Bubble Tea Machine

ECE 445 Design Document

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1. Introduction

1.1 Problem

Bubble tea shops are immensely popular on the UIUC campus. While incredibly tasty to drink, they are not cheap. As the bubble tea fad grows, so does the price of a well-made drink. A person can expect to spend about $6 for their drink. If bought as an infrequent luxury, this price is reasonable. However, many UIUC students purchase bubble tea often. If cheaper high-quality bubble tea could be sold, most UIUC students would eagerly buy it all the time.

In order to lower the price, without impacting the drink’s quality, we would like to automate the bubble tea preparation while maintaining the quality of the ingredients.

1.2 Solution

Our team proposes a Bubble Tea Vending Machine. To use this machine, a person will place a cup under the drink dispenser. The vending machine will have straws, lids, and cups sitting next to it. The user will interface with the machine via a button board that will be on the outside of the machine. The board will have buttons for selecting the size and flavor of the drink. After making all their selections, the user will press start.

The machine will have large reservoirs for milk, tea-syrup mixture, and boba. The boba will be stored in simple syrup in order to preserve the texture. To dispense the liquids, it will use peristaltic pumps. Based on the size selection, it will dispense differing amounts of tea and milk. Boba will be dispensed first to prevent splashing then, the liquids will be dispensed. The boba will be stored in a closed Tupperware container with an opening on the side that functions as a door. This door will be powered by a servo motor and slowly releases boba when it must be dispensed. Once the appropriate amount of boba is in the cup, the door will close again so no more boba is released.

1.3 Visual Aid

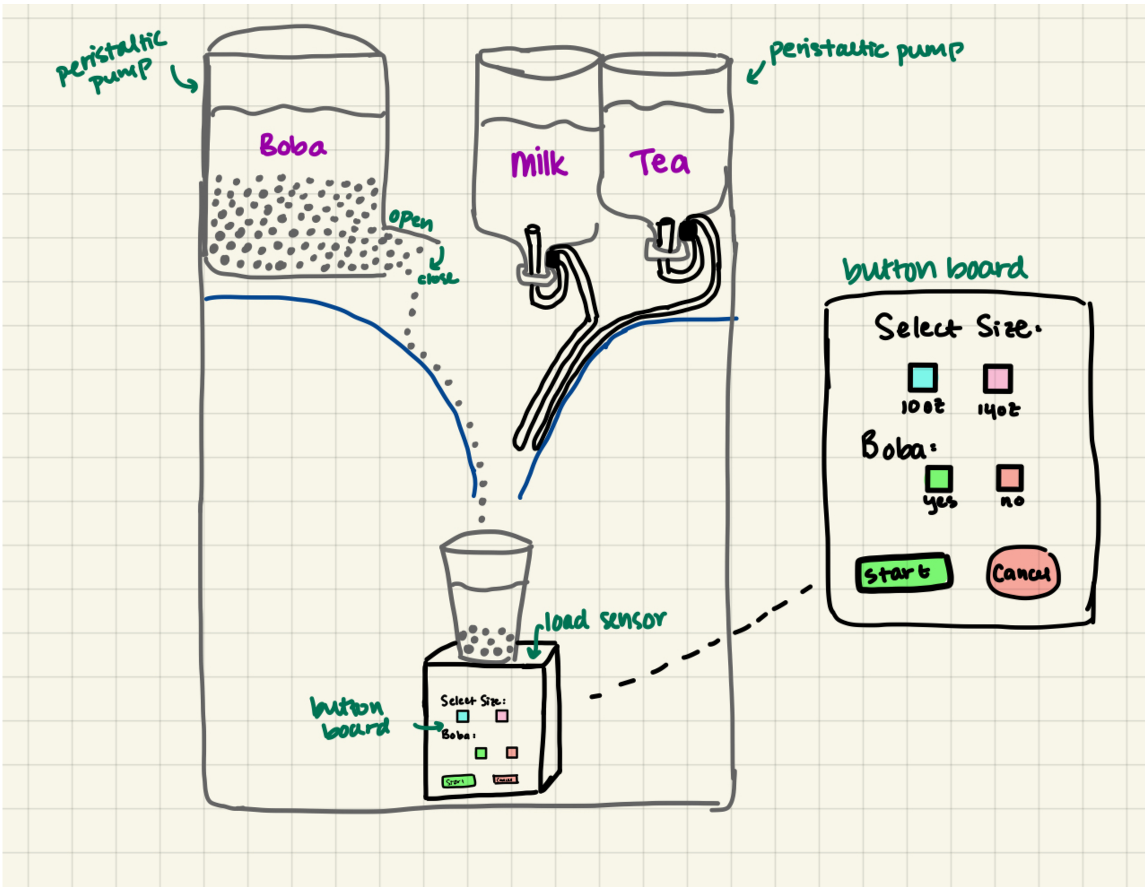


Figure 1. Bubble Tea Machine Visual Aid

1.4 High-Level Requirements List

- The device must provide the user with many combinations of size and ingredients. We will have two size options (10 oz, and 14 oz), and an option for no boba. Each combination will be allowed, giving the user 4 possible drink options.
- The device must be able to dispense pre-calculated amounts of liquid and boba into the cup.

	Boba	Tea	Milk
10 oz	35-42g	(¾ cup)160-175g	(1.5 tbsp) 15-22g
14 oz	35-42g	(5/4 cup) 270-300g	(2.5 tbsp) 30-40g

Table 1. Drink Size Measurements

- The device must start/cancel under the appropriate conditions. It should start only if the "start" button is pressed. The machine should stop the order if the "cancel" button is pressed.

