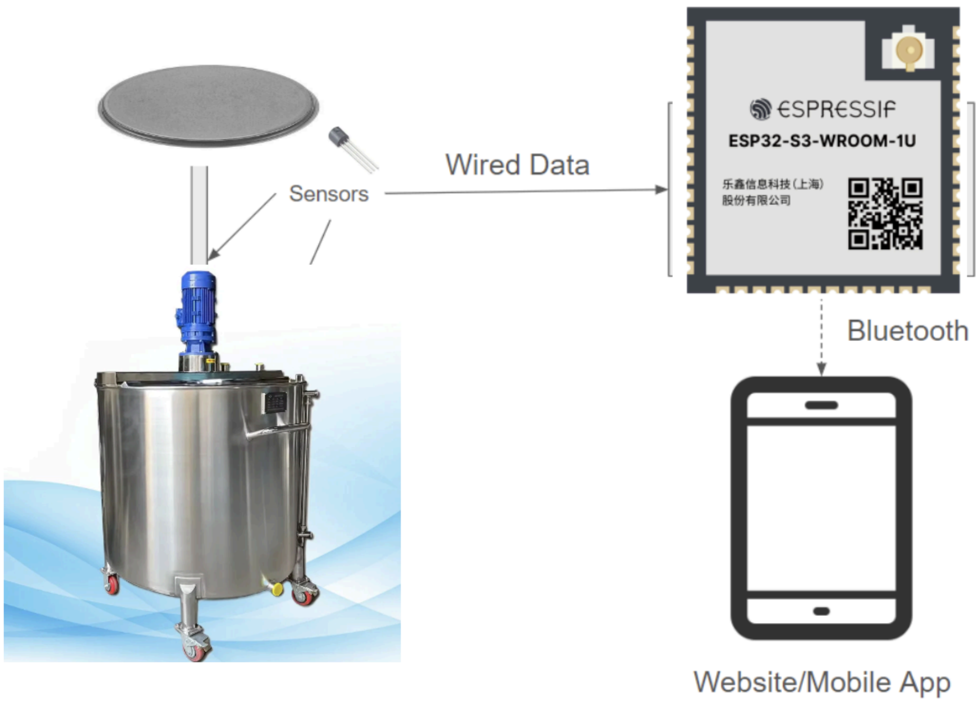
There are some smart yogurt fermentation devices on the market meant to address this issue. However, these devices only allow the user to set a timer and a temperature. It is important to monitor temperature, but time can be an unreliable indicator due to the high amount of variability in the starting culture. This can lead to differing fermentation rates, or even a dead batch of yogurt. In addition, typical yogurt fermentation times range from 8 to 24 hours which makes it difficult for a home cook to constantly monitor their yogurt. If yogurt is left to ferment too long, it will become too sour and thick. Because of all these factors, there would be significant demand for a real-time monitoring device for yogurt fermentation.

1.B Solution

Our solution is to design a real time monitoring device that uses sensors to collect data from the yogurt and transmit the information to a mobile interface. The quantities our sensors will need to measure are: taste, texture, and temperature. Temperature will be measured with a temperature sensor and taste with a pH sensor. We will approximate the texture of yogurt by finding its viscosity. Our design uses a custom rod and paddle that will measure the torque required in a rotation and use this data to approximate viscosity. The torque will be approximated by the current draw in a DC motor. All sensors will be mounted to the lid or sides of the fermentation container for user convenience and ease of use. Our texture and pH sensors will have to directly touch the yogurt to function.

All measurements taken by the sensors will be sent to a microcontroller for processing. The microcontroller extracts useful information from the sensor data and sends the data, via wifi, to a mobile interface, such as a website. This will make it easier for users to monitor their yogurt when traveling outside of their home. Our device will not tell the user when to stop the fermentation process since multiple users may have differing taste preferences. Rather, the goal of our device is to provide the user with enough information to make their own informed decision.

