ECE 198 Design Document – Group 76

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1. Needs Assessment

1.1. Client Definition

Preparing hot drinks has many significant risks. If it is too hot, it can cause scalding and results in a high likelihood of contracting esophageal cancer, one of the most aggressive and least survivable cancers [1] [2]. This is a concern for people who want to avoid scalding accidents or cancer, especially parents of young children and seniors [3] [4]. However, if a drink is too cold for clients, it may not fit their preference for warmer water [5] and can increase the likelihood of colds and fevers in vulnerable populations such as infants or seniors [6].

In Ontario, while esophageal cancer is one of the rarest forms of cancer, its rates have significantly increased in the past two decades [7]. Esophageal cancer is also associated with people in the lower socioeconomic bracket and with people who do not have an adequately diverse diet or who smoke [1]. However, since the actual number of people with esophageal cancer is very tiny relative to the entire population of Ontario at less than 5 in every 100,000 [7], the clients who face this challenge would be people who are at risk of everyday causes that likely cause esophageal cancer, which tend to be children under the age of 10 [3] and seniors over the age of 60 [4]. In the Waterloo Region, this is roughly 100,000 people, based on the 2016 census [8]. Economically, nearly all parents and seniors in the Waterloo Region have the means to a water tap and a kettle regardless of income status [9]. Hence, the customer base count applies to all of them.

1.2. Competitive Landscape

One way to check for beverage temperature is to pour it on the wrist since it has a temperature sensation similar to the forehead, and thus tends to have a better sense of temperature than the hand [10]. However, this method wastes water, which can be costly both practically and financially given the risk to the person testing the water [11]. Another method is to check by sticking a thermometer into the liquid, which requires constant monitoring and can be unpopular, as it risks contamination and requires thorough washing [12]. Therefore, another way is to use a handheld laser thermometer to measure temperature like the ones used for cooking, but this also requires continuous measurement and monitoring and can also be damaging to eyesight if the infrared rays of the thermometer are pointed toward the eyes accidentally [13].

1.3. Requirements

Therefore, a better solution would require a non-contact thermometer that can measure all temperatures of drinks within 5 degrees of the actual temperature. It must also allow the client to select a preferred temperature within the safe drinking range of 8 to 60 degrees Celsius. Then, it should measure temperature every 30 seconds. When the drink has reached within 5 degrees Celsius of the desired temperature, the customer should be notified with a buzzer. The solution should also include appropriate redundancy for errors, such as malfunctioning of the thermometer.

2. Analysis

2.1. Design

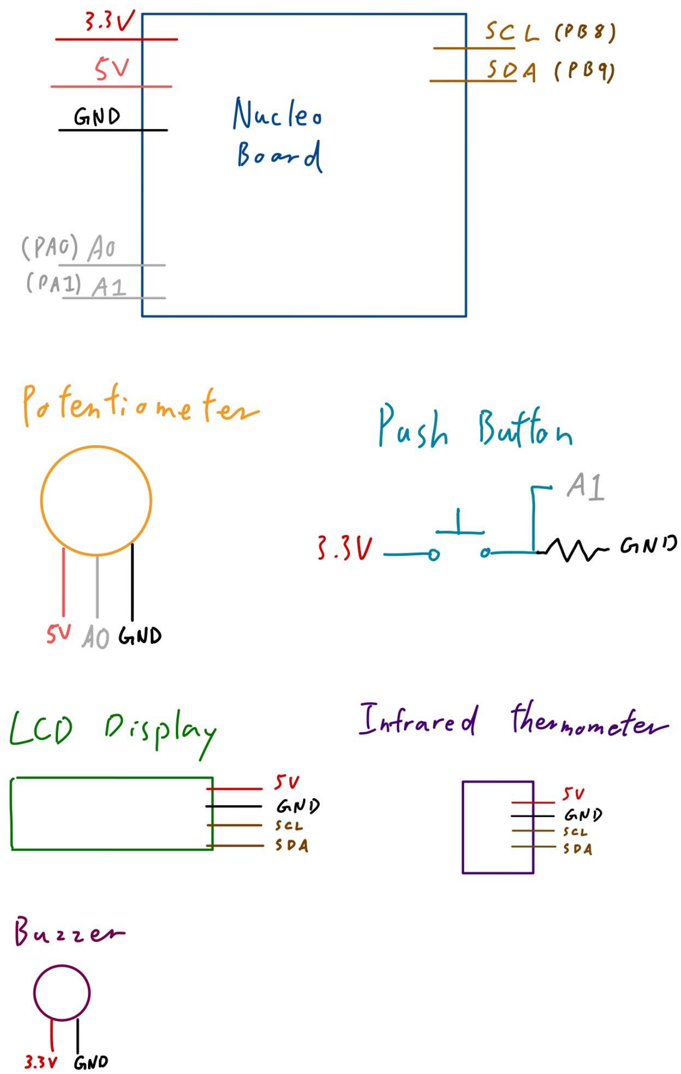
Our solution to the problem will be constructed with a stand, STM32 Nucleo board microcontroller unit (MCU), infrared temperature sensor, LCD screen, buzzer, input potentiometer, and push button. The thermometer is placed on top of the stand, with its lens pointing down, and is up-down adjustable by a knob connected to a rack and pinion gear setup. Moreover, the display will have an LCD adapter module to simplify the connections and use fewer ports on the MCU [14].