2. Design

2.1 Block Diagram

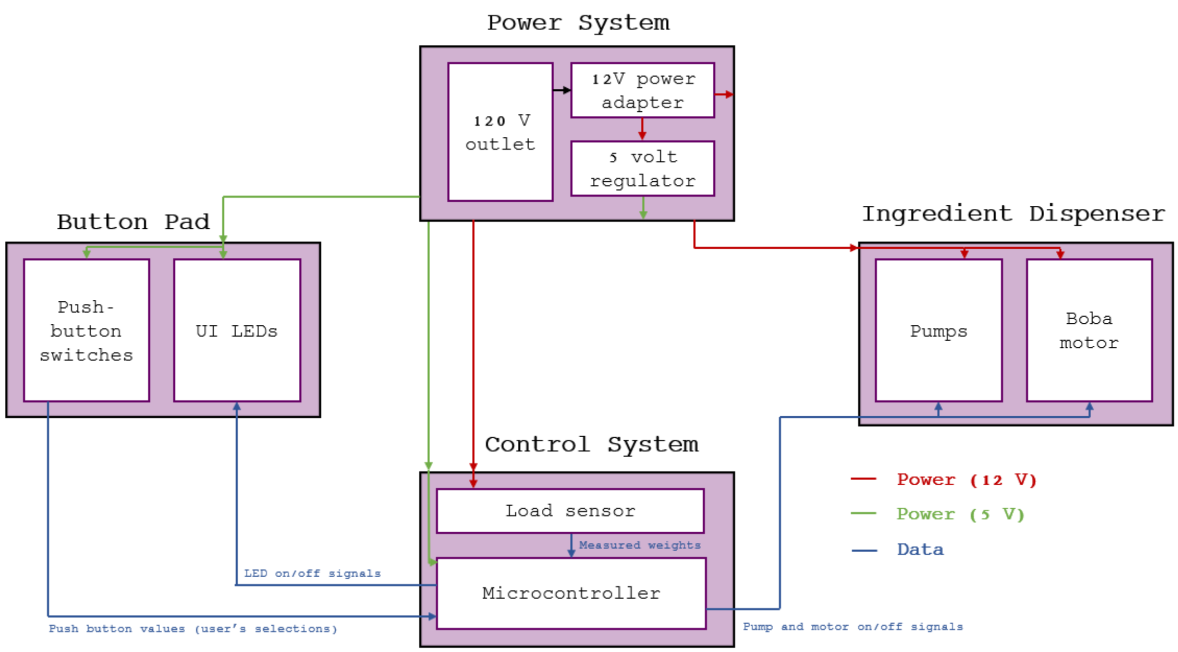
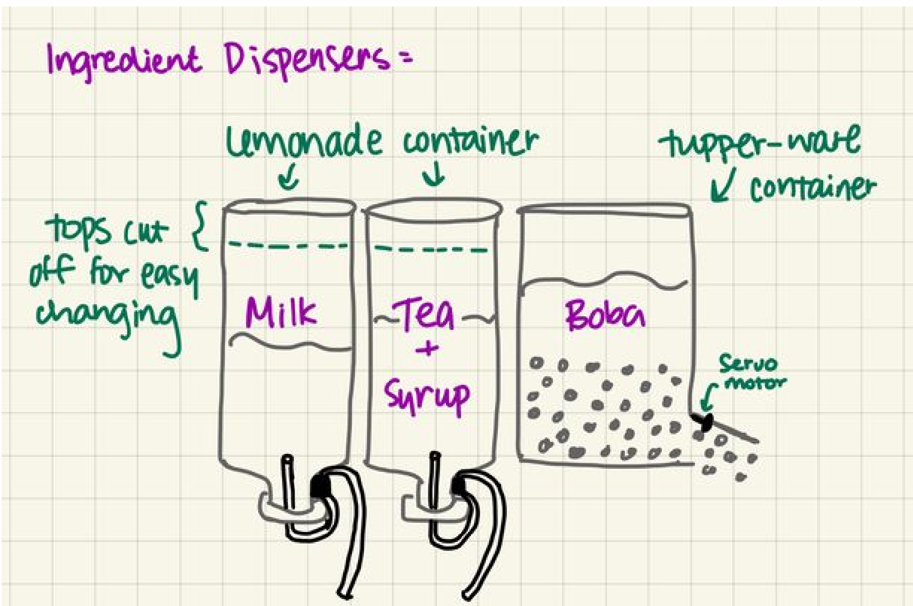


Figure 2. Bubble Tea Machine Block Diagram

The bubble tea machine will contain four major subsystems. The power system will ensure all the other subsystems receive the appropriate amount of voltage and current. The button pad will contain the push-button switches that the user will interface with along with LEDs that display to the user that the drink is being made. The control system takes in data entered by the user and sends signals to the pumps and boba motor when it is time to dispense the ingredients. Additionally, the load sensor will send signals to the ingredient dispensing system when the appropriate weight is reached for each ingredient. Finally, the ingredient dispensing system will release the liquid ingredients via pumps and the boba via a servo motor.