1.C Visual Aid



1.D High-Level Requirements List

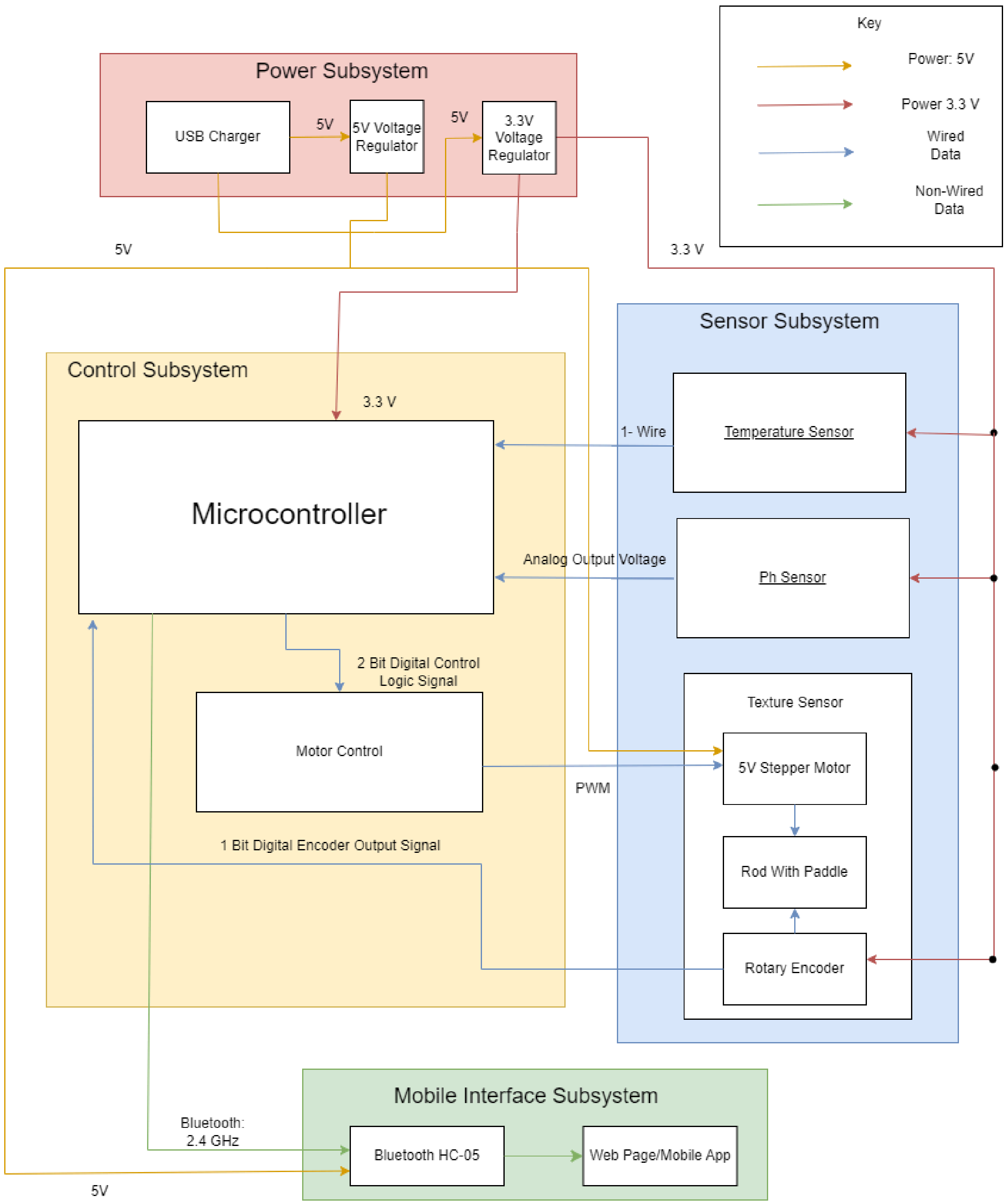
- **Ease of Use/User Interface:** We want our user interface to be easy to use and clear. The mobile application must display the yogurt pH, viscosity, and temperature in a way that is easily digestible and also provide clear actionable feedback on the yogurt fermentation process. Updates to and from the mobile app should be responsive with little latency (less than 1 second).

- **Durability:** The entire device should be able to go through a fermentation cycle (8 to 24 hours) without needing to be recharged.