The user should then press the push button to activate an initial measurement. If the cup is dangerously hot, which is more than 65 degrees [15], it will let out a single ring as a warning. Then, a prompt on the display will ask the user to use the knob on the potentiometer to set a temperature, which can be set by another push of the button.

Then, the user can leave the stand and wait. During this time, the thermometer will take the temperature every 30 seconds. At each measurement, the design will use two factors to determine when the temperature has been reached. First, if the temperature detects a level within 5 degrees of the user’s desired temperature, then the buzz will sound off immediately. Second, if the approximated time based on Fourier's Law of Heat transfer and the calorimetric equation $Q = mc\Delta T$ has been reached, it will buzz. The microcontroller will sound off at the minimum of these two times.

The ring of the buzz will continuously sound off every 5 seconds until the user has pressed the push button again to indicate that the cup is removed.

Circuit schematics:



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Software Design Outline:

To implement the design by integrating the components' input and output, we use the following code skeleton:

```
enum stage { reset, set_temp, watch_temp, buzz };

int main() {
```

```
    stage curr = reset; // controls current stage of design's function
    while (1) {
        if (curr == reset) {
            // wait button start
            string input;
            cout << "Enter start\n";
            cin >> input;
            if (input == "stop") {
                break;
            } else {
                curr = set_temp;
            }
            // start timer
            cout << curr << endl;
        } else if (curr == set_temp) {
            int input;
            cout << "Enter temperature\n";
            cin >> input;
            // take button input
            curr = watch_temp;
            cout << curr << '\n';
        } else if (curr == watch_temp) {
            // take measurement, calculate estimated time, compare
            cout << curr << '\n';
            curr = buzz;
            cout << "taking temp, checking to buzz\n";
        } else if (curr == buzz) {
            // check if push button pressed by user to stop buzzing
            // if so, stop and move back
            // if not, keep buzzing
            cout << "buzzing, press button to stop\n";
            cout << curr << '\n';
            // reset timer
            curr = reset;
        }
    }
}
```

2.2 Scientific/Mathematical Principles

1. Linear interpolation on the variable resistance value of the potentiometer:
    a. To map the 0-1023 value of the potentiometer output to an input target temperature range of 17-60 degrees Celsius to allow the users to pick the desired temperature in that range [16].
    b. The equation involved:

    $$\frac{1023-R}{R-0} = \frac{30-T}{T-15}$$

    where,
    R: Current potentiometer value
    T: Targeted temperature value

2. Approximation of cooling rate using Fourier's Law of Heat Transfer: [17]
    a. Since every single drink must contain water, we will approximate it with the properties of water as follows:

    b. By Fourier's Law, we find that the rate of heat transfer is:

    $q =- kA(dT/dx)$, where:

    - *q* is the rate of heat transfer in Watts
    - *k* is the thermal conductivity of water, which is 0.6 W/m*(°C)
    - *A* is the cross-sectional area, which will be approximated to 0.02 m^2, using the standard coffee cup diameter of 81 mm [18].
    - dT/dx is the temperature gradient, which we will assume to be constant and calculate using the initial temperature measurement and the standard room temperature of 20°C.