2.2 Physical Design



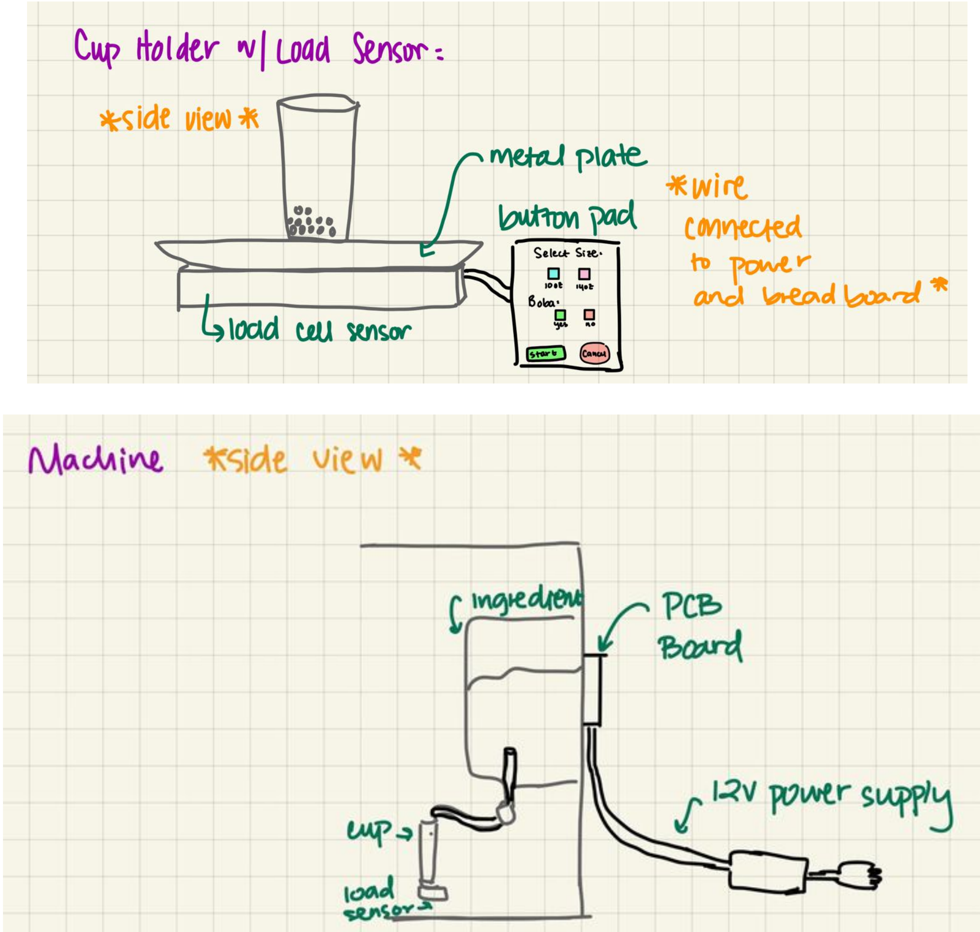


Figure 3. Bubble Tea Machine Physical Design

All components of the bubble tea machine will sit inside a Home Depot Box. The two liquid containers will be made of lemonade bottles while the boba container will be a vertical Tupperware box. The silicon tubing for the pumps will be drilled into the lids of the lemonade bottles. The cup holder will be made with a metal plate sitting on top of a load cell sensor. The button board will be a small breadboard with push-button switches sitting next to the cupholder. We will attach the PCB behind the machine.

2.3 Subsystem Overview

2.2.1 Power System

The power supply will provide power to the whole system. This includes the PCB, the pumps/door, the microcontroller, and the load sensor for the cup. The voltage will need to be initially stepped down from 120 V to a more manageable voltage of 12 V. We know that the motor, the most powerful component, will need 12 V to function with reliable strength. This will be done with the AC/DC wall adapter that steps down from 120VAC to 12VDC. We will then step this down for the other components.

Requirement	**Verification**
1. Bubble Tea Machine must plug into the wall and receive 12VDC ± 5% from the power supply. 2. Voltage regulator must send 5v ± (1.5-4)% to the microcontroller, Servo Motor, and load cell sensor/Hx711 amplifier. 3. Voltage regulator must supply 150-300 mA to Peristaltic Pumps and microcontroller.	1A.Cut off the end of the power supply and use an oscilloscope to check that the output voltage of the power supply stays within 5% of 12V. 2A. Use an oscilloscope to check that 5v ± (1.5-4)% is outputted from the voltage regulator. Check Vo from figure 4. 3A. Connect Vout to Vin in Figure 4. 3B. Change R1 from Figure 4 so that the output current is the appropriate amount for each component. 3C. Probe Vo from figure 4 and measure current with the adjusted resistors to ensure the current supplied is 150-300 mA.

Table 2. Power System RV Table

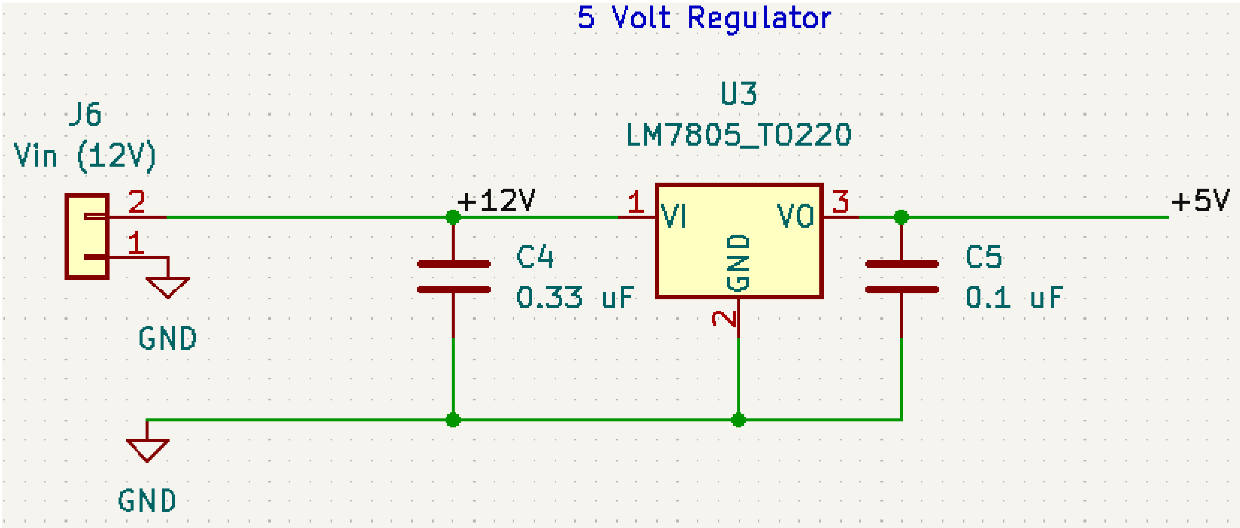


Figure 4. Voltage Regulator Schematic

2.2.2 Button Pad

The button pad will serve as the user interface for our device. The user will make their selections and these will be communicated to the PCB. The button pad will be made up of 6 push-button switches for the 4 drink options (2 size options, Y/N option for Boba, Start, Cancel) available to the user. The data from these buttons will be sent to the control system (PCB) so that the appropriate drink choices can be carried out. Each button requires around 5 VDC (up to 12VDC) and up to 50 mA. The data from the buttons need to be saved so that we can use those signals to be able to control pumps/motors.

Requirement	Verification
1. The push-button switches must send accurate signals to the appropriate ingredient containers. 2. The push-button switches receive 40-60 mA of current.	1A. Connect the start signal from figure 5 (J19) to an oscilloscope and the start signal (pin 28) from figure 6 to a different channel on the oscilloscope. Check that these signals match. 1B. Check that the start_led from figure 6 turns on.

	1C. Repeat 1A. For the 10oz button (J14), and the 14oz button (J16) from figure 5 to their respective signals/LEDs from figure 6. 2A. Connect the 5V for the buttons to a 100Ω potentiometer. 2B. Change the potentiometer until it reaches 40-60 mA. 2C. Measure the current with a multimeter.