- **Real Time Monitoring and Alerts:** The designed app will show the progress of the fermentation (updating the readings and charts at least once every 10 minutes) while providing any necessary alerts to the user if any of the defined conditions are out of range. All sensor readings should be accurate with a +/- 5% error range.

2 Design

2.A Block Diagram



2.B Subsystem Overview and Requirements

- **Power Subsystem**

  The power subsystem will power all the electronic components in this project for the entire duration of the yogurt fermentation process. This will be made possible by using a USB cable which will provide a reliable 5V source from either a USB power adapter or a standard laptop USB port. USB power was chosen over battery power for consistent voltage, higher efficiency, and low-maintenance reasons. A voltage regulator will then be used to step down this voltage to the required 3.3V to power the ESP32 microcontroller, motor, and other sensors.

  - **Requirements:**
    - The power subsystem must supply 3.3 ± 10% Volts to all connected components under a max load of 800mA.
    - The power subsystem must be able to supply continuous power over a maximum time period of 24 hours.

- **Sensor Subsystem**

  The sensor subsystem is responsible for detecting and calculating the necessary measurements for the pH, temperature, and viscosity of the yogurt in real-time. The three main sensors that make up this subsystem are the DFRobot Gravity Analog pH Sensor [4], DS18B20 Digital Thermometer [5] for temperature, and a DC motor with encoder that powers a rotating spindle allowing for viscosity calculations.

  - **Requirements:**
    - The temperature sensor must be able to measure the ambient temperature of the yogurt fermentation container with an accuracy of ±2°C. The temperature sensor must then transmit this information to the microcontroller at a rate of, at least, one measurement per second.
    - The pH sensor must be able to measure the pH of the yogurt with an accuracy of ±0.5 pH. The pH sensor must then transmit this information to the microcontroller at a minimum rate of one measurement per two minutes.

- The texture sensor must be able to measure the yogurt viscosity and transmit this information to the microcontroller at a minimum rate of one measurement per 10 minutes (we would like to avoid disturbing the yogurt as much as possible when it is fermenting). Viscosity will be measured by the torque required to spin the motor which is proportional to the current draw for a DC motor.
- The sensor should be able to classify yogurt into runny yogurt, good yogurt, and thick yogurt. We will use the viscosity of water, 1 centipoise, as reference for too runny and 3 centipoise as too thick.
- All sensors must be able to withstand a maximum temperature of 115°F.

- **Control Subsystem**

  The control subsystem is composed mostly of the ESP32-S3-WROOM [3] microcontroller and a motor driver integrated circuit. The ESP32 microcontroller is responsible for reading and processing all of the data picked up by the sensor subsystem. The processed data is then sent wirelessly to a mobile application where users can monitor the fermentation process and receive any alerts if any preset conditions are out of range. The motor driver IC will serve as an interface between the DC motor and the microcontroller ensuring necessary voltage and current.

  - **Requirements:**
    - The control subsystem must transmit the received sensor data using Bluetooth, at a minimum rate of once every five minutes. Our plan for Bluetooth data transmission is described in the section below.
    - Compute the average value temperature and pH sensor readings to reduce noise.
    - Send a control signal to the motor to rotate ten rotations (or 3600 degrees) every ten minutes.
    - Approximate the torque of the motor using the input current draw of the motor. Then, use this torque to classify the yogurt as either: runny, good, thick.