3. Using Q = mcΔT, we can find the amount of heat lost [19], where:
    a. Q is energy lost, in Joules
    b. m is the mass of the drink, which we approximate with the product of density and average cup volume => 1000 kg / m^3 * 0.0003 m^3 = 0.30 kg. This is the drink's maximum mass, ultimately giving us the maximum possible time to cool down.
    c. c is the specific heat capacity of water, 4.18 J/kg*(°C)

d. ΔT is temperature change, which is the difference between initially measured and desired temperature.

- With the change in energy and its rate of change, we can find the time it takes to undergo the energy change by computing:

  $t = Q / q$, where Q is energy change, and q is the rate of heat transfer.

  The above formula, therefore, has units:

  J / (J/s) = seconds

3. Costs

3.1. Manufacturing Costs

Components:

- A rotary potentiometer: - $4.70 + tax = $5.31
  - Manufacturer: Muzieba - Address: Zhiyuan Rd (M), Longhua District, Shenzhen, Guangdong, 518000, China [20].
  - Distributor: Amazon - Address: 410 Terry Ave N, Seattle 98109, WA [21].
- An Arduino push-button: - $6.98 + tax = $7.88
  - Manufacturer: CUI Devices - Address: 6405 SW Rosewood St, Ste C Lake Oswego, OR 97035 [22].
  - Distributor: Digikey - Address: 701 Brooks Ave South, Thief River Falls, MN 56701, United States [23].
- An Arduino buzzer: - $8.78 + tax = 9.92
  - Manufacturer: PUI Audio Inc. - Address: 1202 E. Yellow Springs Rd. Fairborn, OH 45324 [24].
  - Distributor: Digikey - Address: 701 Brooks Ave South, Thief River Falls, MN 56701, United States [23].
- An LCD display: - $5.75 + tax = $6.50

    - Manufacturer: HiLetgo - Address: Room 1323-1327, Huanqiu Wuliu Zhongxin, HuaNanCheng, PingHu, LongGang, Shenzhen, Guangdong, China. 518111 [25]
    - Distributor: Amazon - Address: 410 Terry Ave N, Seattle 98109, WA [21].
- Male header pins: - $0.20 + tax = $0.22
    - Manufacturer: MCIGICM Shenzhenshi Fanfei Technology Co. Ltd. - Address: Zhonghang Beiyuan Building, Futian District, Zhonghang Road, 42 Shenzhen China [26].
    - Distributor: Amazon - Address: 410 Terry Ave N, Seattle 98109, WA [21].
- An MLX90614 non-contact infrared temperature sensor: - $11.88 + tax = $13.40
    - Manufacturer: Shenzhen Songhe Technology Co. Ltd.
      Address: 7129, Bldg. C, Shenfang Mansion, No.100 Zhenhua Rd., Huaqiangbei, Futian District, Shenzhen, Guangdong China 518000
    - Distributor: Amazon - Address: 410 Terry Ave N, Seattle 98109, WA [21].
- An LCD Adapter for 16 x 2 LCD screens: $8.09 + tax = $9.14
    - Manufacturer: Kuuleyn - Address: 530, No. 8, Area 41, No. 31, Jia'an Rd. Haile Community, Xin'an St., Bao'an Dist. Shenzhen, China 518000
    - Distributor: Amazon - Address: 410 Terry Ave N, Seattle 98109, WA [21].
- 3D printer filament: - no dollar cost, already have
    - Manufacturer: Sunlu - Address: Room 501C, Building 2, No. 35, Jinzhou Road, Tangjiawan Town, High-tech Zone, Zhuhai Guangdong 519000 CN
    - Distributor: Amazon - Address: 410 Terry Ave N, Seattle 98109, WA [21].
- USB A Male to Mini-USB B Male: - part of STM32 Nucleo Board Kit
    - Manufacturer: StarTech.com Ltd. - Address: 45 Artisans Crescent, London, Ontario N5V 5E9 Canada
    - W Store - Address: 200 University Ave West, Waterloo, ON N2L 3G1

<u>STM32F401RE Nucleo-Board:</u> - $34.99 + tax = $39.54

- Manufacturer: STMicroelectronics - Main Address: Chemin du Champ-des-Filles 39 Plan-les-Ouates, 1228, Geneva, Switzerland
- Distributor: W Store - Address: 200 University Ave West, Waterloo, ON N2L 3G1