Table 3. Button Pad RV Table

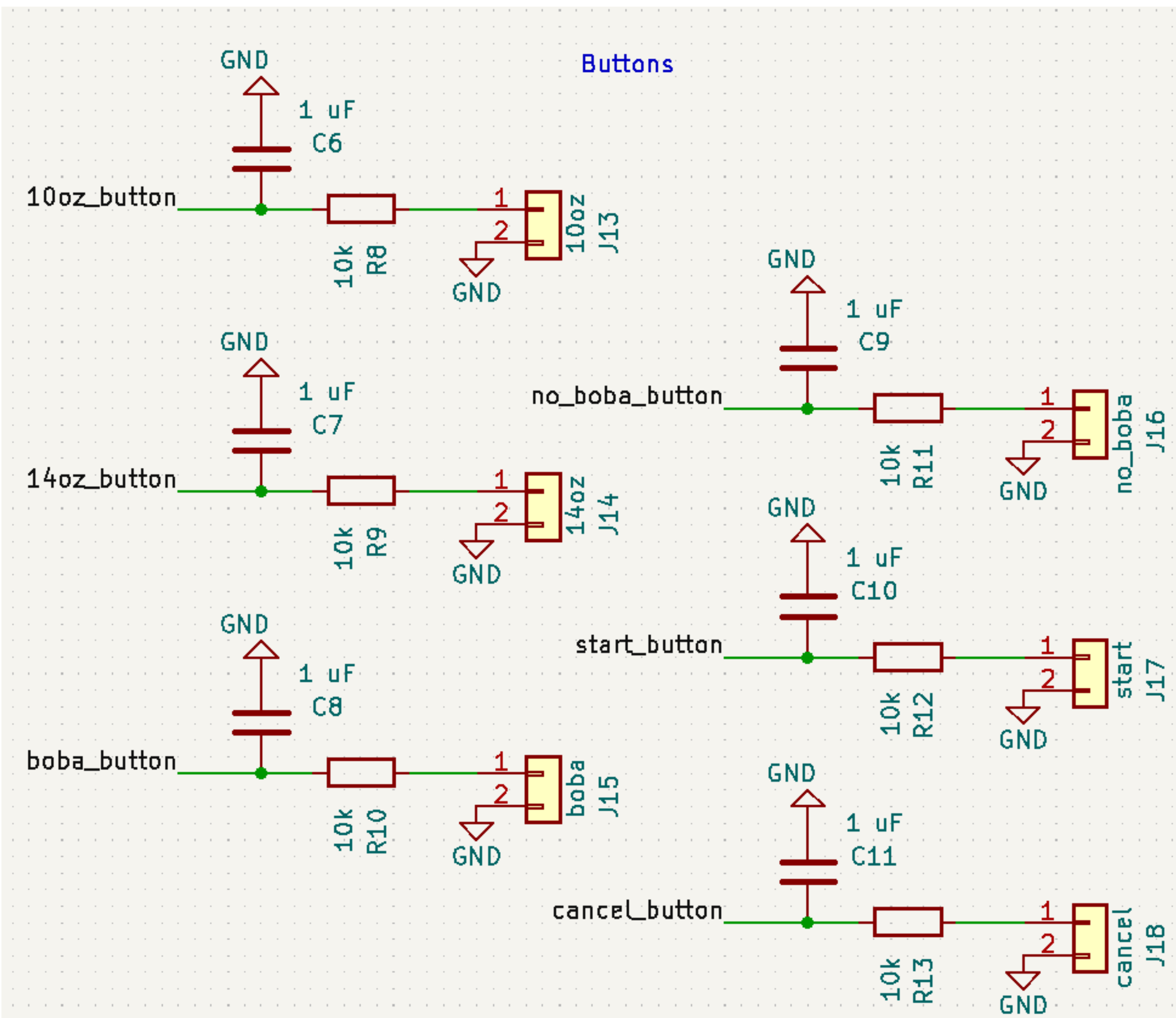


Figure 5. Button Pad Schematic

2.2.3 Control System

The PCB will contain all of the control logic for the bubble tea machine. Data from the button pad is received and the appropriate control signals to the motor/pumps are computed via the ATMega328P microcontroller. The microcontroller will take in input from the button pad and load cell sensor and will send start/stop signals to the motors. The load sensor will be used to detect the amount of boba/milk/tea that falls into the cup. The weight will be used to control how long the door/pumps are open. Depending on the size of the drink, the weight required for each ingredient will differ and the door/pumps will be open for the appropriate amount of time. The logic programmed into the microcontroller consists of determining which options the user chose for their drink (the size and whether or not they want boba) and then telling the servo/pumps to turn on so the boba/milk/tea can pour out into the cup. In the control system logic, the load cell signal will constantly check the voltage output based on the weight on the load cell sensor with a predetermined reference voltage for each drink size. Once the reference voltage has been reached, that motor will turn off. The logic will be written so that the boba is released first, then the milk, and finally, the tea. Since the load cell sensor will detect changes based on resistance differences, the output may be too small to notice a difference. To fix this, we will send the load cell sensor signals through an amplifier (Hx711). Additionally, we have a “cancel” button that the user can press if they want to cancel their order before they press start. This will allow users to begin again if they make an undesired selection (while putting in their drink order). Once the start button is pressed, the cancel button will not impact the production of the current drink. The microcontroller will also supply the clock and PWM signal to our chips.

Requirement	Verification
1. Bubble tea machine should only start making the drink when the “start” is pressed. 2. Bubble Tea Machine should ignore the “cancel” button once “start” has been pressed. 3. Load Cell Sensor stays within appropriate voltages for each drink size. 10oz: (3mV±.75), 14oz: (3.9mV±.75) 4. The microcontroller receives 100-150mA.	1A. Connect boba_motor (pin3) signal (figure 6) to the oscilloscope. 1B. Ensure the signal is high when the start signal (figure 6) is high. 2A. Connect cancel_button (figure 5) to an oscilloscope. 2B. Connect the start_button (figure 5) to a different channel on the oscilloscope. 2C. Connect the cancel_led signal (figure 6) to a different channel on the oscilloscope. 2D. Ensure that the cancel_button signal is only high when the start signal is low and the cancel_led signal is high. Alternatively, we can make sure that the cancel_led is not on when the start_button is high and the cancel_led is on when the start_button is low. 3A. Hook up the green and white wires of the load cell sensor to a multimeter. 3B. Verify that the voltage difference is the appropriate amount for each ingredient and drink size. 10oz: (3mV±.75), 14oz: (3.9mV±.75) 4A. Connect the 5V for the microcontroller to a 100Ω potentiometer.