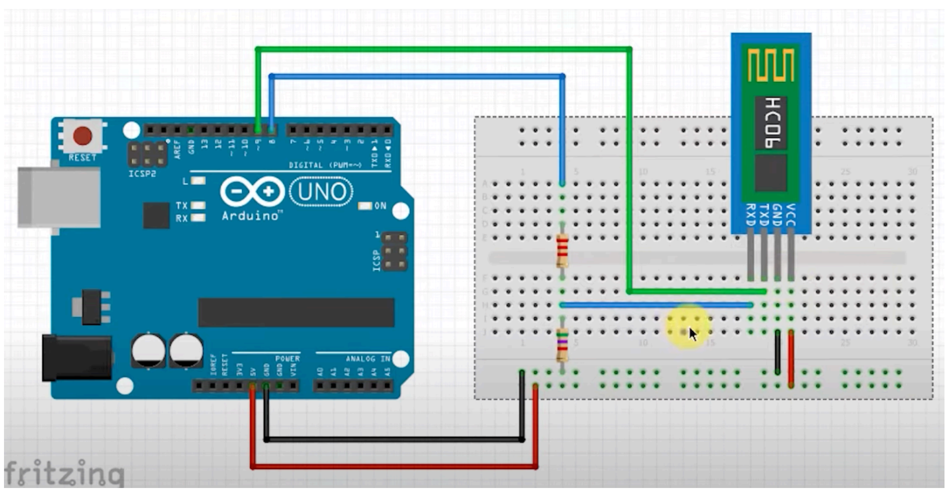
- **Mobile Interface Subsystem**

  The mobile interface subsystem will be an application built on Android or locally hosted on the microcontroller and will display basic sensor readings, graphs, and real-time alerts. An alert would be triggered if any measurement (temperature or pH) is outside of the defined acceptable ranges.

- **Requirements:**
  - The mobile application must display temperature, pH, and viscosity information and be updated at least once every 10 minutes.
  - The app must alert users within 5 minutes if any temperature or pH reading deviates from the acceptable ranges via a push notification.
  - The user interface should be easily understandable to even those without a technical background.

- **Bluetooth/WIFI Usage**

  Since we only need to transfer a few data from several sensors, we do not need a high bandwidth transmission line such as WIFI, bluetooth will do the job. We plan to use HC-05 or HC-06 [6] which are both compatible with breadboard or PCB using arduino. It accepts voltage ranging from 3.6v to 6v, and there are a total of seven slave nodes we can use. After connecting the RXD and TXD pins to the source, we are able to do data transmitting.



bluetooth_terminal

```
#include "Arduino.h"
#include <SoftwareSerial.h>

const byte rxPin = 9;
const byte txPin = 8;
SoftwareSerial BTSerial(rxPin, txPin); // RX TX

void setup() {
  // define pin modes for tx, rx:
  pinMode(rxPin, INPUT);
  pinMode(txPin, OUTPUT);
  BTSerial.begin(9600);
  Serial.begin(9600);
}

String messageBuffer = "";
String message = "";

void loop() {

  while (BTSerial.available() > 0) {
    char data = (char) BTSerial.read();
    messageBuffer += data;
    if (data == ';'){
      message = messageBuffer;
      messageBuffer = "";
      Serial.print(message); // send to serial monitor
      message = "You sent " + message;
```

The first step is to assign pin numbers to RX and TX sides, then, the SoftwareSerial Object would represent our mobile device, and we set a connection between them. The PinMode would be able to set RX and TX to transmitter and receiver of data, then, it is important to set up the baud width of the transmission, in the screenshot it is 9600, we would adjust that depending on our own data. Eventually, there is a loop used for transmitting and receiving data. After the setup in arduino, we need a bluetooth terminal on the mobile device we are using. There are two metrics we are planning:

1. Directly download the bluetooth terminal that is available at the APPLE store, which allows us to transmit data.
2. Building a new app, which is able to show the data transmitted from the sensors, with a personal-designed UI interface by using the MIT app inventor. https://appinventor.mit.edu/ [7].

2.D Tolerance Analysis

The apparent viscosity of a yogurt varies from 1.8 to 3.8cp, and based on the fact that the container of yogurt would simply be a standard cylinder with radius of $r1$, and the radius of the stirrer would be $r2.$ As we are using a simple model, the situation would be: a smaller cylinder stirrer with a larger cylinder container filled with yogurt.

- Radius of stirrer : $r2.$
- Radius of cylinder container: $r1.$
- Angular velocity of stirrer connected to a rotor: $\omega.$
- Viscosity of yogurt: η

After defining all parameters that we need for calculations, we can use the formula in fluid dynamics to calculate the torque that we need to stir the yogurt.

$$\tau = \frac{2\pi * \eta * L * r_2^3 * \omega}{r_1 - r_2}$$

For a normal DC motor, the RMP is around 1000 to 5000, which means the angular velocity is around 104.72 to 523.60 rad/s, with the average number of 314.16 rad/s.