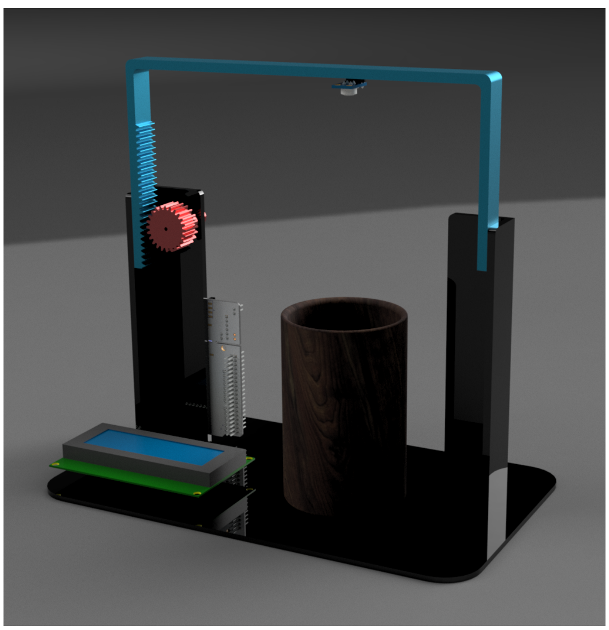
3.2. Implementation Costs

Installation Manual:

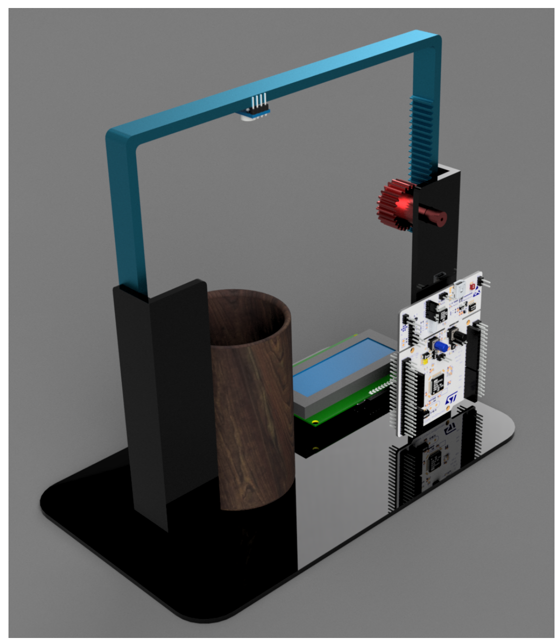
1. Take the stand out of the box.
2. Place the stand on a table and the microcontroller on the side of one of its supports.
3. Plug the USB cable of the STM32 Nucleo-Board into an electrical source.
4. Ensure that the red LED of the microcontroller is on.
5. Check that the button's pins are entirely in the breadboard's sockets.
6. Using a level, verify that the temperature sensor points vertically down.
7. Ensure that the display is working, i.e. it has text prompting you to start.

3D Model of installed setup:

Front view:



Back view:



User Guide:

1. Place a drink cup warmer than room temperature directly under the temperature sensor so that the rim's center is under the lens.
2. Using the stand's knob, adjust the temperature sensor's height to 3-5 cm above the drink's surface.

3. Press the push button on the stand and wait for the display to show the temperature reading.
4. When prompted by the display, turn the knob on the potentiometer to your desired temperature, which will be shown on the display.
5. Push the button again to set your temperature.
6. Wait for the buzzer to sound off.
7. When the buzzer rings, remove the cup.
8. Press the push button another time to stop the ringing.

4. Risks

4.1. Energy Analysis

Potiometer [26]:

- Has 5V voltage, resistance varies between 50 Ω and 10k Ω
- Current used, at maximum, is 5 V / 50 Ω = 0.1 A
- Maximum power expended will be P = IV = 0.1 * 5 = 0.5 Watts

Display [27]:

- With 5 V of voltage, and 1 mA maximum drawn
- Therefore, power used is P = I*V = 0.001 A * 5V = 0.005 Watts

Display Adapter [28]:

- Operates with 5 V of voltage, and 100mA absolute maximum current
- Therefore, power used is P = I*V = 0.1A * 5 = 0.5 watts

Temperature Sensor [29]:

- Uses maximum supply current of 2 mA, takes 5V voltage.
- With this, the power used is P = I*V = 0.01 Watts

Push Button [30]:

- It takes 3V of voltage and uses a 10 kΩ resistor, has its own resistance of 100 mΩ.
- By Ohm's law, the amount of current is I = V / R = 3 V / 10,000.1 Ω = 0.3 mA
- The power consumed is P = I*V = 0.0003 A * 3V = 0.0009 Watts

Buzzer [31]:

- Maximum current of 30 mA, takes 3V voltage
- Therefore, power used is P = I*V = 0.03 A * 3 = 0.09 Watts

Maximum Possible Total energy consumption: 1.1059 W, 0.2333 A

- Limit for a USB 2.0 Port [32]: 2.5 W, 500mA - under limit
- Project limit - 30 W - under limit

Further notes:

- Given our analysis above, it is impossible to exceed physical power and energy constraints on the design.
- Without any capacitor or battery, there will be no storage of electric energy or electric potential energy.

4.2. Risk Analysis

Risks associated with regular use include:

1. If the buzzer rings too early or late, the water will be too hot or cold for the user. This could cause dissatisfaction or outright abandonment.
2. Burns or scalds due to the heat going through the cup and onto the user's hands before measurement.
3. Hearing damage or the causation of ear ringing due to sensitive ears of certain users.
4. Electric shock due to accidental spills of hot drinks and subsequent carelessness around electronic components.

Negative consequences possible from incorrectly using the device include:

1. If the thermometer is stuck into a hot drink for closer measurement, not only could it start to malfunction due to the stains of any oils or grease, but there could be internal damage due to a large amount of heat being transferred by contact.
2. Removing the cup before the buzzer has sounded off, thus inducing a possible indefinite run of the program.
3. Setting a temperature below ambient temperature, which is never reached, possibly resulting in an indefinite run.

Negative consequences possible from using the device differently from its intended purpose include:

1. If the device is used to measure the temperature of food, the potentially much higher temperatures of the food can damage the thermometer and the stand, roughly 3 - 5 cm from the items measured. This could cause the design to malfunction and leech chemicals from the materials of the stand or circuit boards into the environment. In addition, the measurement could be inaccurate as the internal temperature of foods such as roast chicken can be much higher than the external temperature due to the coat of oil.
2. If the device is used to measure body temperature, the imbalanced placement of the design could cause components to detach and the whole design to fall apart. Moreover, with the cone-shaped vision of the thermometer, the measurements could be erroneous when the average of measurements is taken from all points in the cone vision.

The design could malfunction if:

1. Steam or other residuals that have evaporated from the drink accumulate on the lens of the temperature sensor.
2. The push button or potentiometer breaks, thus disabling vital means for input that the user needs.
3. The stand might be adjusted too harshly and could break apart, thus ruining the design and turning it into the equivalent of a previous competing design.

5. Testing and Validation

Our test plan for our design will involve:

1. To test that the temperature measurement regularly occurs:
    a. Take a cup of hot, newly boiled water, set it up underneath the thermometer, set a preferred temperature, and start the measurement. This must occur in an indoor environment with a stable ambient temperature.
    b. Time 30 seconds for the measurement, and check that new numbers appear on the display every 30 seconds.
    c. To pass, rounds must occur every 30 ± 5 seconds.
2. To test for measurement accuracy:
    a. For the first round, take a cold drink from the vending machine, and pour it to fill three-quarters of a cup. Press the button, and check that the initial measurement is accurate within ± 5 °C of the actual temperature, as measured by a laser thermometer. If that is true, then pass.

   b. For the second round, take hot boiling water, set it up as seen in 1a), and check the initial temperature measurement is also within ± 5 °C of the actual temperature for it to pass. This can be tested concurrently with test 1.
3. To test the ability of the user to set temperatures:
   a. Set up a boiling hot water drink as in 1a), then turn the knob on the potentiometer as far as possible on either side.
   b. Observe the temperature you have set as mentioned on the display. To pass, check that temperatures can be set between 8 and 60 degrees Celsius.
4. To test buzz accuracy:
   a. While waiting for the drink to reach the desired temperature, check that the display's "time remaining" does not wildly fluctuate, i.e. it does not change by more than 10 minutes at each update.
   b. As soon as the temperature is within 5 degrees of the desired temperature, the buzz should sound off, regardless of the previous time remaining.
5. To test redundancies:
   a. After placing the hot water underneath the thermometer, set a temperature, but remove it before reaching the desired temperature.
   b. The following temperature measurement should be nearly the room/ambient temperature. Therefore, the design should automatically shut down within the next few minutes.

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