	4B. Change the potentiometer until it reaches 100-150 mA. 4C. Measure the current with a multimeter.

Table 4. Control System RV Table

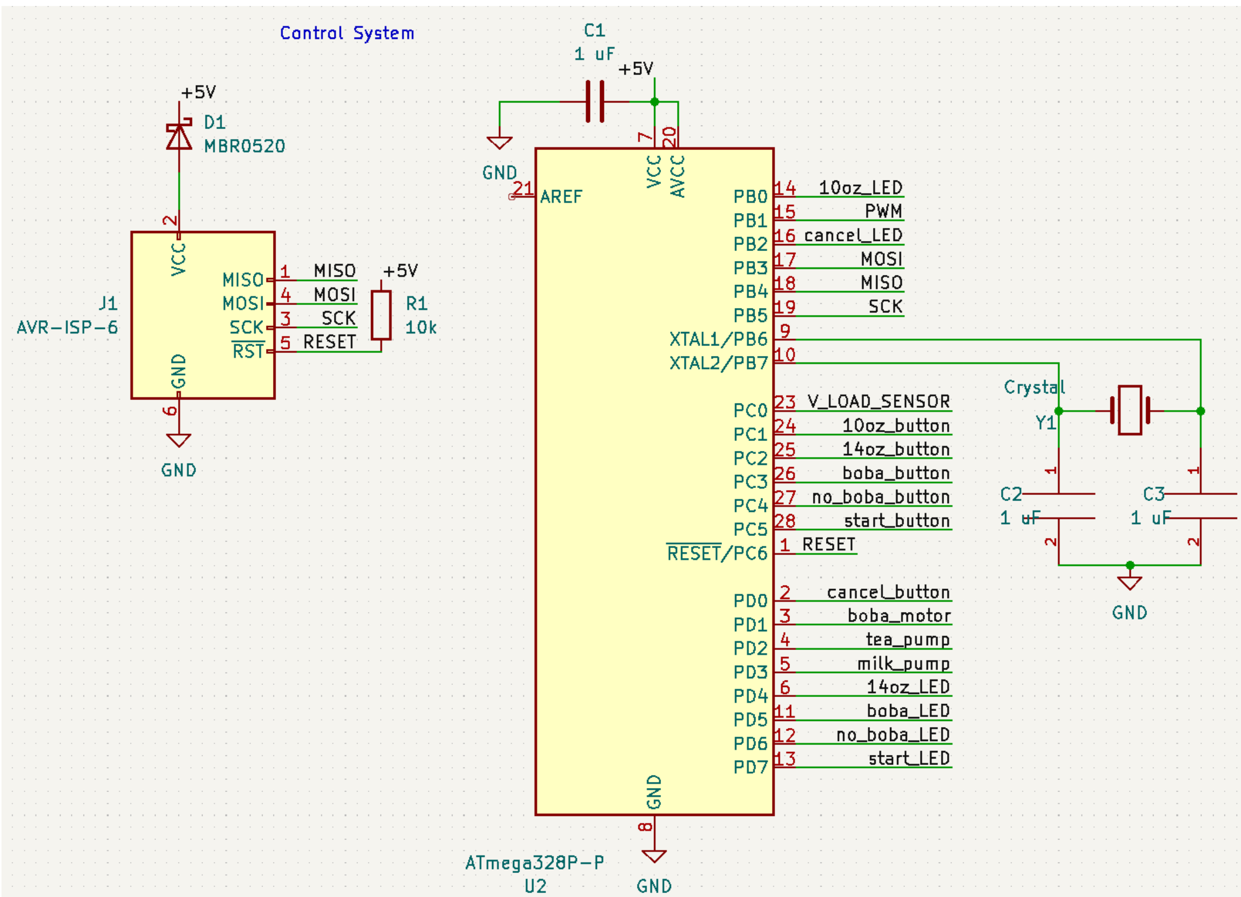


Figure 6. Control System Schematic

2.2.4 Ingredient Dispenser System

Each reservoir of ingredients (boba, milk, tea) will be a plastic container. The liquid ingredients require Peristaltic pumps with silicon tubing. A peristaltic pump has 2 tubes, one placed in the reservoir and one placed in the cup. The liquid dispenser will be a lemonade bottle with the silicon tube drilled into the lid so it reaches the liquid. The boba dispenser will be a Tupperware container that has a little door hinged to the bottom right corner. A simple servo motor will control the opening and closing of the door. The pumps and the door will be controlled by the PCB (button presses and load sensor). Once enough weight has been detected in the cup (based on the size of the drink), the door/pumps will be turned off. To power the dc motors (pumps), we will use an H-Bridge motor driver chip (L293D). Since we have 2 different liquid ingredients, we need 2 peristaltic pumps (each with 1 DC motor). The H-bridge will allow us to power each pump independently. The boba door will use a servo motor which will be powered by a servo trigger. The trigger has 3 potentiometers, one for how far the servo motor should turn when the switch is open, one for how far the motor should turn when the switch is closed and the last one for time for the motor to move from the first position to the second position. The trigger will also receive input from our load cell sensor and then supplies voltage to our servo motor. Both the pumps (DC motor) and the servo motor need PWM signals. While the servo trigger utilizes a microcontroller already built into the board (which takes care of the PWM signal), the H-bridge doesn't. To send the PWM wave to our H-bridge, we will use our ATMega328P.

Requirement	**Verification**
1. Servo motor must run when powered by the servo trigger. 2. The pumps (DC motor) must run when powered by the H-bridge.	1A. Connect servo motor output from servo trigger (figure 7) to a multimeter. 1B. Check that 5v±0.25 is being supplied. 2A. Connect Vcc2 (pin 8) from

3. The Servo motor trigger should leave the door of the servo motor open for 7-10 seconds for the boba to be dropped. 4. PWM signal is supplied to H-bridge accurately (circuit works). 5. Servo motor receives 4-6 mA. 6. Peristaltic Pumps receive 200-300 mA.	figure 8 to a multimeter. 2B. Check that 12v±0.25 is being supplied. 3A. Connect the out pin of the servo motor trigger pin to the oscilloscope. 3B. Adjust the time potentiometer (potentiometer C) until open for 7-10 seconds. 3C. Ensure that the servo motor does not shut before the completion of seconds. 4A. Connect PWM signal from figure 8 to oscilloscope. 4B. Check that the wave we see on an oscilloscope is an accurate PWM wave. 4C. Connect PWM signal (en1 in h-bridge) from figure 8. 4D. Check that the wave we see on an oscilloscope is an accurate PWM wave. 5A. Connect the 5V for the Servo Motor to a 100Ω potentiometer. 5B. Change the potentiometer until it reaches 4-6 mA. 5C. Measure the current with a multimeter. 6A. Connect the 5V for the Peristaltic Pumps to a 100Ω potentiometer. 6B. Change the potentiometer until it reaches 200-300 mA. 6C. Measure the current with a multimeter.