The next step is calculating the work done for the rod paddle to go for a full circle, i.e. 360 degree.

$$W = \tau * \theta$$

, where W stands for the work done, τ is the torque, and θ is the degree that the rod is spinning.
Also, for a normal DC motor, the resistance would be relatively small, around 10 to 100 ohms, since it allows more current to flow through. And we know the equation that:

$$W = \frac{U^2}{R}, U = \sqrt{W * R}.$$

Since this is the tolerance analysis, we will obtain the maximum voltage that the motor needs to spin a full cycle in the fluid, with the maximum approximation of other parameters such as the radius of the rod and container.

$$W = 2\pi * \frac{2\pi * 0.0038 * 0.1 * 0.01^3 * 523.6}{0.06 - 0.01} = 1.57e - 4 \text{ Joules}$$

And for the voltage, we get:

$$U = \sqrt{W * 100ohms} = 0.016 \text{ V for each full circle}$$

Therefore, the 3.3V motor should fulfill our purpose well without any malfunctioning in voltage.

For temperature tolerance, typical yogurt-making temperature is around 105 to 112 F, so any type of stirring rod , sensors, and glass cylinder container would be able to tolerate this temperature.

pH Probe

- Probe Type: Laboratory Grade
- Detection Range: 0~14
- Temperature Range: 5~60°C
- Zero Point: 7±0.5
- Response Time: <2min
- Internal Resistance: <250MΩ
- Probe Life: >0.5 years (depending on the frequency of use)
- Cable Length: 100cm

3 Ethics and Safety

As engineers developing a product, we must consider any ethical and safety issues that may arise because of our project. The IEEE Code of Ethics states that we must “hold paramount the safety, health, and welfare of the public” [1]. Our biggest concerns with this project would be health and safety related since our project involves food.

Food contamination is a major safety concern with our project. When possible we will avoid direct contact with the yogurt. However, some sensors such as the pH and texture sensor will need to be directly touching the yogurt in order to function properly. Thus, any materials used in the exterior of these sensors must contain non-toxic materials. In addition, the sensors and any part of our device that gets exposed to the yogurt needs to be able to withstand a cleaning and sanitation process. There are also some electrical safety concerns regarding the sensors and wiring that are directly exposed to the yogurt. These components must be able to withstand external temperatures of 112 F and be insulated from liquid to protect the user. We will refer to the NSF/ANSI 2 standards that cover proper sanitation and safety protocols for all equipment that comes into contact with food [2].

The IEEE Code also lays out ethical and professional guidelines we should act on as engineers. The code states that we must, “uphold the highest standards of integrity, responsible behavior, and ethical conduct in professional activities” [1]. As such, we will treat each other with respect, be non-discriminatory, and avoid injuring one another. We also agree to act with integrity by crediting any work we reference and avoid plagiarism.

4 Citations

[1] Institute of Electrical and Electronics Engineers. "IEEE Code of Ethics." ieee.org. https://www.ieee.org/about/corporate/governance/p7-8.html (accessed Sep. 19, 2024).

[2] American National Standards Institute. "NSF/ANSI 2-2022: Food Handling Equipment." ansi.org. https://blog.ansi.org/nsf-ansi-2-2022-food-equipment-standard/ (accessed Sep. 19, 2024).

[3] Espressif Systems. "ESP32-S3-WROOM-1 Datasheet" espressif.com. https://www.espressif.com/sites/default/files/documentation/esp32-s3-wroom-1_wroom-1u_datasheet_en.pdf (accessed Sep 19, 2024).

[4] Mouser Electronics. "Gravity Analog pH Sensor", https://www.mouser.com/catalog/additional/DFRobot_ProductOverview_Gravity_Analog_pH_Sensor.pdf (accessed Sep. 19, 2024).

[5] Analog Devices. "DS18B20 - Programmable Resolution 1-Wire Digital Thermometer", https://www.analog.com/media/en/technical-documentation/data-sheets/ds18b20.pdf (accessed Sep. 19, 2024).

[6] B. N. Bits, "Adding Bluetooth to Your Arduino Project with an HC-05 or HC-06 Bluetooth Module," YouTube, https://www.youtube.com/watch?v=NXlyo0goBrU (accessed Sep. 19, 2024).

[7] "MIT App Inventor," Massachusetts Institute of Technology, https://appinventor.mit.edu/ (accessed Sep. 19, 2024).