Table 5. Ingredient Dispenser RV Table

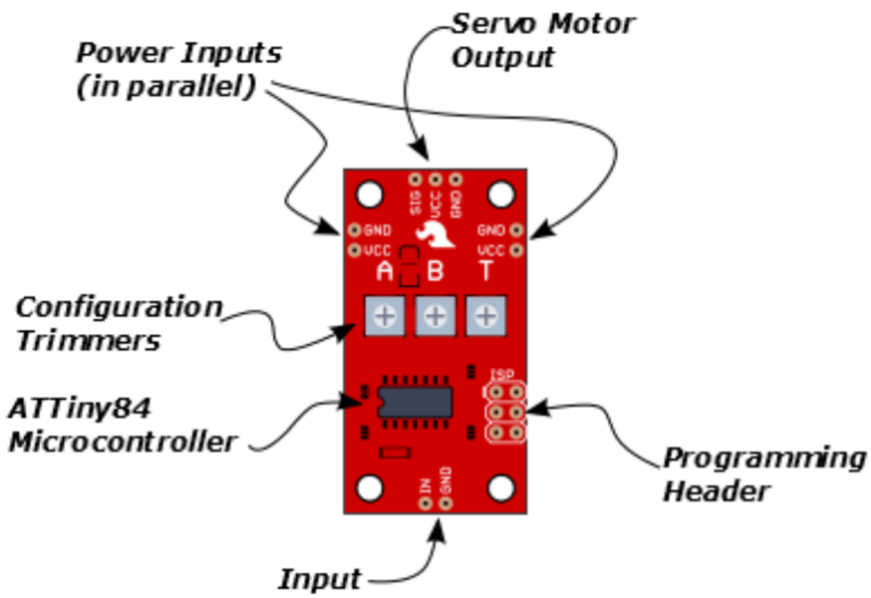


Figure 7. Servo Trigger Pinout

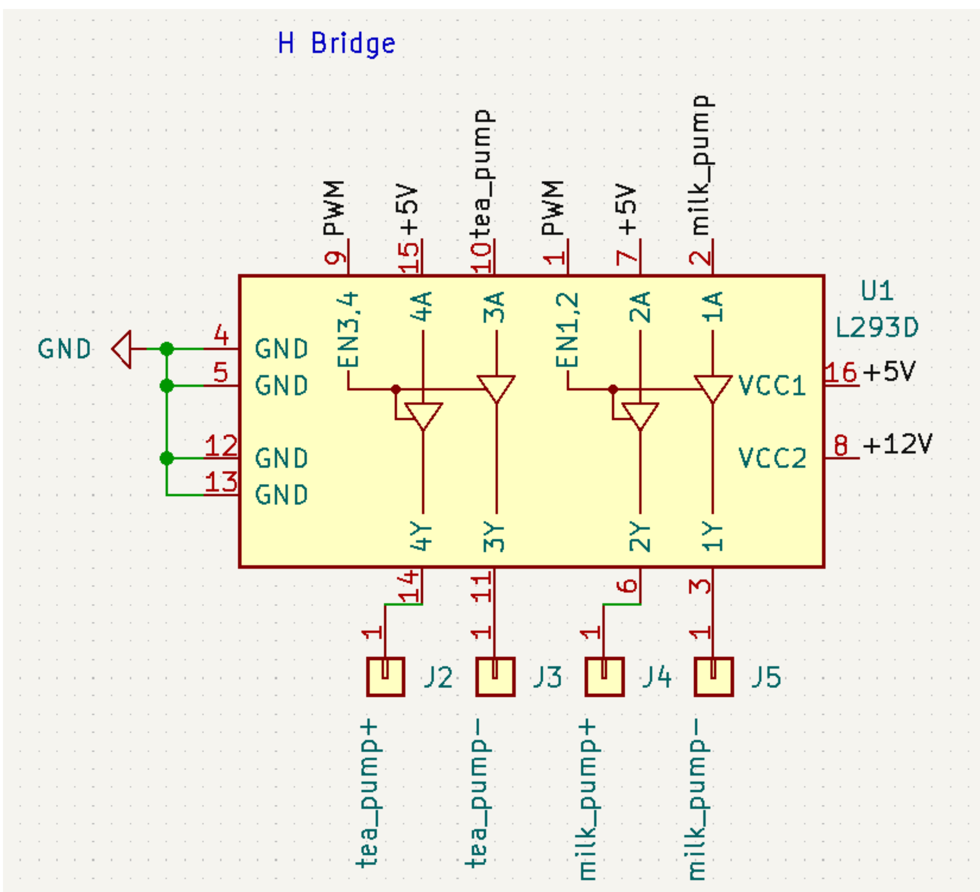


Figure 8. Ingredient Dispenser Schematic

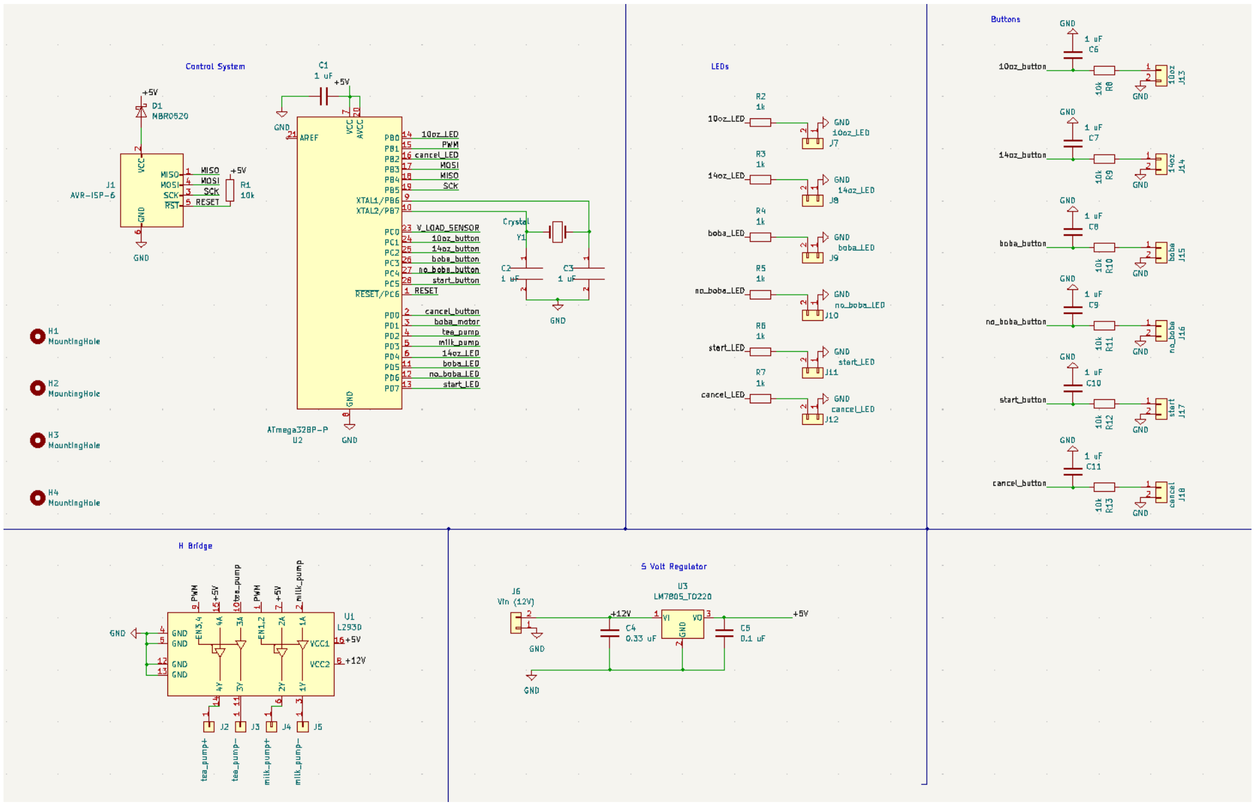


Figure 9. Overall Schematic

2.4 Tolerance Analysis

A potential risk we would face is accurately measuring the weight of ingredients in the bubble tea cup. If the load cell sensor that we use is not accurate enough, the boba motor may release more/less boba than what is anticipated, resulting in inaccurate quantities in the drink. The load cell sensor we plan to use has a capacity of 1kg, and we anticipate our cup and plate to be around 35-40 grams. Using the formula from Renesas [6], $\varepsilon = \sqrt{\varepsilon C^2+((\varepsilon Z*L*N) / W)*t)^2 + (\varepsilon S*t)^2}$ where N is the number of load cells, L is the rated capacity (500g), t is the temperature change (range), and W is the maximum load we will measure. Unfortunately, the load cell sensor that we plan to use (Adafruit product id: 4540) does not have helpful values, we will estimate the accuracy with the Sparkfun load cell sensor's datasheet (SEN-14728). Using the values from the table below (provided from SEN-14728's datasheet [7], we get the accuracy of the 1kg load cell sensor to be .2291%, which is about ± 2.29g = $\varepsilon = \sqrt{(0.05)^2+(((0.01)*(500)*1) / 1000)*20)^2 + (0.01*20)^2}$. For our largest drink, the total grams we anticipate it having is 340-387g. Since the load cell sensor gives us accuracy within 2g, this will fall within our desired range of total weight. Therefore, the accuracy should fall within our desired range for the 10oz and 12 oz drinks as well.

Symbol	**Definition**	**Value**
εC	Combined Error	0.05 %FS
εZ	Temperature coefficient of ZERO	0.1 %FS/10 °C
εS	Temperature coefficient of SPAN	0.1 %FS/10 °C

Table 6. Load Cell Sensor Accuracy Symbols

3. Cost and Schedule

3.1 Cost Analysis

3.1.1 Labor

According to the Illini Success Annual Report 2019-2020, a Computer Engineer would make an average of $99,145. This leaves us with an hourly wage of $47.67. Assuming we each work around 14 hours a week, with 8 weeks remaining (112 total hours) and using the formula ($/hour) * 2.5 * hours to complete, the total labor cost of a computer engineer would be $13,347.60. Each of us would average around $5,339.04 for labor costs.

3.1.2 Parts

Module	Product ID	Price per Unit	Quantity	Price
12V Power Adapter	1470-3113-ND	$11.66	1	$11.66
5v Voltage Regulator	MC7805CTG-ND	$0.65	3	$1.95
ATMega328 Microcontroller Bootloader Uno	X000048	$5.87	2	$11.74
Peristaltic Pumps	1150	$24.95	2	$49.90
Silicone Tubing	3659	$3.50	1	$3.50
1kg Load Cell Sensor	1528-4540-ND	$3.95	1	$3.95
500g Load Cell Sensor	1568-1899-ND	$11.25	1	$11.25
HX711 Amplifier	1568-1436-ND	$9.95	1	$9.95
Load Sensor Combinator	474-BOB-13878 (Mouser)	$1.95	1	$1.95
H-Bridge Motor	Bridgold-31	$8.99	1	$8.99
Servo Motor	900-00005-ND	$16.72	1	$16.72
WIG-13118 Servo Motor Trigger	1568-1363-ND	$17.95	1	$17.95
				Total: $149.51

3.2 Schedule

Week	Tasks	Emily	Saisita	Tracy

2/21	Design Doc Check, Finalize + Order Parts	Complete Design Document, Draft+Finalize PCB layout	Complete Design Document, Draft+Finalize PCB layout	Complete Design Document, Draft+Finalize PCB layout
2/28	Design Review, PCB Board Review	Complete Design Review, Finalize parts order	Complete Design Review, Finalize PCB layout and get board approved (first-round order)	Complete Design Review, Finalize PCB layout and get board approved (first-round order)
3/7	Order PCB and request machine shop work	Buy components for the build of the design (mechanical components), Test load sensor output (reference voltage) to determine resistor values, bring project to the machine shop (if we've received parts)	Buy components for the build of the design (mechanical components), Test load sensor output (reference voltage) to determine resistor values, bring project to the machine shop (if we've received parts)	Buy components for the build of the design (mechanical components), Test load sensor output (reference voltage) to determine resistor values, bring project to the machine shop (if we've received parts)
3/14	Spring Break	- - - - - - - -	- - - - - - - -	- - - - - - - -
3/21	Finish Soldering PCB and write out microcontroller code	Write out microcontroller code, work on individual progress report	Solder PCB, work on individual progress report	Write out microcontroller code, Help Tracy Solder PCB, work on individual progress report
3/28	Individual	Test input and	Test output to	Test output to

	Progress Reports Due	output from load cell	the servo motor. Make sure servo motor and motor trigger powers the servo appropriately.	pumps. Test pumps with load cell sensor and check that the motor driver powers the motor appropriately.
4/4	Test all components	Test all inputs and outputs together	Test all inputs and outputs together	Test all inputs and outputs together
4/11	Complete all tests	Finish testing, create mock demo	Finish testing, create mock demo	Finish testing, create mock demo
4/18	Mock Demos	Mock Demo, begin final demonstration (last-minute touch-ups)	Mock Demo, begin final demonstration (last-minute touch-ups)	Mock Demo, begin final demonstration (last-minute touch-ups)
4/25	Demonstrations	Final demonstration, start working on final paper	Final demonstration, start working on final paper	Final demonstration, start working on final paper
5/2	Final Paper Due	Finish Final Paper, add last-minute touch-ups	Finish Final Paper, add last-minute touch-ups	Finish Final Paper, add last-minute touch-ups

4. Ethics and Safety

4.1 Food safety

We recognize that any product that touches food will have some safety concerns. IEEE Code of Ethics agrees to “uphold the highest standards of integrity, responsible behavior, and ethical conduct in professional activities.” Further, “to hold paramount the safety, health, and welfare of the public”. We have taken into consideration the necessity to inform the user of both proper cleaning practices and to ensure that we use food-safe components in our design.

4.1.1 Cleaning

This device needs to be properly cleaned between uses. Hot water and soap are effective to clean out all the reservoirs. There will be a “cleaning” mode for the device that will run all pumps to be cleared of any residue. For this to work, reservoirs should be filled slightly with hot water and a large cup placed in the cupholder.

4.1.2 Food-safe components

All components and reservoirs will be entirely food-safe. The main concern is the tubing, so we will avoid PVC tubing. There are many alternatives, including silicon tubing.

5. Citations

[1] *IEEE Code of Ethics*. IEEE Code of Ethics. (n.d.). Retrieved February 02, 2022, from https://www.ieee.org/about/corporate/governance/p7-8.html

[2] *Variable voltage power supply using the LM317T*. Basic Electronics Tutorials. (2018, February 15). Retrieved February 20, 2022, from https://www.electronics-tutorials.ws/blog/variable-voltage-power-supply.html

[3] *Bubble Tea - 16 fl oz*. Nutritionix. (n.d.). Retrieved February 23, 2022, from https://www.nutritionix.com/i/nutritionix/bubble-tea-16-fl-oz/565c78f34e9bc9f308b6151b

[4] *Getting started with load cells*. (n.d.). Retrieved February 23, 2022, from https://learn.sparkfun.com/tutorials/getting-started-with-load-cells/all

[5] Industries, A. (n.d.). *Strain gauge load cell - 4 wires - 1KG*. adafruit industries blog RSS. Retrieved February 23, 2022, from https://www.adafruit.com/product/4540#technical-details

[6] RA Family (2020), *RA2A1 Weight Measurement Example Using a Load Cell* (Application Report No. R01AN5519EJ0100). Retrieved February 23, 2022, from https://www.renesas.com/us/en/document/apn/ra2a1-weight-measurement-example-using-load-cell?language=en

[7] Tal221 miniature load cell - cdn.sparkfun.com. TAL221 Miniature Load Cell. (n.d.). Retrieved February 23, 2022, from https://cdn.sparkfun.com/assets/9/9/a/f/3/TAL221.pdf

[8] YouTube. (2017, December 3). *Electronic Basics #33: Strain Gauge/Load Cell and how to use them to measure weight*. YouTube. Retrieved February 23, 2022, from https://www.youtube.com/?gl=IT

[9] *Illini Success Annual Report 2019-2020*. Box. (n.d.). Retrieved February 24, 2022, from https://uofi.app.box.com/s/1t8xj69117lrsqm7753ujnrg8yyrtcwn

[10] *Measurement conversion*. Cuisinivity. (n.d.). Retrieved February 24, 2022, from http://www.cuisinivity.com/guide/measurement.php

[11] Omega Engineering Inc. (2020, July 2). *How to check the Load Cell with a multimeter*. https://www.omega.com/en-us/. Retrieved February 24, 2022, from https://www.omega.com/en-us/resources/load-cell-troubleshooting

[12] Posted by Bryon Williams & filed under Article Library, M. N. (2019, June 10). *Load cell sensitivity explained: Calculations, Definitions & More - Montalvo*. Montalvo Corporation. Retrieved February 24, 2022, from https://www.montalvo.com/article-library/depth-look-load-cell-sensitivity/

[13] *Servo trigger hookup guide*. (n.d.). Learn at SparkFun Electronics - learn.sparkfun.com. Retrieved February 24, 2022, from

https://learn.sparkfun.com/tutorials/servo-trigger-hookup-guide?_ga=2.92835165.114547007.1645937649-1847925532.1643341661

[14] *Atmega328 pinout*. Learning About Electronics. (n.d.). Retrieved March 3, 2022, from http://www.learningaboutelectronics.com/Articles/Atmega328-pinout.php

[15] JayconSystems, & Instructables. (2017, September 29). *Getting started with the ATMega328P*. Instructables Circuits. Retrieved March 3, 2022, from https://www.instructables.com/Getting-Started-With-the-ATMega328P/

[16] *MA7800 series positive-voltage ... - SparkFun Electronics*. uA7800 Series (Rev. J). (n.d.). Retrieved March 6, 2022, from https://www.sparkfun.com/datasheets/Components/LM7805.pdf